

A-Series EMU Railcar Review



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A-Series EMU Railcar Review

Client: Public Transport Authority

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Glossary

Abbreviation	Definition
AC	Alternating Current
ATO	Automatic Train Operation
ATP	Automatic Train Protection
BCU	Brake Control Unit
BS	British Standard
CoG	Centre of Gravity
DC	Direct Current
DCU	Door Control Unit
DDA	Disability Discrimination Act
DMA	Driver Motor A
DMB	Driver Motor B
EMU	Electrical multiple unit
EN	EuroNorm
FEA	Finite element analysis
GO	General overhaul or F service
GPS	Global positioning system
GWRC	Greater Wellington Regional Council
HVAC	Heating ventilation air conditioner
IGBT	Insulated-gate bipolar transistor
LED	Light emitting Diode
LTI	Lost time incident
MCB	Main circuit breaker
MDP5MD	Mean distance per 5 minute delay
NDT	Non-destructive testing
OHL	Overhead Line
OEM	Original equipment manufacturer
PIS	Passenger information system
PTA	Public Transport Authority (Perth)
QR	Queensland Rail
RCM	Reliability Centred Maintenance
TCU	Traction Control Unit
TS	Tube stock (London Underground)
TC	Train cancellation
UGL	United Group Rail
WSP	Wheel slip/slide protection

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Executive Summary

Introduction

The Public Transport Authority of Western Australia has commissioned AECOM to conduct a residual life study of the A-series rolling stock fleet. The A-series railcars were first introduced in 1991 with an intended design life of 30 years.

The Public Transport Authority's intention is to determine the most appropriate outcome for the long-term future of the A-series railcars. The recommendation made as a result of the investigation will be used as input into the asset management and capital replacement plans of the A series railcar fleet.

The study focuses on the necessary work packages required for each of the following options:

- Straight replacement at end of service life
- Life with existing technology and or minor enhancements of the railcar.
- Re-engineering life

The study considers the remaining lifespan of the A series fleet as well as the operating expenditures associated with its continued operation and potentially degrading performance. Due consideration is given to the intermediate options of minor and major functional enhancements which would enable reliability and maintainability improvements to be realised.

In order to identify the residual lifespan of the railcars a detailed fatigue life and structural assessment of the A-series railcars is undertaken.

Methodology

To enable better granularity in the study the alternatives for continued operation of the A-series fleet are further represented by the Options as defined in Table 1.

Table 1 Options definition

Option Number	Ref	Title	Duration of extension (years)	Operating life	Year extended to
Option 1	1	Design life expiry	N/A	30	2021
Option 2	2a	Life extension (Minor mods)	5	35	2026
	2b	Life extension (Minor mods)	10	40	2031
Option 3	3a	Life extension (Re-engineering life – DC traction)	20	50	2041
	3b	Life extension (Re-engineering life – AC traction)			

Work packages appropriate to the scope of each Option were derived during the course of the study. In order to identify the suitable scope for each Option it was necessary to conduct a comprehensive review of the operating paradigm of the A-series.

Results

The A-series can be considered in a good state of repair given their age. However there are a series of technical issues that were identified during the course of this study that should be attended to. Reliability has been maintained at a level lower than that normally expected of a similar aged fleet. Availability of trains in terms of on-time running performance is below target but the contribution of rolling stock incidents to the network performance is relatively small by comparison to other factors such as 'weather'.

A comprehensive FEA model has been generated for fatigue life prediction. However, the results of the fatigue life study of the carbody suggest that the A-series railcars are experiencing concentrated high stresses at eight locations. The stresses being generated through the modelling are of sufficient magnitude to lead to a very short fatigue life. It is implied that the carbodies should have experienced some cracking already in the asset life.

Asset inspections have been undertaken in the localised high stress areas, it has been observed that the welded joints between door pillars and sole bar are of an improved classification than the drawings prescribe. Sensitivity analysis has been undertaken and it is evident that small changes to the vehicle stresses imparted by a number of assumed loads have a significant impact on the damage incurred and fatigue life of the carbody. Further refinement of the load inputs is necessary to improve the accuracy of the model outputs.

From a financial perspective, values associated with the packages range from AU\$141 million to AU\$645 million and typically the period of life extension drives the level of investment (refer to Table 2). However, these values should be taken into consideration given the depth of analysis and the scope of work.

Table 2 Cost estimates for each Option package

Option1	Option 2a	Option 2b	Option 3a	Option 3b
\$141,344,000	\$247,948,500	\$372,547,000	\$592,172,000	\$644,400,400

These cost projections would need to be weighed against CAPEX & OPEX costs of replacement vehicles if the existing fleet were to be decommissioned at the dates determined for each package.

The cost of re-engineering associated with Option 3b, which included re-motorisation to AC traction was comparable to that of the new Matangi stainless steel rolling stock delivered to Greater Wellington Regional Council.

A strategic risk assessment was undertaken during the course of the study. It is apparent that the strategic risk exposure to PTA also increases with the term of life extension.

The main areas of concern for extended operation of the A-series include, failure to realise the benefits of upgrades involved in the re-engineering, lack of system compatibility and versatility of the A-series for continued operation, continued operation of A-series will reduce buying power for new rolling stock, reliability and safety features of A-series are not succinct with new rolling stock technology.

Options 1 and 2a present opportunities for decommissioning the A-series fleet in alignment with break periods in existing maintenance agreements, and potential order points for new rolling stock. Options 1 and 2a require the lowest investment by PTA and a good improvement to rolling stock reliability is believed achievable through the employment of reliability centred maintenance processes coupled with maintenance exam balancing and maintenance task blocking.

Recommendations

The following recommendations are made:

- Asset inspections are recommended to check for the presence of cracks and verify the consistency of welds with the carbody design;
- Further refinement of the FEA load inputs are necessary to improve the accuracy of the model outputs and validation of the fatigue life prediction should be undertaken before deciding on a preferred Option;
- The recommendations for work packages in each of the Options should be employed;
- Improvements to 'Weather', 'Passenger complaints', 'Electrical' and 'Driver' lost time incident reports should feature as part of an initiative to improve on-time running performance; and,
- PTA should give due consideration of the suitability of the A-series to the future business and system needs.

1.0 Introduction

The Public Transport Authority of Western Australia (PTA) has commissioned AECOM to conduct a review of the alternative options pertaining to the continued operation and the remaining life of the A-series railcar fleet.

PTA is responsible for operating Perth's urban passenger rail system which includes the operation of two Electrical Multiple Unit (EMU) rolling stock fleets, the A-series and the B-series which serve five lines which achieved 41 million passenger journeys during 2012.

The A-series railcars were manufactured in a joint venture between ABB (now Bombardier Transportation) and Walkers Limited (now Downer Group) in Maryborough, Queensland and were purchased with a planned economic life of 30 years. The A-series fleet was delivered in two batches, 43 off between 1991 and 1993 and a further 5 off in late 1998 to early 1999.

Since the majority of the fleet has now surpassed 20 years of service of an intended design life of 30 years, it is now entering the final third of the intended service life. PTA has engaged AECOM to consider the various engineering options regarding the fleet's residual or potentially extended life.

For the benefit of the reader this report has been split into two distinct components. A comprehensive analysis of the A-series' operation has been conducted and part one of this report explains the historic nature of the fleet, its operation and service patterns and discusses those elements of the operating paradigm which are both important and relevant to the scope of this study.

The second part of this report focuses on a number of 'Options' available to PTA for the future operation of the A-series fleet.

2.0 Scope

The majority of the A-series fleet is entering the final third of its intended design life and as such PTA is evaluating the future of the A-series railcar fleet. PTA has engaged AECOM to undertake a study of the A-series EMU railcar fleet, to a number of options which could be pursued regarding the fleet and to recommend the most appropriate option for the fleet in the future.

The study considers the remaining lifespan of the A series fleet as well as the operating expenditures associated with its continued operation and potentially degrading performance. Due consideration is given to the intermediate options of minor and major functional enhancements which would enable reliability and maintainability improvements to be realised.

In order to identify the residual lifespan of the railcars a detailed fatigue life and structural assessment of the A-series railcars has been undertaken.

2.1 Purpose

The Public Transport Authority's intention is to determine the most appropriate outcome for the long-term future of the A-series railcars. The recommendation made as a result of the investigation will be used as an input into the asset management and capital replacement plans of the A series railcar fleet.

2.2 Scope

The deliverable required is a comprehensive report of the Public Transport Authority's A-series fleet, which encompasses the following;

- An assessment of the condition and performance of the A series fleet including a structural assessment, FEA and fatigue modelling followed by an inspection of a railcar,
- A consideration of the options:
 - Straight replacement at end of service life;
 - Life with existing technology and or minor enhancements of the railcar; and,
 - Re-engineering life (including time taken to re-engineer, transportation to/from facility and number of railcars out of service at one time during the re-engineering and prototype options). Consideration to be given to where the re-engineering could occur.
- Budget estimate of costs of all options considered (with advantages and disadvantages),
- Performance targets suitable for each option, and how these performance targets support the achievement of Public Transport Authority's on time running target of 95% of scheduled services being within 4 minutes of timetable,
- A summary of the risks associated with each of the options, based upon those identified via strategic risk assessment,
- Experience from other rail systems, Europe/America/Australasia,
- A recommendation from an engineering perspective as to which option is preferred and why this option has been selected.

3.0 Methodology

This section of the report describes the methodology that was applied in order to establish the present condition of the A-series fleet.

From the commencement of the project AECOM conducted reviews of the fleet maintenance data, material usage, asset inspections, and interviews with maintenance personnel amongst other processes to establish a general appreciation of the current asset condition of the A-series fleet.

A selection of the evaluation activities are summarised below in Table 3 for information.

Table 3 Methodology

Evaluation Area	AECOM Methodology
Fatigue life assessment	FEA modelling is conducted to assess the residual fatigue life of the assets through a structural analysis of the carbody.
Condition assessment of sample EMUs	Mechanical and electrical anecdotal evidence inspected to form appreciation of current asset health through a tacit assessment. Asset inspections are also undertaken to identify the presence of corrosion for the readily visible areas of the carbody.
Current maintenance / operational costs	Review of current maintenance tasks undertaken and an analysis of the current costs of these activities is undertaken. Interviews with maintainers and fleet engineers are undertaken.
Operating reliability / availability	Review performance data and statistics, plot trends, look at variances in performance and costs analyse the trends.
Commercial benchmarking	Review against current commercial expectations of on-time running and whether these can be met with the A-series in the future in the light of the above reviews and assessments.
Spare part supply chain integrity	Perform an "at risk" parts analysis (obsolescence etc.) and compare this with the life expectancy and chart future supply chain. Study repair and overhaul statistics and compile lists of parts used and inventory requirements.
Environmental review	Review latest requirements against the present A-series design. Identify any systems requiring action in the immediate future.
Impacts on existing facilities and industrial arrangements	Review of the steps needed to increase the life of the A-series fleet and assess how this affects the existing facilities.
Impacts on stock and contracts	Review of the steps needed to increase life of the A-series fleet and assess how this affects the existing stock inventory and the current maintenance contracts that are in place.
Market analysis	Conduct a review of the operating systems around the world that have incorporated re-engineering of life in order to continue the operation of ageing rolling stock assets.
Forecast future maintenance / operational; costs	Using the data provided by the client of the existing costs, establish a predicted cost of maintenance for several fleet maintenance plan concepts.
Optimal replacement timing	Assessment of life cycle costs and evaluate when this will become least cost efficient against the cost of new rolling stock.
Strategic risk assessment	Conduct a risk assessment of the strategic risks associated with each of the options in the study.

4.0 Cost Analysis

4.1 Methodology

This section explains the methodology and the process that were applied to generate the cost estimations which were consolidated during the course of this study.

For the majority of cases, existing data has been provided by PTA or the maintenance service provider. Typical costs retrieved from PTA and the maintenance service provider included, but was not limited to:

- Maintenance contract value
- Material costs, retrieved from inventory system
- Maintenance fitter labour rates
- Overhaul costs

Where cost information was required but not available from PTA or the maintenance services provider, quotations were sought from established suppliers of equipment or works. Those suppliers with existing familiarity of the A-series railcars were considered most suitable to quote for works. Scope was developed during conversations with PTA and the maintenance service provider as well as the suppliers in order to qualify an appropriate content was estimated.

A selection of the suppliers approached during this process is listed below, though this list is not exhaustive:

- Faiveley
- Knorr Bremse
- Alstom Transport
- ART Engineering

The suppliers were approached because of their existing or historic association and familiarity with the A-series. However, quotations were retrieved within the timescales of the project and as such the values retrieved are reflective of high level scope definition, limited exposure to A-series railcars, and short periods for development of estimates.

4.2 Qualifications and Assumptions

The following qualifications and assumptions apply to the costs presented in this study:

- Estimates provided in the report are in accordance with the requirements of a Class iv estimate as designated by procedure CPPR006;
- Pricing information provided by PTA and the maintenance service provider are accurate and form the basis of the estimates in this report;
- Cost escalation has not been applied to estimates;
- Costs and quotations which were retrieved from historic data are indexed by 5% per year to generate 2012 representative prices, unless stated elsewhere;
- Currency exchange adjustments are not made and have not been accounted of in the cost estimations, with the exception of costs in Table 11;
- Referring to Table 11 currency exchange rate adjustments have been made based on the rates appropriate at the time of expenditure. Currency exchange rates were retrieved from www.x-rates.com and then validated against alternative rates providers for the specified periods;
- Maintenance contract prices are taken from the A-series Maintenance Agreement 21JUL11 Contract No. 2010051 and assumed to be accurate regarding the present scope delivery;
- No escalation of the maintenance contract values has been made for adjustment of rates in the future;
- Forecasting of maintenance contract prices allows for escalation only due to degrading asset condition (associated with Option 2b, 3a, and 3b specifically) and is representative of extra maintenance that may be required;
- Cost analysis for the power consumption of the A-series was calculated from data provided by PTA for 2012 rates;

- Estimates are exclusive of owners indirect costs, such as the cost to PTA of administering a contract, changes to contracts or employing and managing contracts or works;
- The Option estimates do not account for costs associated with future endemic failures, unforeseen events and failure events which AECOM has not been notified of;
- Costs associated with decommissioning the A-series fleet are not included in the package valuations;
- Residual values of assets are not calculated;
- New rolling stock prices provided in Section 5.5 were sourced from Railway Gazette or Railway Technology;
- The cost of continuing to maintain the fleets during decommissioning is not included in the Option package estimates;
- Individual quotes supplied by OEM vendors which were retrieved during the course of this report are subject to the terms, conditions, assumptions and exclusions of the vendors. Vendor quotes and associated terms and conditions are included in the Appendix G for reference. AECOM does not accept liability for the accuracy or reliability of such quotations;
- A contingency of 5% has been applied to the Maintenance Contract; and,
- A contingency of 15% has been applied to all other values estimated or quoted in this report;

Option specific qualifications

Option 1

- The existing maintenance contract continues to be employed for the period of operation until the railcars are decommissioned. This is an extension to the current maintenance contract of 1.5 years. It is assumed that the price will remain constant for the extended period;

Options 2a

- Indicative estimations are made for alternative maintenance contract arrangements. It has been assumed that a the introduction of a new maintainer may lead to a price escalation over the existing rates possibly resulting from forming a more pessimistic opinion of the asset condition and, or PTA negotiating less favourable terms than those which exist in respect of the current maintenance contract;

Option 2b

- The maintenance contract value extending beyond the duration of the existing agreement has been escalated by 20% to compensate for the age of the fleet and further wear and tear which will be incurred as a result. The escalation of 20% is indicative based on the experience of AECOM, it is recommended that PTA reviews this value and recommends to AECOM appropriate adjustment if necessary;

Option 3a

- Future energy consumption predictions and associated costs are based on 2012 rates, future energy price escalation is excluded from the estimates;
- A fleet wide DC traction motor rewind programme is excluded from the suppliers quotation for traction modernisation works (Option 3a) an adjustment is made in the report for inclusion of the associated motor re-wind costs;
- The DC traction motor upgrade quotation provided by the vendors excluded the provision of a facility to undertake the works. Two provisionally suitable facilities were identified. However, neither facility owner would provide a lease only quotation. A quotation was retrieved for the provision of a facility through an escalated labour rate which included a value for 'overheads' in addition to the typical hourly rates for the provider's personnel. The traction modernisation quotations were adjusted to factor in the value of the local labour provision by the facility owners;

Options 3b

- Future energy consumption predictions and associated costs are based on 2012 rates, future energy price escalation is excluded from the estimates;
- During the first 15 years of operation, maintenance of new rolling stock is expected to cost 50% of the value of the current A-series maintenance value. This is based on information provided on the New Zealand rolling stock fleets; Matangi and Ganz Mavag. This is provided for high level conceptual comparisons of new versus old rolling stock maintenance costs.

5.0 Part One – Understanding the operating paradigm of the A-series

This section of the report introduces the operating paradigm of the A-series, by reviewing the fleet's service life. A comprehensive analysis has been undertaken of the data that exists from the fleet's introduction from 1991 to present day. The following sections summarise the notable events and proceedings that have occurred during this period and discusses the effects the A-series had on the Perth metropolitan railway and the impacts that the A-series vehicles were exposed to.

In order to assess the requirement for any potential undertakings forming part of the 'Options Analysis' as required by the Scope, it was necessary to interpret the operational data available for the A-series fleet.

This section catalogues the findings of the following studies:

- Service operation duty cycle
- Maintenance regime
- Reliability
- Obsolescence
- Availability

It has been necessary to understand the historic operation of the A-series fleet, and the patterns of its service life in order to identify the areas in most need of attention and to better contemplate the effects of modifications or lack thereof, to continuing the A-series service life for each option being evaluated.

The findings in the following sections are based on the following analyses and activities:

- Fault data – reported from EMU asset management system
- Asset inspections of railcars 236, 246 during GO/F exam (railcars 201,247 undergoing A or B Services)
- LTI data and train cancellation data
- Materials expenditure
- Smart rider data
- OEM maintenance manuals
- PTA adopted maintenance manuals

Interviews with a series of key stakeholders were undertaken during the study, see Table 4:

Table 4 Interviewed stakeholder parties

Name	Title	Organisation
Garry Taylor	Rolling stock Manager	PTA
Rodney Raymond	Prospector Engineering Manager	PTA
Geoffrey Hingston	Electrical Engineer	PTA
Les Robinson	Mechanical Engineer	PTA
Maurice Cox	Assistant Mechanical Engineer	PTA
Carl Delaney	Operations Manager	Bombardier Downer
Paul Dubyniak	Maintenance Manager	Bombardier Downer
Ian Bertram	DMU Shed maintenance lead	Bombardier Downer
Kenny Currin	EMU Shed maintenance lead	Bombardier Downer

5.1 A-series Overview

The A-series railcars were manufactured in a joint venture between ABB (now Bombardier Transportation) and Walkers Limited (now Downer Group) in Maryborough, Queensland.

The A series fleet was supplied to the Public Transport Authority in two separate lots:

- Supply of 43 railcars – Delivery 1991 to 1993
- Supply of 5 railcars – Delivery December 1998 to March 1999

The A-series vehicles are permanently configured as two-car units. A basic schematic is provided in Figure 1.

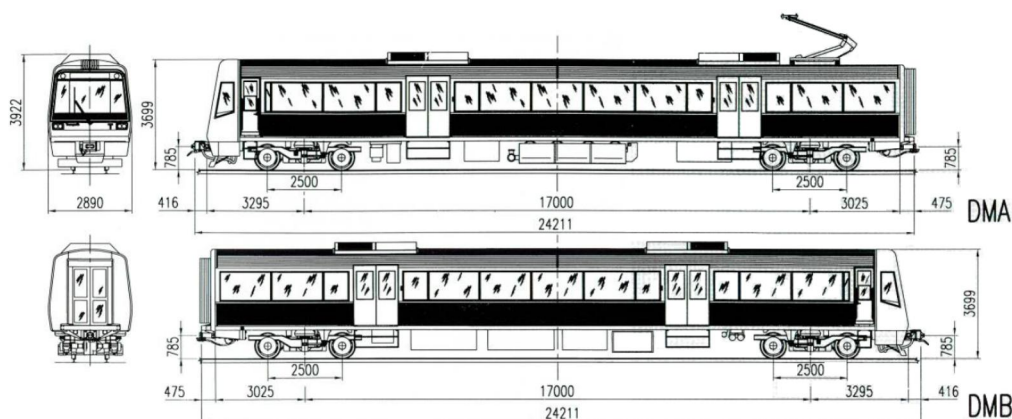


Figure 1 A-series railcar schematic

There are some minor differences between the two deliveries nominated above, resulting mainly from the passage of time between the two procurement phases and technology developments in the interim period. However all A-series railcars are both electrically and mechanically compatible.

A-series railcars are capable of speeds up to 110 km/h. The two cars of each unit are permanently coupled with semi-permanent drawbar style couplers, whereas coupling of multiple units is undertaken via a Scharfenberg automatic coupler. System power is provided by a 25kV AC overhead line

There has been little work undertaken to update or to renew the main train systems, including train management, braking and propulsion systems. However, communication systems have been updated to a modern system utilising automated message announcement system which utilises GPS to play route messages at set locations.

High level technical data is provided in Table 5.

Table 5 A-series railcar technical summary

Item	Technical Description
Train Configuration	2-car units, DMA and DMB cars
Gauge	1067mm
Railcar length (over coupler faces)	48,422mm
Car length (over coupler faces)	24,211mm
Tare mass	90,000kg (48,000kg DMA and 42,000kg DMB)
Power supply	Overhead line 25 kV AC, 50Hz
Seating arrangement	Longitudinal bench seating (63 seats)
Standing capacity at crush	153
Seated capacity at laden	63
Maximum acceleration rate	0.8m/s ²
Maximum deceleration rate	1.12m/s ²
Maximum service speed	110 km/h
Propulsion system	Six separately excited DC traction motors

5.2 Summary of Fleet Operations

5.2.1 A-series

The A-series' operate predominantly on the East to West heritage lines of PTA's network, namely:

- Armadale Line – travelling in a south-east direction from Perth to Armadale, there is also a spur line serving Thornlie, a station which opened in August 2005.
- Fremantle Line – travelling in a westerly direction from Perth towards Fremantle.
- Midland Line – travelling east from Perth to Midland.

A network diagram is illustrated in Figure 2



Figure 2 PTA route network diagram

An image of A-series railcar 212 at Perth station is presented in Figure 3.



Figure 3 A-series railcar 212

Since September 2009 the requirement has been to operate 45 railcars during the peak service from the fleet of 48 railcars. This availability scheme enables one railcar to be stopped for a rolling 12-week general overhaul (F service) and one railcar to be stopped for either a rolling modification program or for major repairs.

The off-peak service requirement is for 36 railcars between the morning and afternoon peak periods as well as the evening service. Weekend services are served by 20-21 railcars.

The average annual mileage in 2012 was 144,360 km per two-car unit. This value is attributed on the basis that the total of the whole of fleet mileage in 2012 was 6,784,826 km during a 52-week year and the sum of the total mileage is distributed evenly between the 47 railcars. Railcar 246 was out of commission for the entirety of 2012 and therefore is assumed to have not contributed to the fleet mileage.

Key performance parameters derived by PTA for operating the network services are;

- A reliability target of 30,000 kilometres (as required by the railcar maintenance contract) per Lost Time Incident (LTI) where an LTI is defined as any delay greater than or equal to four minutes that is caused by a railcar fault.
- The reliability target of 30,000 kilometres per LTI is to be achieved after an initial ramp up over two years following the commencement of the maintenance contract.
- A reliability target of 200,000 kilometres per Cancellation where a Cancellation is defined as a train being withdrawn from service because it was not capable of completing the timetabled journey.
- The PTA strives to achieve a 95% target for on-time running of scheduled services.

Prior to the current maintenance contract for the A-series being commissioned, PTA identified a reliability target of 30,000km per LTI as adequate to enable the on-time running target of 95% to be achieved.

It is worth noting that PTA imposes stricter Key Performance Indicators (KPI) on itself than those used throughout the country by other public transit authorities/rail operators. This is reflected by PTA monitoring its performance on the occurrence of LTIs where the metric is a delay of four minutes or more, whereas it is known that other rail operators across Australia record LTIs upon the occurrence of a delay of five minutes or more.

5.2.2 B-series

The PTA also operates a more modern EMU fleet on the urban network, the B-series.

The B-series (EMU) fleet comprises of 46 three-car units, procured and delivered in multiple lots

- Phase 1 – 31 railcars delivered from 2004
- Phase 2 – 15 railcars delivered from 2008
- Phase 3 – 22 railcars (original order of 15 railcars extended to 22 railcars) to be delivered from 2013

The B-series' predominantly provide services on the North to South lines of the PTA's network (refer to Figure 2), namely:

- Joondalup Line – travelling from Perth and the underground station northbound Joondalup. A large proportion of the alignment is integrated with the centre of the Mitchell Freeway reserve.
- Mandurah Line – travelling in a southward direction, from Perth's underground station south to Mandurah. Part of the alignment is integrated in to the centre of the Kwinana Freeway reserve.

The maximum operating line speed is 130km/h – a speed which is unachievable by the A series railcars.

Figure 4 shows an image of a B-series EMU.



Figure 4 B-series railcar 487

The B-series railcars comprise of three cars permanently coupled with semi-permanent drawbars. B-series railcars operate as singles or pairs forming a six-car train.

The B-series features Bombardier MITRAC Traction system with IGBT inverters powering 8 AC traction motors distributed amongst the three vehicles providing a 66% motorised unit.

It is understood that the B-series railcars were designed primarily for operation on the Mandurah to Joondalup lines and not specifically to provide services currently undertaken by the A-series on the East-West heritage lines. It is understood that in some extreme operating conditions, the B-series rolling stock may experience some adverse impacts from operating on the heritage lines, specifically the Perth to Fremantle line. The lifespan of some components may be impacted as a result of the increased duty cycle. It should be noted that the OEM has communicated that these impacts are only possible in extreme operating conditions, which have been defined as:

1. Temperatures exceeding 40⁰C;
2. AW2 loading condition (fully laden);
3. Maximum wheel wear (on condemning limits); and,
4. Low line voltage performance (19 kV).

There is an extremely low likelihood of these events compounding in a way that would impact component reliability, however, even in such circumstances, the OEM has advised that limiting the maximum operating speed to 80 km/h will mitigate the risk of rolling stock components being adversely impacted. It has been calculated that the implementation of a speed restriction of this small order has as an almost negligible impact on the timetabled operations for the Fremantle line.

The B-series railcars are of a different configuration and interior layout, however they are compatible with the existing infrastructure on the heritage lines.

5.3 Maintenance Summary

The content of this section provides the audience with an appraisal of the maintenance history of the A-series fleet so that the future performance projections as discussed in Section 7 for each of the Options can be better estimated.

A-series trains are maintained at Claisebrook depot, located in East Perth and linked to the Armadale and Midland lines.

The depot facilities at Claisebrook enable light and heavy maintenance requirements of the A-series to be managed. Component and system overhauls are typically conducted off-site.

A maintenance and cleaning contract was commissioned with Downer Group and Bombardier Transportation (Maintenance Pty Ltd) as a joint venture which commenced on 1 January 2012 for a period of 7.5 years, with an optional extension for a further 7.5 years at PTA's discretion.

5.3.1 Gap analysis of the OEM and PTA planned preventative maintenance services

The current planned preventative maintenance regime consists of the activities described in Table 6:

Table 6 Current planned preventative maintenance regime

Service	Description
A service (4 weekly)	General inspection of the railcar, testing and checking of control systems and switches, and inspection and adjustment where necessary to some equipment including air conditioners, traction motors, and main compressor.
B service (12 weekly)	In addition to the content of the A service examination, perform testing, checking, and inspection of other components such as the high voltage equipment, condenser fins and motors of air conditioner, air reservoirs and bogie equipment.
C service (36 weekly)	In addition to the content of the B service examination, detailed further checking and adjustment of components of equipment such as couplers, auxiliary compressors, and traction motors.
D service (72 weekly)	In addition to the content of the C service, significant use of consumables such as lubricants on equipment, cleaning and inspection of more components, and replacing of oil in the main compressor.
E service (144 weekly)	In addition to the content of the D service, replacement of micromesh oil filters and intrusive inspection of pantograph cylinder for corrosion.
F service (general overhaul)	In addition to the content of the E service, refurbishment, intrusive maintenance, and re-calibration of equipment.

A gap analysis of the differences between the current regime and the original OEM recommended regime identified that the current maintenance regime outlined above, was first implemented in 1995. Prior to this, the Original Equipment Manufacturer's (OEM) recommended regime was employed. The transition period from the OEM's maintenance regime to the current regime can be seen in Figure 5 whereby the periodicity of the A service was extended from three weeks to four weeks.

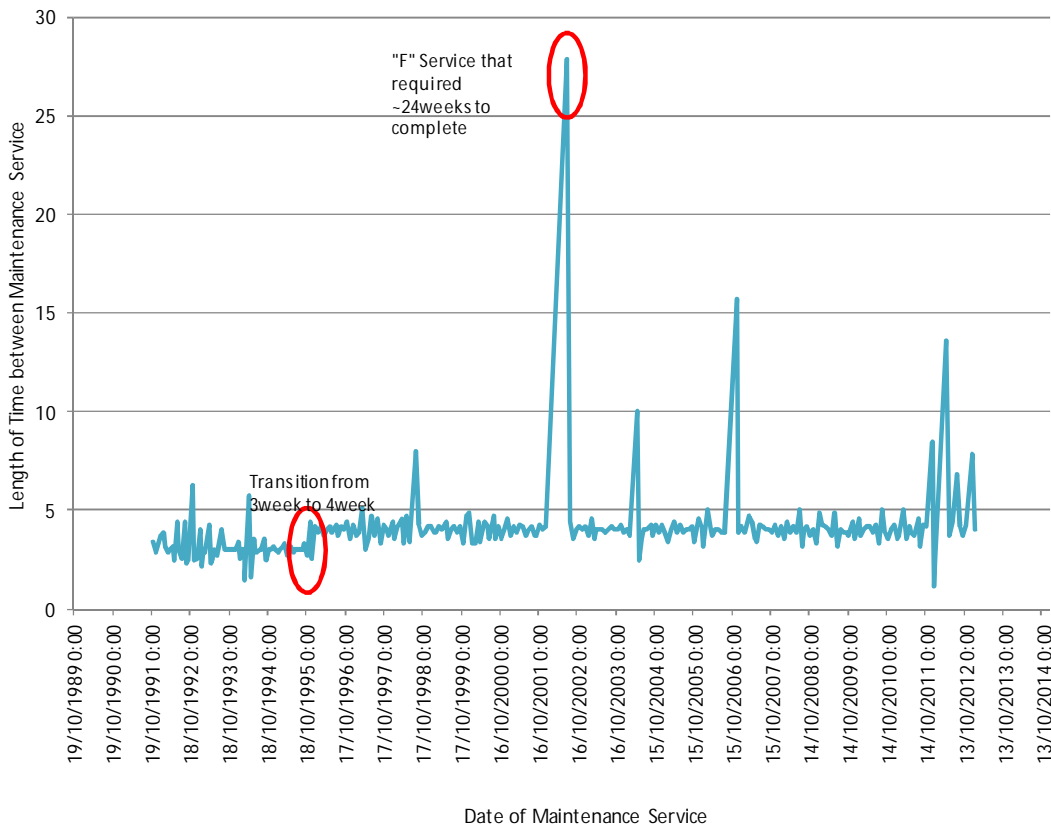


Figure 5 Maintenance Intervals of railcar 1

The graph in Figure 5 presents the length of time between maintenance services for railcar 201 during the period 1991 to the present day. Each of the spikes represents a service. The smaller spikes represent the A and B services, whereas the larger spikes represent larger maintenance undertakings such as C, D, E and F services as marked on the graph.

Comparison of the OEM and PTA maintenance regimes is identified below:

- Extension of A service from 3 weekly to 4 weekly
- Extension of B service from 9 weekly to 12 weekly

Gap analysis of the maintenance regime was undertaken to a maintenance task level and further differences between the OEM recommendations and PTA schedules were observed. It was identified that some task content was extracted from the services and individual task periodicities were extended. The detailed maintenance regime gap analysis is presented in Appendix A. A high level summary of the main differences between the OEM and PTA maintenance regime exam content is summarised in Table 7. The table also identifies those failure modes that may have eventuated from, could be detected or are associated with the activities listed.

Table 7 Extension of task periodicities

Activity	OEM Periodicity (weeks)	PTA Periodicity (weeks)	Potential faults which could occur or be detected during maintenance activity
Inspection of primary and secondary suspensions	3	12	Splitting of airbags and vibration issues
Inspection and replacement of earth brushes on bogie	9	36	Earthing faults
Cleaning, checking, and lubricating of auxiliary converter components	36	72	Leaking capacitors, converter disc faults, circuit breaker trips

Activity	OEM Periodicity (weeks)	PTA Periodicity (weeks)	Potential faults which could occur or be detected during maintenance activity
Checking the traction motor over-current relays for correct calibration	36	144	Overheating of traction motor contactors and underperformance of motor speed
Removing the pantograph dust boot and inspecting the cylinder for corrosion	72	144	Wear and tear of rams and seals
Main circuit breaker operation testing, changing the interrupter and cleaning the air filter	72	Not identified in manuals but could be listed separately	Tripping of main circuit breaker often with no fault found
Hydraulic dampers removed and tested for correct function throughout a complete stroke	72	Tested at bogie overhaul which is to be every 8 years*	Dampers leaking and seizing
Replacement of sprung finger contacts in auxiliary converter	72	Condition based (currently being replaced)	Overcurrent leading to burnout of thyristors
Removal of end covers and old grease of axle box bearings and clean and regrease before re-fitting end cover	144	Limited to grease injection every 72 weeks	Overheating of axle box and damage to axles
Statutory replacement of sprung finger contacts in thyristor converter	288	Condition based replacements	Overcurrent leading to burnout of thyristors
Inspection of pantograph system and replacement of components	288	Pantograph overhaul is conducted as part of a separate programme	Corrosion to the copper contactor, cracks to the mounting points, and centre bands fatigued
Overhaul of gearbox	288	Condition monitoring of oil in gearbox	Leaking, low amount of oil may cause motor burn
Overhaul of hydraulic dampers	288	Replaced on condition	Dampers leaking and may seize

*Bogie overhaul periodicity is reported to be 8 years. Neither the OEM or PTA manuals refer to a specific maintenance periodicity for overhaul of bogies. It is reported by PTA that of the fleet of 48 railcars, only five to nine railcars have received bogie overhauls (20 – 36 bogies of 184) during the period of operation.

The OEM recommended maintenance regime for the A-series was deviated from three to four years after service introduction. Typically, during the first few years following fleet introduction there are often 'teething problems' experienced, resulting from compatibility and integration issues occurring. It is often necessary to undertake series' of modification programmes to achieve steady state fleet performance during this period. In order for a maintainer to make valid enhancements to an asset's maintenance regime the asset should be in a stable state of performance over a sustained period enabling the maintainer to develop a more comprehensive understanding of the assets interaction with the system.

It is possible that implementing changes to the maintenance programme of the A-series so shortly after its service introduction, was sub-optimal for preserving long term asset performance.

Although follow up reviews are understood to have taken place of the appropriateness of the maintenance regime changes, no documented evidence was provided during the course of the study which assessed the effectiveness of the significant changes implemented in 1995 or those iteratively after 1995.

Without review of the findings it is difficult to determine the resultant effect on the A-series other than consideration of the present fleet reliability as discussed in Section 5.4.

Conducting a Reliability Centred Maintenance (RCM) study is an appropriate methodology for the determination of the suitable maintenance tasks to be undertaken on a railcar and is recommended as a means of improving rolling stock reliability.

5.3.2 Schedule of planned preventative maintenance services

Analysis of the maintenance services for railcars 201, 210, 220, 230 and 247 was performed. The current planned preventative maintenance regime is considered cumulative rather than balanced, whereby the content of each maintenance service (A through to F) is conducted on the same occasion.

Assessment of the annual kilometres travelled has identified the average weekly kilometres accrued for the A-series fleet over the period of 1999 – current, have increased from approximately 2650 km travelled per week to 2900 km per week, an increase of 13,000 km per railcar per year on average or approximately 10% of the annual service duty during this period.

Concurrently, maintenance periodicities have remained largely unchanged at four-week intervals between A and subsequent services. The annual service duty on the vehicles has increased by approximately 10% over the past 14 years and a large proportion of the fleet is over 20 years old.

It is considered worthwhile to perform a review of the periodicities of maintenance services to ensure the fleet can achieve the required reliability in light of possible increases in future mileage and aging of the fleet.

It is understood that the railcars have been maintained in accordance with a time based maintenance schedule, although maintenance scheduling is also tracked on a kilometre basis.

Analysis of the kilometres travelled and time periodicity between maintenance for services A-E for railcars 201, 210, 220, 230, and 247 from 1999 to current times has identified that there were very few occasions where planned maintenance work was deferred. Only 2-4% of train maintenance activities were conducted outside the planned preventative schedule by a margin of 10% or greater, thus exceeding the maintenance interval by over 30 days and exceeding 3300 km (the four-weekly maintenance interval of 3000 km and a tolerance of 10% as used by operators in Europe to track on time maintenance delivery) between maintenance interventions.

It is observed that PTA is conducting routine planned preventative maintenance on-time consistently and the fleet will have benefitted in terms of reliability from this performance. It is recommended that the historic performance of on-time maintenance is continued (by the maintenance service provider) and instances of deferred work are avoided.

5.3.3 Heavy maintenance

A separate workshop (DMU workshop) is used to perform the F service and general overhaul activities, whereas running maintenance (scheduled services A-E) is conducted in the EMU shed. Conducting maintenance in this arrangement means that the occupancy of roads for heavy maintenance during F services does not impact the availability of the running maintenance facility.

The illustration in Figure 5 shows that the first F service undertaken on railcar 201 required 27 weeks offline for the work to be completed, well beyond the expected duration of four weeks. Since then, completion times for F services have improved gradually and more recently F services require eight to twelve weeks for completion.

It has been observed on other projects that extended maintenance durations serve to compound delays and lead to inefficiencies in works undertaken which can compromise both reliability and availability. For example, a railcar that is taken out of service for an extended period of time will experience many maintainer shift changeovers, many lunch breaks and other interruptions. Each of these disruptive occurrences will lead to extension of downtime, increased risk of omitted maintenance activities, inconsistency in inspections and workmanship.

The two main issues which result are that the facilities and the railcar are not available for a long period of time impacting on availability and that inconsistencies in maintenance will arise ultimately leading to more frequent failures and therefore lower reliability.

It is understood that the content of the maintenance services (prior to the maintenance contract being initiated) is blocked in such a way that parts of maintenance services are completed in the periods of off-peak operation.

It is possible that balancing and optimisation of the maintenance regime could further reduce the 'shop time' for servicing railcars and should reduce inconsistencies in undertakings.

5.3.4 Major overhaul of A-series fleet

The A-series fleet are currently undergoing a major overhaul (F-service) at Claisebrook depot. The following tasks are being performed:

- Replacement of window frames
- Overhaul or replacement of seat frames
- Replacement of cab equipment and electronics on a condition basis
- Replacement of door leafs and bodyside saloon door actuators on a condition basis
- Repairs to underframe componentry and casings on a condition basis

Prior to the rolling stock maintenance contract being implemented on the 1st of January 2012, major overhaul had been performed on railcars 201-233. Railcars 234, 235 and 246 (following an incident where underframe equipment damage was incurred) were completed during 2012. The remaining cars will be completed through the maintenance contract

In addition to the content of the F-service/general overhaul the following work is proposed by the maintenance contractor to be undertaken:

- Overhaul of main compressors
- Installation of new air dryers
- Replacement/overhaul of the pantograph
- Overhaul of HAVC
- Overhaul of brakes
- Overhaul of traction system including rewind of the traction motor (on condition basis, approximately four out of six motors per railcar are rewound) and component replacements on the traction control unit
- Overhaul of bogies

The overhaul scope, terms and conditions and suppliers are still being finalised. The programme for overhaul concentrates the scope on a per unit basis such that the main systems are removed from a unit overhauled and replaced. This programme is expected to commence at a rate of one railcar completed every month, but the maintenance contractor hopes to accelerate this rate during the programme and improved availability of rotatable spares would also improve the schedule rate. It is expected that if the first 10 off railcars are completed at a rate of one railcar every four weeks, the availability of spares and improved efficiencies in programmes might see a reduction in the programme length of a railcar to two weeks. This should enable a scheduled completion of the fleet in a little over two years as per the programme in Figure 6.

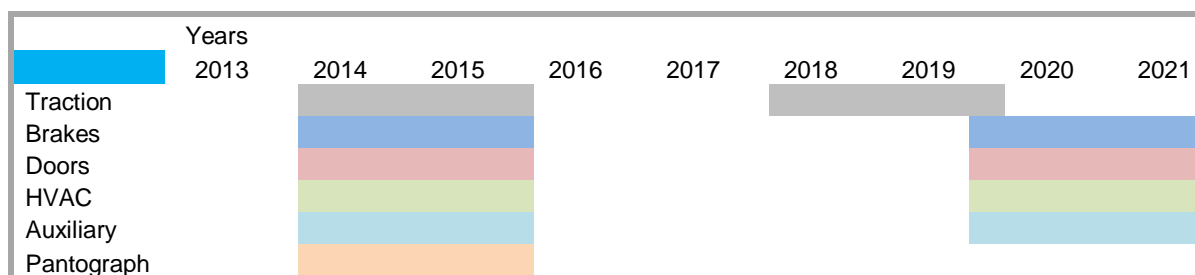


Figure 6 Projected overhaul programme to be conducted by maintenance contractor

It was identified during the course of this study that many of the periodicities for component overhauls had been extended from the original OEM recommendations, but furthermore the overhauls have not been conducted at the adjusted periodicities. The bogie overhaul is used as an example, it is understood from information provided that the OEM maintenance interval for bogie overhauls was intended to be every eight years, and this period was extended to nominally 10 years by PTA. However, reports indicate that a maximum of 18 railcars have received bogie overhauls, though the true value might be as low as five railcars. This information suggests that at least 30 railcars have not received bogie overhauls since fleet introduction. Results presented in Appendix B suggest that endemic failures leading to LTIs have not materialised or have not been detected as a direct result.

5.3.5 Maintenance labour and material costs

The maintenance services contractor has provided high level information to enable a financial value to be attributed to each of the maintenance services.

The current labour resource requirements for each of the services and an associated estimate of the labour cost are presented in Table 8:

Table 8 Maintenance Labour Requirements

Service Type	Total Linear Hours	Duration (days)	No. and Type of Employees	Total Cost (excl. overheads)
A	5	1	1 Mechanical Fitter ,1 Electrical fitter, 1 T/A Mate	\$480
B	8.5	2	1 Mechanical Fitter ,1 Electrical fitter, 1 T/A Mate	\$816
C	14	2	1 Mechanical Fitter ,1 Electrical fitter, 1 T/A Mate	\$1,344
D	16	3	1 Mechanical Fitter ,1 Electrical fitter, 1 T/A Mate	\$1,536
E	18	3	1 Mechanical Fitter ,1 Electrical fitter, 1 T/A Mate	\$1,728
F	Unknown	~3.5 months	5 staff	Unknown

It is understood that whilst the durations specified in the third column of Table 8 represent the number of total shop days a railcar spends in the maintenance facility, maintenance is blocked in such a way that railcars are returned for peak service operation. It is thought that there is an opportunity for further refinement of the maintenance regime through balancing and blocking of tasks which may improve shop time of the railcars.

With reference to Figure 7, the general trend of year on year material costs shows a gradual increase both the scheduled and unscheduled material costs. This also correlates with a periodic increase in the kilometres travelled. It is noticeable that materials spend is increasing at a faster rate than the kilometres travelled. Whilst the relationship between the two is not expected to be linear, it is expected that the greater rate of materials spend increase is also partly attributable to the increasing age of the fleet and general mechanical wear on componentry. It is worth noting that the impacts of inflation and supply chain issues (obsolescence) are not factored in and would affect the materials spend. It is expected that as the fleet continues to age, the material spend increases will accelerate.

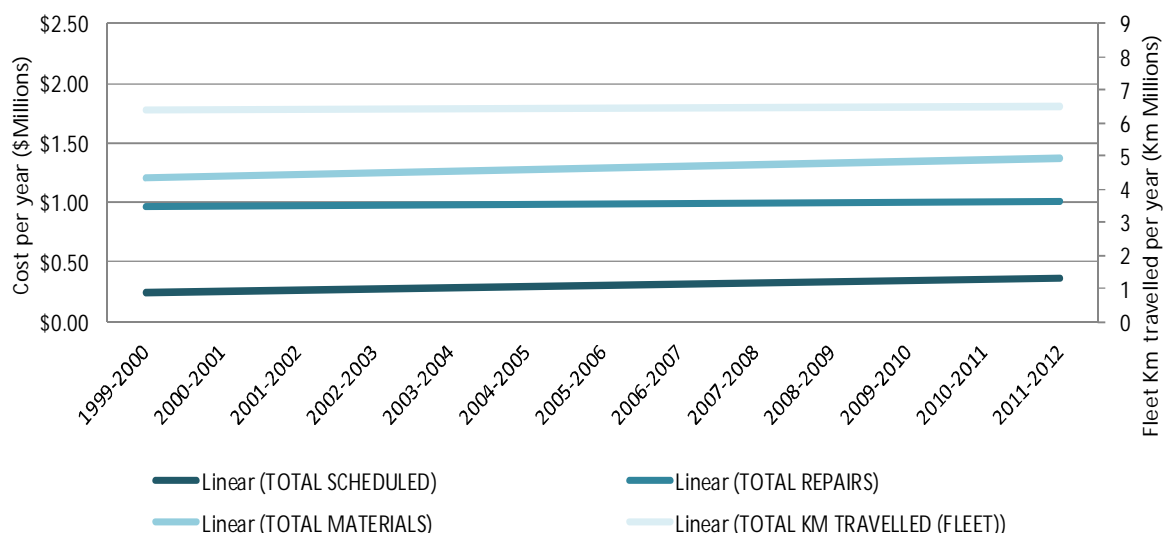


Figure 7 Year on Year Material Costs versus Fleet Kilometres Travelled

5.3.6 Section summary

The A-series fleet is now in the order of 20 years old (with the exception of railcars 244-248). The maintenance regime was changed after a period of 3 years in operational service, whereby maintenance intervals were generally extended and service content was reduced. Since this intervention the maintenance regime has changed little. Concurrently, the service duty cycle demonstrates a basic trend between materials cost and duty cycle. The figure shows the annual distance travelled has increased by approximately 10% during the past decade (patronage figures during this period were not made available for analysis). Additionally materials expenditure has increased over this period even though component overhauls were deferred from their intended periodicities.

The deviations from the OEM's recommended preventative maintenance activities may have impacted the reliability of the fleet and consequently the availability of train services. Whilst it is recognised that OEM maintenance instructions often leave room for refinement, attributes such as the aging of the fleet and increasing service duty (kilometres travelled) are likely to have contributed to the growing number of faults over time and the maintenance schedule has not evolved to counteract the effect of these changes. The number of faults over time versus distance travelled and maintenance periodicities for A and B services are shown in Figure 8.

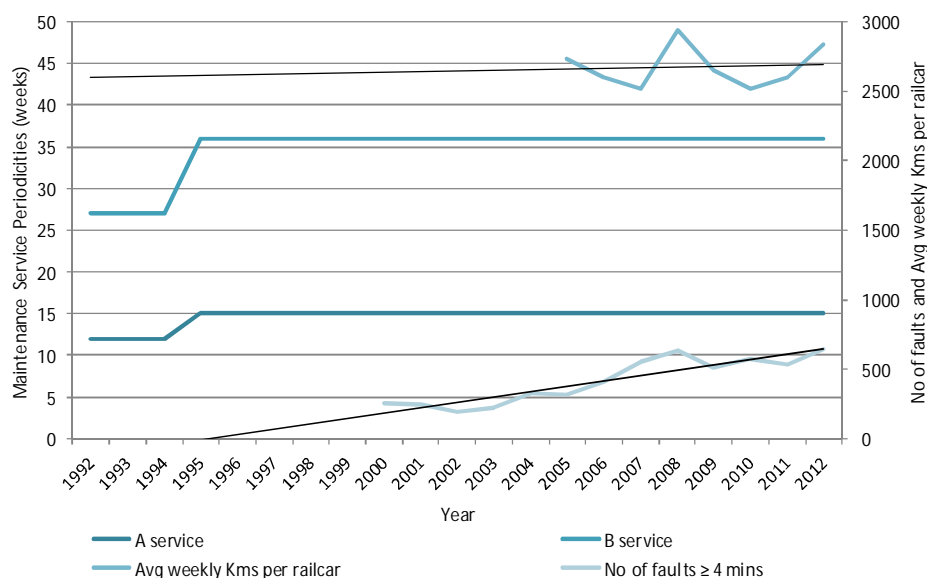


Figure 8 Maintenance, Mileage, and Faults

It is expected that improvements can be made to the current maintenance regime in order to achieve greater reliability and availability as well as potentially reducing the labour resource requirement and material spend. Whilst the existing maintenance contract is in place, labour and material expenditure remains largely the responsibility of the maintainer, however the residual effect of not implementing improvements could be borne by PTA in the longer term.

It is recommended that an RCM study be conducted in alignment with maintenance optimisation initiatives such as moving to a distance based maintenance schedule, balancing the maintenance schedule and not deferring component overhauls.

The following points are concluded from studying the maintenance regime of the A-series:

- The OEM maintenance regime is no longer followed and may be having a detrimental effect on the reliability.
- PTA modified the OEM maintenance schedule within four years of fleet introduction;
- The modifications to the OEM maintenance regime deployed by PTA comprise of periodicity extensions to A and B services as well as sub task elements of the larger services and maintenance activities;
- Maintenance is blocked such that parts of services are conducted between peak times;
- The service duty cycle in terms of kilometres travelled by the fleet has increased approximately 10% over the past 10 years;
- The maintenance schedule is based on a time based periodicity;

- Regular maintenance service periodicities are well adhered to, with only 2-4% being deferred;
- Component overhauls periodicities are not adhered to and work is deferred or not undertaken; and,
- Materials expenditure has increased over time.

In light of the observations made regarding the current maintenance regime it is expected that the following recommendations may achieve greater reliability and availability as well as potentially reduce the labour resource requirement and material spend:

- Conduct a RCM study to identify low reliability systems and key maintenance improvements;
- Deploy a revised maintenance schedule with appropriate periodicities;
- Track maintenance and conduct maintenance planning using distance rather than time;
- Fragment large services and exam and balance the maintenance regime to even out workload and increase train availability;
- Introduce maintenance blocking to optimise maintenance undertakings and consistency; and
- Avoid deferring component overhauls.

5.4 Present Reliability and Performance

An analysis of the fleet reliability and availability was undertaken during the course of this study. Reliability has been considered in terms of total failures occurring, lost time incidents and train cancellations. Similarly so performance has been reviewed and measured considering a 95% target for on-time running.

5.4.1 Reliability

The assessment of the current reliability of the A-series fleet is based on data provided for the year 2012. On 1 January 2012 a maintenance contract was awarded to joint venture group Bombardier Transportation and Downer Group. The 2012 period provides the most current and meaningful data able to reflect present reliability of the fleet in terms of the kilometres travelled between lost time incidences (LTIs) and train cancellations (TCs).

The PTA defines a lost time incident as an event where a train is delayed for a period greater than or equal to four minutes. This is a more stringent metric than the national industry standard of greater than or equal to a five minute delays. Figure 9 below conveys the LTI performance during the 2012 period. The graph shows a slight decrease in reliability from 10,750km per LTI at the outset of the maintenance contract to its lowest level for the year of 8,150km per LTI during the beginning of the second quarter. It is evident that the trough in reliability experienced during the second quarter is endured for a short period before reliability increases again and stabilises at approximately 15,000 km per LTI from the end of quarter 2 onwards for the remainder of the year achieving an annual average of 12,750km per LTI.

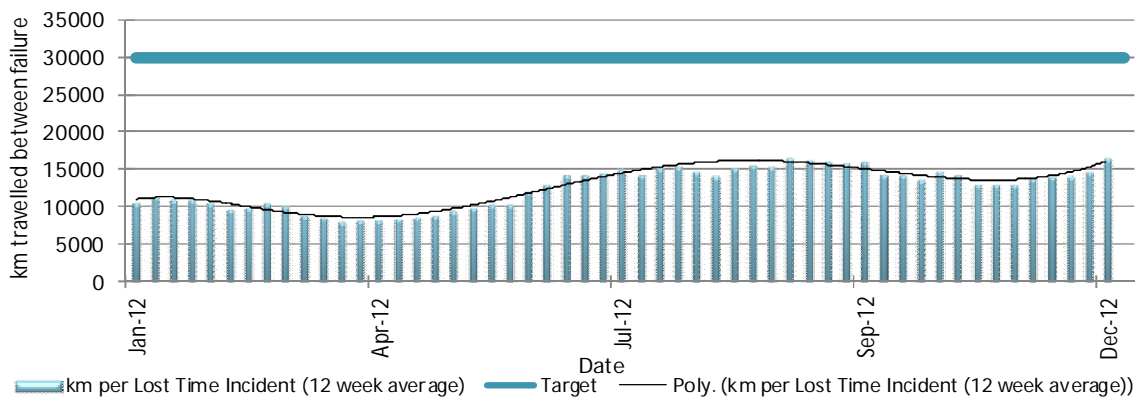


Figure 9 A-Series kilometres per Lost Time Incident \geq 4 minutes (2012)

The PTA reports a target reliability of 30,000 km is required in order to achieve a system performance of 95% on time running. The maintenance contract requires the maintenance services provider to achieve a reliability of 30,000km per LTI after a ramp-up period of two years following contract initiation.

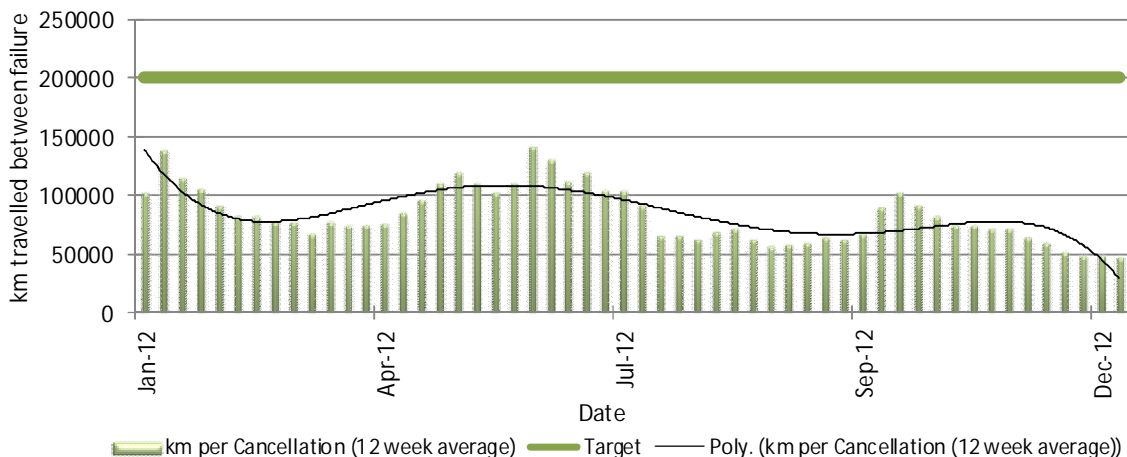


Figure 10 A-series kilometres per Train Cancellation Incident (2012)

It is apparent from Figure 10 that there has been a decrease in the distance travelled per train cancellation. Large fluctuations in performance are evident throughout the year, but the trend is for a declining performance. This data is consistent with reports from the PTA regarding an increase in the LTIs for delays of equal to or greater than 15 minutes (data not available). It can be inferred that the occurrence and resolution of smaller impact failures is improving during the 2012 period whereas the responsiveness to more significant rolling stock failures and events is worsening. It is reported that the maintenance contractor is not currently achieving the levels of reliability agreed to in the terms of the contract.

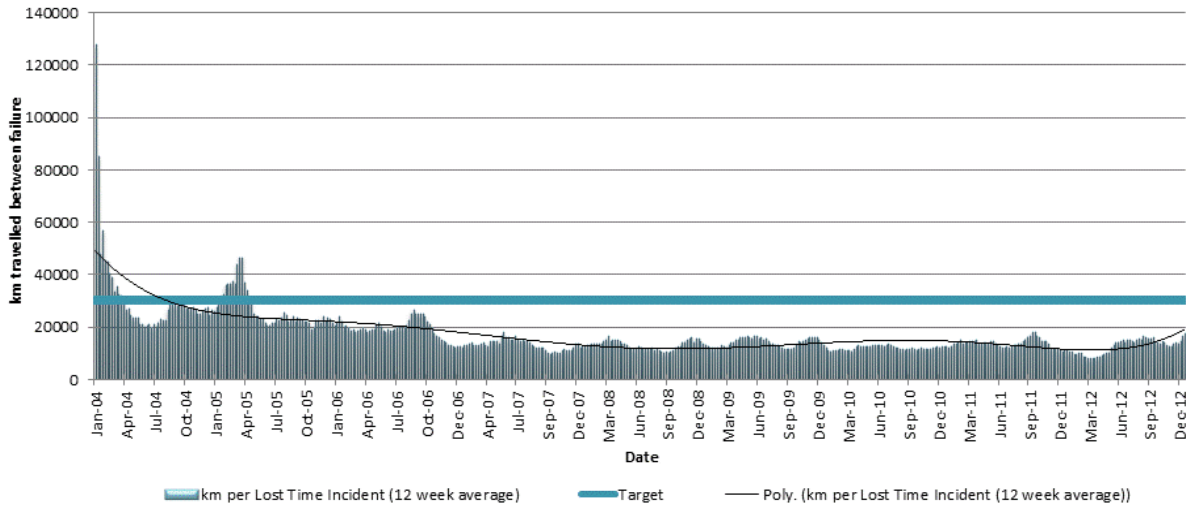


Figure 11 A-series kilometres per Lost Time Incident ≥ 4 minutes (2004-2012)

Historic reliability data is presented for the period January 2004 to present. It is evident from the data plots in Figure 11 that there are three phases of reliability. For a period of approximately three quarters of a year from July 2004 to April 2005 a reliability of 30,000km or greater was achieved. Between April 2005 and October 2006 a reliability of approximately 20,000km per LTI was maintained. From October 2006 to December 2012 a reliability of 15,000km per LTI was maintained (some fluctuations where reliability periodically lifted or lowered are observed in this period). It is apparent that a reliability of 30,000km per LTI has not been achieved since April 2005, however reliability has not continually decreased over this period as might be expected with an expiring asset. However, given the good state of asset health and opportunities to improve upon the maintenance regime it is considered feasible that reliability of 30,000 km per LTI and beyond is achievable.

It is noted that comparisons between the reliability performance of the A-series prior to, and after the maintenance contract award are difficult if there are differences in the way the faults and incidents are recorded.

A- series LTI and TC data was categorised on a train system basis for further analysis. System allocation of the LTIs and TCs incurred during 2012 are displayed in Figure 12. Excluding “Miscellaneous” items which were activities unidentified or not categorised, it can be seen the majority of LTIs are related to faults in the saloon and cab, Automatic Train Protection (ATP) system, electrical control, air and brakes. Traction, communications and electrical control all feature highly in terms of fault attribute proportions.

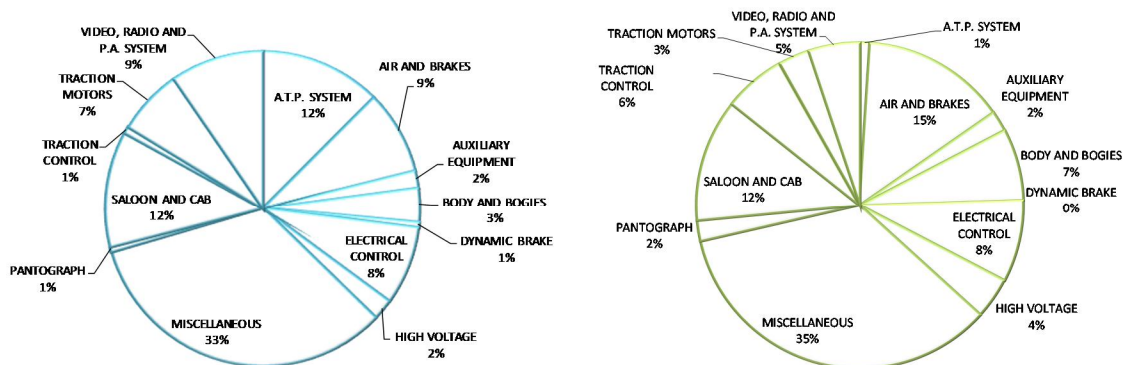


Figure 12 LEFT: Pie Chart of LTIs ≥ 4 minutes in 2012

RIGHT: Pie Chart of Train Cancellations in 2012

It is apparent from Figure 12 that there is some commonality between the systems leading to the greatest number of LTIs and those leading to the highest frequency of train cancellations with the exception of ATP. The graph on the right also shows the inclusion of 'body and bogies' as a major contributor to train cancellations attributable to rolling stock.

It is recommended that due to the significant proportion of 'miscellaneous' faults that PTA considers a further breakdown of categorisation for the faults attributed to this segment.

5.4.2 Performance

AECOM has assessed the factors contributing to the on-time running performance and identified that the proportion of events leading to LTIs resulting from rolling stock related issues was only 13%.

Figure 13 shows the breakdown of events leading to lost time incidents on the PTA network during 2012.

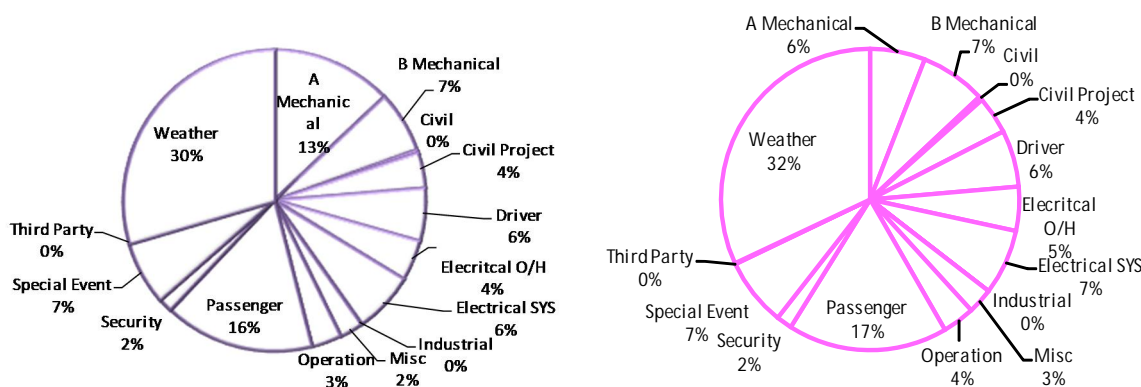


Figure 13 LEFT: Actual Operational Delay distributions at 12,758km/LTI (Jan'12 – Dec'12)

RIGHT: Hypothetical Operational Delay distributions at 30,000km/LTI

The current performance of the A-series trains in terms of achieving on-time running services given LTIs ≥ 4 minutes and LTIs ≥ 5minutes is at 93.52% and 95.88% respectively (Figure 14 and Figure 15). Given PTA's internal target of ≥ 4 minutes for LTIs, the data analysis conducted as part of this report suggests that the target of 95% on-time running is not presently being met.

It can be seen in Figure 14 that if the reliability of the rolling stock is hypothetically improved from the current 15,000 km per LTI to 30,000 km per LTI and all other systems on the network which impact on-time running remain constant, the overall on-time running performance benefits from only an additional 0.48% (greater than or equal to 4 minutes) increasing on-time running from 93.6% to 94.0%. The effect of this improvement still falls short of achieving the overall operational performance target of 95%. Due to the nature of the relationship (exponential) between rolling stock failures, mean distance per LTI and on-time running it is not possible for rolling stock reliability alone to be improved to an extent where a 95% target for on-time running is achieved, if all other contributors remain unchanged.

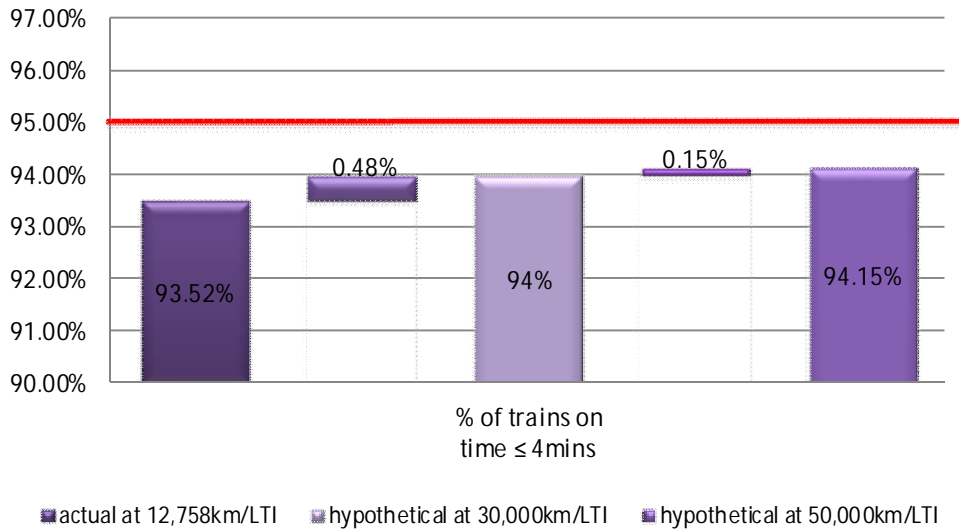


Figure 14 Actual versus Hypothetical Operational Performance in 2012 for percentage of trains on time ≤ 4mins

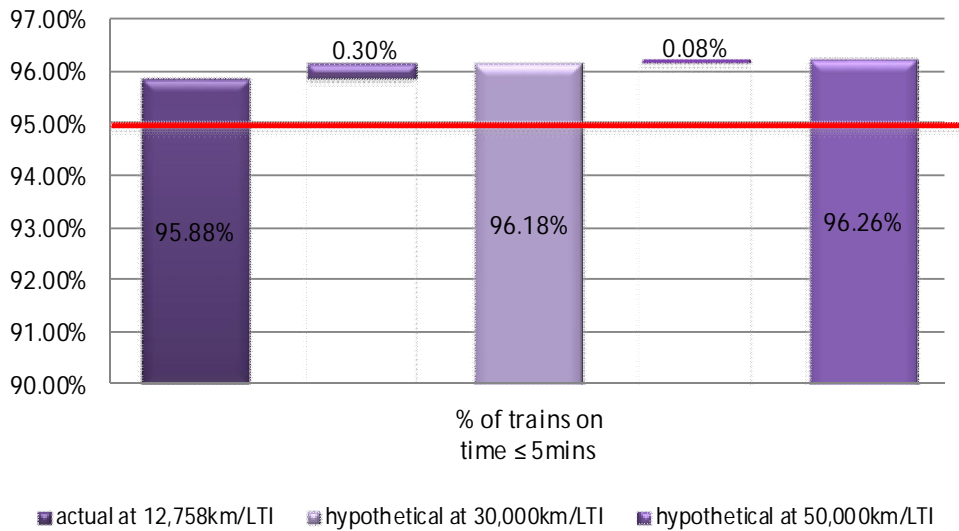


Figure 15 Actual versus Hypothetical Operational Performance in 2012 for percentage of trains on time ≤ 5mins

It is interesting to note that a similar study was conducted during the development of the performance targets as prescribed in the maintenance contract. The analysis conducted using 2008/2009 data is presented in Figure 16. The graph shows that there is a greater impact of increasing the rolling stock distance per LTI on on-time running for the 2008/9 period than the 2012 period (0.78% versus 0.60%). This is explained by observing the proportional distribution of system faults in Figure 17. Figure 17 shows the total rolling stock faults have decreased in absolute numbers from 3,145 to 2,786 but also proportionally to from 22% to 13% between 2008 and 2012. This suggests that the A-series rolling stock faults have slightly reduced over the period but the system has performed poorly by comparison and the rest of the system faults have increased by a large amount. By far the greatest contributor in 2012 to the total system faults is 'Weather'. It is also noticeable that this element has increased by the greatest percentage since 2008/9 also.

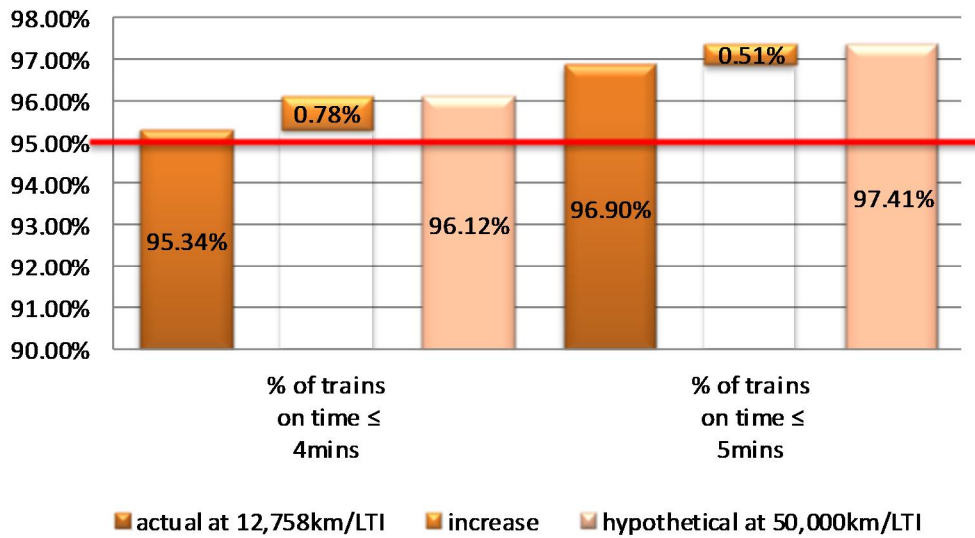


Figure 16 Actual versus Hypothetical Operation Performance in 2008/2009

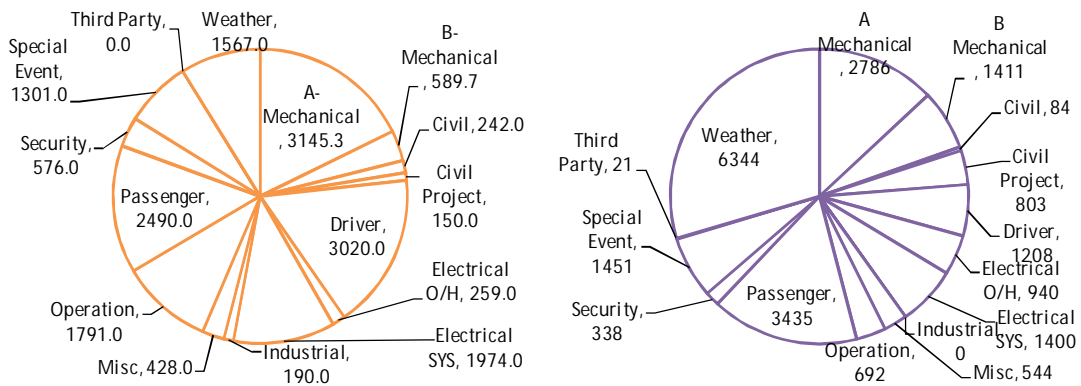


Figure 17 LEFT: Actual Distribution of Operational Delays (2008/2009)

RIGHT: Actual Distribution of Operational Delays (2012)

5.4.3 Benchmarking

In order to put the present reliability performance of the A-series in context, the reliability of similar fleets has been assessed. Fleets of a similar age, design or utilising common technology types were considered relevant in this comparison. Key items of comparison are presented in Table 9.

Table 9 Similar aged fleets reliability comparison

Tube Stock	Year of introduction	Cars per train	Data range from	Reliability	Reliability Metric	Distance per annum
				km/fault	Km/LTI	Km
A-series	1991	2	2012	12,500	≥4 mins	140,000
QR EMU	1981	3 and 4	2012	8,000	≥5 mins	110,000
Central Line 92 TS	1992	8	2010	9,375	≥1 mins	909375
Class 321	1998-91	4	2009	22,000	≥5 mins	Unknown

QR fleet

AECOM has recently conducted an Asset Assessment of the Queensland Rail EMUs and identified that the fleet is averaging marginally above 8,000km per LTI (where a LTI is understood to be defined as a delay of 5 minutes or more).

There are 87 railcars in the QR EMU fleet, configured into three-car units with a maximum operating speed of 100 km/h. The railcars are motorised in two batches; 67 x 8-motor and 20x 6-motor three car sets. The railcars feature axle mounted 135 kW DC traction motors service mileage per railcar per annum is approximately 110,000 km on a network system which is not dissimilar to the East/West Heritage lines served by the A-series.

The availability performance target for the Queensland Rail fleet in terms of on-time running is 96% (where the metric for on time running is preventing LTIs of equal to or greater than 5 minutes) it has been identified that the system achieves in the order of 89% on-time running, though the proportion of this target apportioned to rolling stock is unknown.

Based on the data presented above the A-series fleet and PTA network is out performing that of QR.

Central Line 1992 London Underground tube stock

The Central Line 1992 Tube Stock (92TS) provides a reasonable basis for comparison with the A-series. The 92TS was constructed in a similar era as the A-series. 92TS features DC traction motors fed from a 630V DC third rail system. The railcars feature a full ATO and ATP operating system with fully blended dynamic regenerative rheostatic and E.P. brake with slip/slide protection. Automatic controlled spring applied, air-released parking brakes. The traction equipment is Brush Traction/ABB G.T.O. thyristor, dc chopper control with all axles motor by Brush Electrical Machines type LT130, frame-mounted traction motors.

The railcars achieved 9,375 km per fault (where a fault is attributed to any event incurring a delay of one minute or more). This value whilst lower than the typical distance per LTI of the A-series is a far more onerous target and is achieved when undertaking a mileage duty cycle in the order of six times greater than that of the A-series.

Notably there are fairly significant differences between the A-series and 92TS fleets both in terms and design and operation. The 92TS uses a DC power supply for the DC traction equipment, meaning there is no rectification equipment for converting an AC supply for DC traction as in the A-series. The duty cycle of London Underground tubestock is far more onerous in terms of the acceleration and deceleration profiles, the Central Line is no different, it is understood to have been operating for a long period way beyond the expected duty cycle as defined in the fleet's Basis of Design both in terms of patronage and distance travelled. Additionally it is evident from Table 9 that the railcars are covering nearly seven times the annual distance of the A-series.

British Rail Class 321 EMU

Class 321 railcars received the worst reliability for any ex-British Rail EMU fleet in the UK for 2007/2008 – the reliability of the fleet was recorded at 22,000 km per LTI (in this period an LTI was measured as mean distance per 5 minute delay, this metric was later made more onerous and reduced to mean distance per 3 minute delay). Class 321 railcars feature DC traction, fed by a 25 kV overhead lines and were manufactured in 1988 and therefore make a reasonable basis for comparison to the A-series. The railcars are currently the focus of a detailed traction modernisation study.

5.4.4 Section summary

PTA strives for a 95% on-time running target to be met. According to the data which has been provided, at present that target is not being achieved. There are many contributing factors to LTI's on the network, the largest relating to 'Weather'. Rolling stock contributes only 13% of all LTIs. Should PTA seek to improve the overall LTI performance, it is recommended that the organisation should take a holistic approach to reducing LTI's. Due to the proportion of rolling stock contributions to LTI performance, a rolling stock reliability of approximately two million kilometres per LTI would have to be achieved for a 95% on-time running performance to be realised if all other factors on the network remained the same.

5.5 Technical Summary

A technical summary of the A-series fleet is provided in this section. It includes an evaluation of the A-series fleet's current condition and likely future maintenance requirements. This evaluation is based on findings from the inspection of railcars 236 and 246 which were undergoing F service at the time of the study and railcars 201, 247 and 234 during A and B services. Discussions were held with a series of personnel from PTA and Bombardier Transport/Downer EDI organisations. Additional technical information on the fleet, including asset health assessments is detailed in Appendix B.

5.5.1 Carbody

The A-series carbody structure is stainless steel housed underneath a stainless steel exterior skin.

Railcars 236 and 246 were presented to AECOM for inspection during the period of this study. Neither railcar displayed any signs of corrosion to the carbody structure in the areas visible during the depot visits. Window frames in the saloon and door apertures were visible. Residual evidence of corrosion was detectable from the removal of the aluminium window frames but it was apparent that corrosion had not ingress into the carbody skin or sub-structure. Very minor corrosion was witnessed on the roof of railcar 247 whilst in the EMU shed for an A service. The very mild surface corrosion was localised to a series of rivet heads which were reportedly heavily cleaned with wire brushes and gauze.

Overall, the carbodies are in very good condition and do not contribute to more than 1% of the total LTIs and TCs reported for the fleet. Some carbody roofs show signs of corrugation which is understood to be a result from heat expansion and contraction of materials. QR EMUs have also shown corrugation in a consistent or worsened state than that observed on some A-series though it is not understood to have adversely affected the fleet operation or the structural integrity of the carbody in anyway. One railcar of the A-series fleet is reported to have incurred physical damage to the roof in the pantograph well leading to a large crack propagating in this area in the order of 500mm long and incurring water ingress. However, the damage is understood to have been generated by physical damage through impact and not through general fatigue. It has since been repaired and is not of immediate concern to the maintenance personnel.

A FEA study was performed on the carbody structure as part of this works, refer to Section 6 for carbody FEA results and discussion.

The underframe appears to be in a good state of health showing little signs of corrosion. Railcar 246 had suffered an incident where the underframe boxes were impacted. AECOM was able to inspect the underframe cut-outs showing very clean stainless steel sheeting and excellently conditioned looming which had previously been routed in protective trays.

Fixings for underframe boxes are generally sound though a valid observation is that they do not feature secondary retention. The exteriors of some underframe equipment cases are suffering badly with corrosion and repairs are ongoing.

Of concern is the identification of cracks in some mountings of the transformers. It is understood the cracks originate from welding issues which occurred during manufacture and the fatigued brackets are being tested and re-welded. It is not known whether this will become an endemic defect and it is recommended that frequent inspection of the transformer mountings is conducted with the use of NDT and ultrasonic techniques.

A general point of note is that the A-series railcars do not feature anti-climber devices to reduce over-riding events or modern Crash Energy Management (CEM) structures and systems for energy absorption in collisions. These features are fundamental requirements of modern international crash worthiness standards such as BS:EN 15227:2010. Any extended operation of the A-series should incorporate a comprehensive review of carbody modification to incorporate such technology in the train design.

5.5.2 Cab

Cracking was evident on several of the GRP frontages inspected during this study. The cracks were forming longitudinally in line with the carbody from the joint between Cab GRP and the stainless carbody. The cracks are not substantial but are great in number and should be monitored frequently going forwards. It is notable that the A-series frontage has a distinctly older look in comparison to the newer B-series and has discoloured over time probably resulting from UV exposure. It is understood that the GRP frontage does not house any major substructure for the vehicle and could be easily regenerated with little intrusion to the carbody design or equipment contained in the cab area.

Fatigue of cab glass surrounds is evident and sealings have perished on numerous vehicles. Fracturing and corrosion of cab door hinges has also occurred. It is understood that these issues should be rectified through planned overhauls in the near future. Inadequate cab dashboard backlighting is reportedly an issue of discomfort to drivers.

The current system uses filament bulbs for back lighting displays, gauges and push buttons with the exception of a LED backlight for the speedometer. It was noted that a complete upgrade program for the dashboard backlight is readily available if required.

The traction brake controller poses a concern whereby drivers are finding them 'notchy' and lacking consistency in the range of motion as a result of an overhaul that was conducted by the OEM in 2009/2010. Whilst not directly affecting reliability, the maintainer and the OEM Faiveley are currently investigating this issue.

5.5.3 Saloon interior

General condition of the interior is good. Saloon interiors feature fluorescent lighting tubes overhead (reliability analysis shows they are a frequent failure item) although the only recordable train cancellation or LTI events result from lighting blackouts. LED saloon lighting could replace the existing fluorescent tube lighting to maintain consistent brightness with improved reliability and reduced energy consumption.

The power supply of incandescent headlights is currently being modified to be separated from the main train power supply system. This will prevent power surges, caused by failing inverters tripping the main circuit breakers. To date 26 railcars out of 43 have been completed. The last five railcars (railcars 244-248) were commissioned with a separate power supply for the headlights.

Carpets were replaced fleet-wide from 2002 to 2007 and those observed are in a good state of repair. Grab poles are removed and renewed, a mixture of grab pole conditions has been witnessed in service operation, with poles heavily scratched and showing large areas of bare metal as well as very clean and new poles. Notably this is an aesthetic issue rather than one concerning reliability of the vehicles, but nevertheless has a strong customer facing implication.

Originally, the A-series trains featured two inward-facing rows of bench seats either side of the car forward of the front set of doors and to the back of the rear set of doors, with transverse two plus two seating between the doors

However, the A-series have been reconfigured with two inward-facing bench rows running the entire length of the car. This reduces the number of seats available but increases standing room capacity. The present seating layout is illustrated in Figure 18.

Each car also has four wheelchair spaces available.

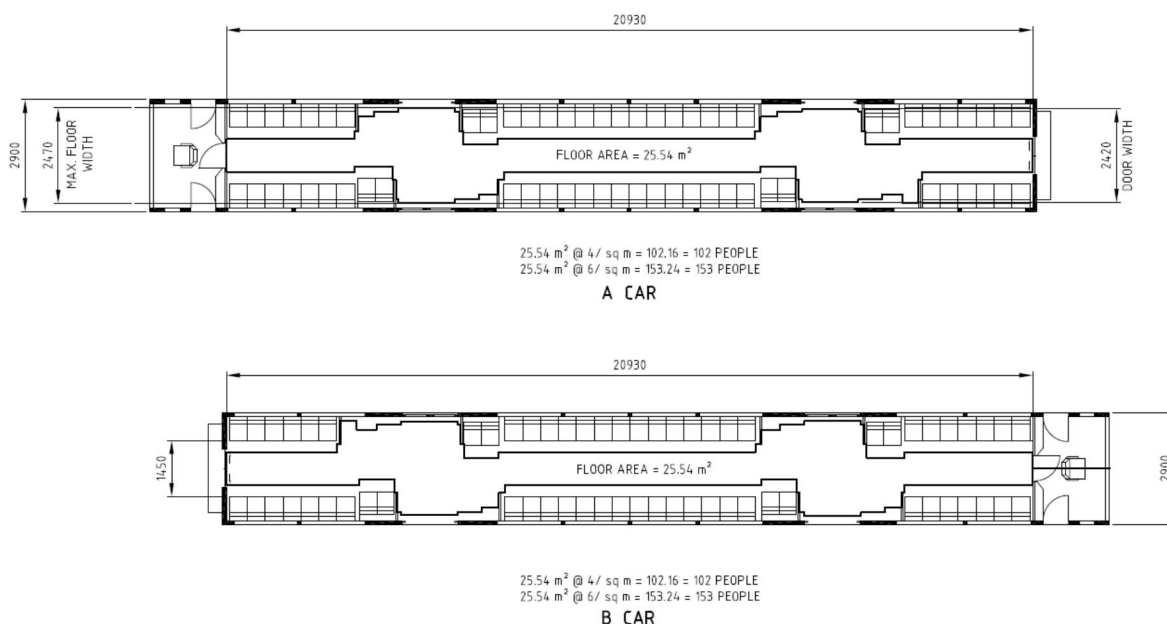


Figure 18 Longitudinal bench seating layout of A-series railcars

5.5.4 Wiring and electrical cables

Wiring was inspected in the following cab areas, below and in the cab desk housing, in cab back wall equipment cupboards as well as exterior underframe equipment boxes and in cable trays routing the underframe looms (where removed on railcar 246 whilst undergoing repair work). The physical condition of the looms is considered exceptional for a railcar of this age. Cables remain neatly packaged and well bunched, looms are restrained frequently and diligently to avoid rubbing, erosion and damage. Cables were found in a very good order, showing no signs of strain, over-extension or tight bends heat stresses. Electrical insulation properties are unknown and it is understood flash-testing has not been conducted recently. However, earthing issues are typically localised to a limited number of train sub-systems, and electrical faults associated with power of signal transmission resulting from cable wear are not of substantial proportion in the reliability data provided, other than the faults reported for the ATO system.

It is recommended that the wiring specifications are checked against modern standards in terms of, but not limited to; fire retardant properties and toxicity.

5.5.5 Traction

The traction system is showing signs of its age and degrading condition as a result of general wear of the motors. Further there are early signs of potential obsolescence of components in this system.

The motors are original and currently undergoing a condition based overhaul maintenance program whereby 60 to 70 percent are likely to receive a re-wind of coils and the remainder are planned to undergo basic overhaul. It is reported that presently traction motor overhauls are taking approximately three months per motor through a single supplier, however it is understood that there have been multiple suppliers available previously and overhaul durations were in the order of three weeks per motor. However, the shaft and frame will remain from the existing motor which raises concern as a result of the unknown life expectancy associated with the pinion and drive.

It is understood that the traction motor overhaul is undertaken at five year intervals approximately with a commutator grind performed in situ every two and half years.

There are some reports of overheating occurring with gearboxes and axle bearing boxes. Gearboxes are currently being overhauled every five years. Axle bearings have injections of grease every 72 weeks and are monitored for bearing wear. They are replaced with expired wheelsets. The re-greasing methodology differs from the procedure recommended by the OEM manuals which prescribes a bearing clean and regrease by detaching of the axle end cover. A further difference is noted in the periodicities for maintenance of gearboxes and axle boxes whereby they are overhauled every 288 and 144 weeks respectively. The traction control system is a 20 year old system and experiencing a range of faults including leaking capacitors, semi-conductor failures through overheating, pitting in the doors, and micro arcing and earthing faults are experienced due to aged and worn insulation of the thyristor converter. Condition based overhaul of thyristor converters are planned to commence in the near future. Traction control circuit boards have been identified as requiring a custom built replacement and likely to be more feasible than re-soldering the current boards if they were upgraded. No plans at this point in time have been expressed to commence this process.

It is recommended that motor armatures and pinion shafts are tested for integrity on a routine basis during overhaul. Traction motors should receive a fleet wide overhaul programme which includes re-winding the motor coils if an extended lifespan is expected.

It should be noted that A-series railcars had previously operated on the Joondalup to Mandurah line (On opening of the Perth to Mandurah line in 2007, A-series ran services between Cockburn Central to Whitfords, Prior to the B series coming on line in 2004, the A-series ran the Currambine to Perth services) during commissioning and early operation of the B-series fleet. It is reported that during periods of sustained operation of the A-series on the North to South lines there have been increased occurrences of traction motor flash overs due to sustaining high operating line speeds.

5.5.6 Bogies

Bogie frames on inspection showed no signs of cracks and appear to be in good state of health. Bogie equipment functionality is representative of the age of the system. Whilst little heavy maintenance work has been undertaken on the bogies historically, data suggests that the condition of the bogies has not yet been adversely affected and less than one percent of the total faults attributable to rolling stock are related to bogies. According to the 'EMU' railcar data base, 24 railcars received bogie overhauls between 2002 and 2011, of which four were completed prior to 2005. However it has also been reported that the Paradigm system records 18 railcar sets in total having received bogie overhauls, and further reports indicate that 5 railcars have received bogie overhauls. Thus there appears to be conflicting reports and possibly issues with maintenance traceability in regards to this activity.

It is reported by the maintenance contractor that bogie overhauls will be performed again over the upcoming years and then routinely in a programme of eight-year intervals. Major issues identified include cracking of rubber casing on primary suspension springs and axle boxes and gearboxes reportedly overheating. Though these items are relatively infrequent the resultant impact could be as severe as derailment. In addition to the current 72 weekly axle box grease injections and monitoring of gearbox oil, it is recommended the upcoming overhauls include additional maintenance of gearboxes and axle boxes, which would as a minimum, include the scope of the OEM manuals. Gearbox oil sample monitoring should be undertaken at frequent intervals.

It is also recommended that a non-destructive test (NDT) and ultrasonic examination programme is undertaken to validate the structural integrity of the frames and welds. It would also be prudent to conduct an FEA study of the bogie to predict a residual fatigue life. Verifying bogie frame structural integrity is a key element in determining the feasibility of life extension as replacement of the bogies is of significant cost and would make life extension of the fleet less attractive.

5.5.7 Passenger doors

Passenger door leafs are currently being overhauled or replaced with new leafs (new doors were designed from reverse engineering the existing leafs and are being replaced on a 'like for like basis) on a condition basis during the F service. Door leafs are aluminium honeycombed with stainless sheeting panels on the exterior, the honeycombing has poorly deteriorated though the leafs have proven to last 20 years. Some manufacturing issues are being experienced with new doors and as a result are causing some issues in operation which aren't detectable prior to fitment, however it is reported that issues are being addressed with the supplier.

Door overhead equipment including door tracks and actuators are experiencing warping, fatigue and, oil contamination from the main compressor. Door actuators and door tracks are being replaced fleet-wide on F-services. It is recommended all door overhead equipment be replaced to improve reliability of the fleet. Faults with door tracks and leafs as well as door control units have contributed to 8% of the rolling stock delays and train cancellations over the past 12 years. Issues experienced with door control units (DCUs) are delays in detection and location of incorrect door status. An installation programme for DCUs on railcars 201-243 commenced in the early 2000's and was completed in 2011. During this period it is believed that some of the replacement components have become obsolete during this period. It is recommended that the DCUs should be considered for replacement to mitigate further risk of obsolescence and potentially degrading reliability. A significant proportion of DCU faults have resulted from platform detection system introduction and integration issues from 2011 which have since been resolved. A programme of overhaul of the main compressors is commencing and it is likely to improve the future performance and reliability of the existing pneumatic door system which currently experiences oil contamination issues.

5.5.8 Brakes and air

The brake and air system contributes 15 percent to the total of the fleet's operational delays and train cancellations attributable to rolling stock. Contributing factors are largely due to failure of obsolete active electrical components and tripping of wheel slip protection. It is recommended to replace the brake control unit and consider replacement or upgrade of the WSP system for improved sensitivity against trips and to de-risk obsolescence.

Failing mechanical components including fatigued callipers, and corroded brake ratchets and manifolds are currently being replaced on a condition basis. Fleet wide replacement of worn polymer bearings is to commence soon. Degraded and worn mechanical and pneumatic components are also causing noise issues noticeable and reported by passengers.

According to reliability data provided, tripping of the main compressor motor is an increasing attribute of brake failures. From the discussion held trips occur more in the summer time due to overheating of the compressor motor. Between 12 and 18 main compressors were last overhauled from 2002 to 2011 on a condition basis.. Some main compressors also experience oil and water condensation mixing. However, most main compressors have been modified to a six pole motor to enable sufficient heat to prevent condensation. It is recommended that installation of a new compressor should occur in the event of life extension. However, the maintenance contractor reports a programme of overhaul will commence soon, which should be considered before deciding on replacement. It is understood the OEM for the brake system is reluctant to commit to an overhaul programme of the callipers due to inconsistencies in the modification status and mechanical wear to the bogie mounted brake equipment between railcars. The OEM has recommended that the bogie mounted brake equipment, in particular brake callipers, should be replaced on all railcars.

5.5.9 Heating ventilation air conditioning (HVAC)

The HVAC system contributes to one percent of all rolling stock failures. However, there are a series of issues reported by maintainers which may begin to impact the failure frequency in the near future and lead to reduced reliability of the system. Of most concern is the HVAC compressor. This is experiencing mechanical component fatigue and electrical component failure resulting in short circuiting of the motor and earth faults that cannot be traced. Oil carry over occurs from the compressor to other components such as valves and evaporator and condenser coils affecting their performance. The HVAC system also has refrigerant leaks and the system piping is showing signs of age. Although maintainers are commencing an overhaul of the compressors with new air dryers which will reduce oil carry over, it is recommended a system upgrade be performed if life extension is considered.

There are a large number of complaints reported from drivers as documented in the reliability data provided, particularly on hot days during summer. Currently, cooling in the cab is provided by a recirculation of the saloon air by a blower fan forcing air through into the cab. A valid consideration for continued operation would be the installation of a cab HVAC unit for improved driving comfort.

5.5.10 Automatic train protection

The ATP system contributes to a large proportion of train delays and cancellations attributable to rolling stock. The majority of ATP failures result from transmission faults whereby the transmission rack is experiencing communication issues with the antenna. An increasing number of ATP faults are attributable to the damaged buttons on the driver's cab panel triggering the ATP system. This is currently being addressed through ATP panel button upgrades across the fleet.

ATP components such as the transmitter, receiver, and recorder cards have been replaced and cables are replaced on a condition basis since they were first installed from 1990 to 1994. ATP system changes should be considered on a holistic basis. The network system needs should be evaluated before committing investment to on-board or line side modification or improvement programmes.

5.5.11 Communication system

The nature of this system is highly prone to technical obsolescence. With upgrades to the communication system completed on all trains during the past year it is already recognised that elements of the systems are facing obsolescence risk. Reported issues which have since been largely resolved include incorrect information displayed on PIS displays and passenger intercom announcements as well as lack of door 'gongs' when trains are stationed at platforms, and system crashes requiring resetting for rectification. There have also been intermittent failures with the train radio control, corrosion of the aluminium roof mounted antennas, these issues are not yet affecting reliability however may pose future risk.

RAPID (Recording and Passenger Information Dissemination) software crashes contribute to the greatest quantity of communications system failures. PTA is working with the maintenance contractor for a solution.

5.5.12 Auxiliaries

The main issues observed with the Auxiliaries are leakage of capacitors in the converter, tripping of the circuit breakers and early failure of batteries (resulting from faulty battery chargers). It is known that capacitors have been recently replaced. These should be replaced with more reliable batteries. Note active components such as the semi-conductors and capacitors are being replaced with component stocks built up during historic purchasing programmes by PTA, where the components are now obsolete. Subsequently, replacement models will need to be sourced over the forthcoming years to allow for additional lead times.

5.5.13 Couplers

The electrical coupler heads have failed to perform due to worn flexible components and seals or damaged electrical contacts. This is a common occurrence with auto-couplers being frequently engaged and disengaged through normal service operation. The male and female connections become bent, damaged and dirty through constant use and interim repairs, such as pin replacement become more frequent with time. Some corrosion is evident on the couplers and headstock and should be monitored over time.

5.6 Market Analysis

A comprehensive review of market conditions pertaining to the content of this study has been conducted.

The following reviews were conducted:

- Case studies of life extension studies and projects nationally and internationally, such as:
 - Philadelphia Area Transit Company - PATCO (stainless steel carbodies, DC traction)
 - VIA Rail (stainless steel carbodies)
 - Hong Kong MTR (reconfiguration, traction modernisation)
 - QR (Stainless steel carbodies, DC traction, commonality in the design)
 - Ganz Mavag New Zealand (business case of modernisation versus replacement)
- Reliability and performance benchmarks (use of case studies above and 92 Central Line TS)
- New rolling stock prices (Australian build and International EMU builds)

The results of the case study analyses are presented in the Appendix C in detail. Information of specific interest and relevance to the Options considered in this study is referenced where applicable throughout this section. Though a few key points are summarised below:

- Operators of stainless steel carbody structured fleets have observed very long fatigue life of railcars with minor structural modifications required for sustained life for periods of 50 years or greater.
- Typically major modernisation schemes, refurbishments and regeneration projects are valued between 50 and 75 percent of the cost of replacement rolling stock in each instance.
- Often scope of refurbishments or modernisation schemes are expanded from initial estimates due to unforeseen issues when rolling stock is more intrusively inspected and disassembled.
- More frequently it is observed that original DC traction systems are replaced by AC traction, however, DC modernisation schemes are also observed and successful business were proven (in the case of PATCO) AC traction system replacements for original modernisation.
- Operating costs for existing stock post deployment of modernisation schemes are projected to be greater than those of new rolling stock, in the order of 50% for the Ganz Mavag versus Matangi case.

Benchmarking of reliability and availability performance was undertaken and discussed throughout the course of the report. Rolling stock of similar age, technology or operation has been used for benchmarking and comparisons the results of the analysis are presented in Table 10.

Table 10 Reliability performance comparison for similar rolling stock fleets

Tube Stock	Year of introduction	Cars per train	Data range from	Reliability	Reliability Metric	Distance per annum
				km/fault	Km/LTI	
A-series	1991	2	2012	12,500	≥4 mins	140,000
QR EMU	1981	3 and 4	2012	8,000	≥5 mins	110,000
Central Line 92 TS	1992	8	2010	9,375	≥1 mins	909375
Class 321	1998-91	4	2009	22,000	≥5 mins	Unknown

In order to consider what the potential replacement options for the A-series and the associated costs are likely to be, a review of national and international tenders was undertaken to identify new rolling stock prices. Table 11 summarises a few key values below. Contract values were published by Railway Gazette.

Table 11 New rolling stock market analysis

Class	Country for delivery	Manufacturer	Country of origin	For	Contract size	Total contract value AUD	Price base	Unit price per car
X'trapolis	Aus	Alstom	Italy/ Australia	DOT Victoria	38x6 car	\$564	2008	\$2.48M
Matangi	NZ	Hyundai Rotem	South Korea	GWRC	48x2 car	\$145M	2008	\$1.51M*
Matangi	NZ	Hyundai Rotem	South Korea	GWRC	35x2 car	\$115M	2012	\$1.63M* *
B-Series	Aus	Bombardier	Australia	PTA	22x3 car	\$243M	2012	\$3.7M
A-Train	Aus	Bombardier	Australia	Transport S.A	22x3 car	\$269M	2011	\$4.08M
378	UK	Bombardier	UK	NLR	23x4 car	\$525M	2007	\$4.00M* **
379	UK	Bombardier	UK	Eversholt	30x4car	\$264M	2010	2.20M** **

*The contract value was priced in NZD; the exchange rate applied was 0.7069, provided by x-ratesexchangerates.com

**The contract value was priced in NZD, the exchange rate applied was 0.8165 provided by x-ratesexchangerates.com

***The contract and car price includes a 12 year maintenance contract an adjustment of -30% has been applied, and is affected by a weak AUD, contract was valued in GBP the exchange rate applied was 0.4645 GBP to AUD, provided by ratesexchangerates.com at average 2007 value.

****The contract and car price includes a 36 month maintenance regime an adjustment of -10% has been applied, contract was valued in GBP the exchange rate applied was 0.58 GBP to AUD, provided by ratesexchangerates.com at average 2010 value.



Figure 19 A-Train impression courtesy provided by AdelaideNow

It is suggested that the Adelaide A-train is the next generation evolution of the (Bombardier/Downer) B-series, as illustrated in Figure 19. The contract value presented in Table 11 is consistent, albeit slightly inflated, with that of the recent B-series order commissioned by PTA. The Unit cost for the B-series and A-train are in the order of AU\$4 million per car.

The railcars are a favourable three-car configuration manufactured with stainless steel carbody shell, featuring AC traction and MITRAC control software. A notable feature is that the railcars are designed with two doors per saloon bodyside.



Figure 20 Greater Wellington FP Class Matangi manufactured by Hyundai Rotem

Figure 20 shows Unit FP4103 Greater Wellington Regional Council (GWRC) FP Class Matangi at a station platform. Railcars are two-car configuration featuring two saloon doors per side and 8 AC traction motors drawing power from a 1500v DC overhead catenary system. Stainless steel is used for carbody construction and capacity (seated and standing) is 277 distributed between the two cars. The FP class Matangi's, manufactured in South Korea, are valued at approximately AU\$1.6 million per car, approximately a third of the price of rolling stock manufactured in Australia.

Purely for the purposes of comparison, the costs for two recent Bombardier Transportation Electrostar orders (Class 378 and 379) are presented in the Table 11. The Electrostar's are the most widespread EMU class operating in the UK at present and new rolling stock prices are in the order of GB£1.2 million per vehicle, or AU\$1.8 million. Note, that the Electrostar fleets feature aluminium carbodies.

The requirement for increasing rolling stock capacity is unclear at present both in terms of schedule and quantity. However, it is understood there is an increasing demand for capacity expansion. For the purpose of this report it is assumed that new rolling stock will be required from 2018 or 2025 for deployment on the East-West heritage lines in order to either supplement or replace the A-series fleet.

A high level schedule has been provided in Figure 21 to illustrate the associated timescales with a new fleet procurement cycle which has been used in the Options analysis.

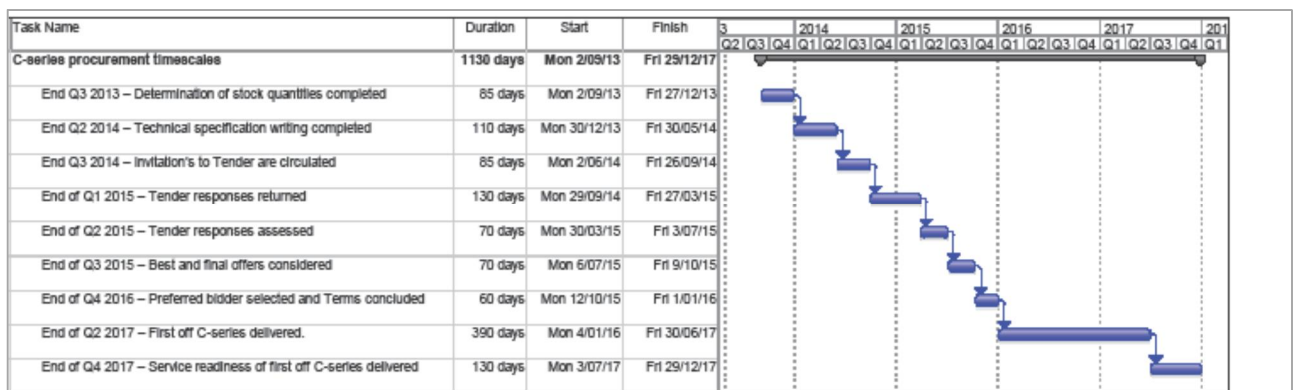


Figure 21 Indicative schedule of new rolling stock procurement

It is a reasonable assumption that a large rolling stock order should return a more favourable unit price due to the economies of scale benefitting the 'one-off' costs (such as; engineering design, process engineering, manufacturing flow development, jig development etc.) through distribution over larger order volumes. On this basis it would be beneficial if capacity occurs in consolidated parcels. However, for a number of reasons (political, funding, schedule) it may not be feasible to consolidate rolling stock orders this way and alternative programmes of procurement may be administered similar to that of the B-series.

5.6.1 Section summary

The purpose of the analysis conducted in this section was to provide an overview of the lessons learned in life extension projects which have relevance to the future operation of the A-series fleet. The feedback from those involved in rolling stock life extension projects is that the costs of major re-engineering works are generally in the order of 50-75% of new rolling costs though the operating costs of continued operation of existing assets can be up to 50% greater than that of new rolling stock.

New rolling stock prices were acquired in order to provide a benchmark against which re-engineering costs associated with Option 3 can be later compared. It is evident that stainless steel rolling stock of simple system design can be procured from the international market for as little as AU\$1.6 million per car, whereas Australian manufactured rolling stock carries a heavy price premium of AU\$4 million per car. If stainless steel and 'buy-Australia' legislation are not critical requirements of a new procurement scheme there are EMU fleets available from Europe and elsewhere with advanced systems and technology achieving high reliabilities (in the order of 100,000km/LT \geq 3 minute delays) available for approximately AU\$2 million per car (though exchange rates are currently favourable to Australia they are subject to change).

5.7 Disability Discrimination Act (DDA) 1992 Compliance

5.7.1 Review documentation

PTA is currently in the process of producing a document detailing compliance of the A-series railcars with the DDA requirements. The section presents a high level investigation into A-series DDA compliances based on conversations with PTA personnel and a review of the following documentation in order to assess the implications on the PTA A-series railcars. It excludes review of the DDA requirements applicable to associated rail infrastructure:

- Disability Standards for Accessible Public Transport 2002, Australian Government, May 2011
- Australian Standard AS1428.1 (2009), Standards Australia, 2009
- Australian Standard AS1428.2 (1992), Standards Australia, 1992

5.7.2 Evaluation

The PTA has performed appropriate modifications on all of the A-series railcar vehicles to comply with a majority of the DDA requirements. Those that have not been complied with have been presented to the DDA with the following rationales:

- Hearing Augmentation (using hearing aid loops) – installation is costly as it would require stripping of the fibreglass panelling along the length of the train. The PTA has consulted hearing impaired stakeholders with this matter and they are satisfied with the current ridership conditions. Australian Standard AS1428.2-1992 Clause 21.1 requires the system to cover at least 10 percent of the total area of a railcar.
- Exterior door opening buttons are above the Australian Standard AS1428.1-2009 Clause 13.5.3(b) compliance levels of 1200mm above the plane of the train floor – to relocate these is costly and disruptive to services as it would require modification of the stainless steel body exterior necessitating long down times for the vehicles. The PTA has had very few ridership complaints pertaining to this non-compliance. However to deal with any potential boarding issues, there are Customer Service Assistants at selected stations to assist people with disabilities as they enter and exit to and from the trains.
- The Emergency Door Release button is located at the top of the door entrance. Whilst this item is not specifically outlined in the DDA, it may potentially present a form of door control, which would then be considered non-compliant with the DDA. Re-locating the passenger emergency door release button to a more suitable area for people with disabilities would require interior modification.

PTA is in the process of conducting an internal compliance review, the results of which are not yet available. It is recommended that due consideration is given to pending changes with the standards and how the existing design may or may not meet the standards. Similarly due consideration should be given to the compatibility of planned or potential future train modifications and enhancements to meeting DDA standards.

Transport Standards state that compliance must be achieved over a 30-year period from 2002 for passenger rolling stock, within the following interim progress requirements:

- 25% by the end of 2007
- 55% by the end of 2012
- 90% by the end of 2017
- 100% by the end of 2032 (For trains only – other rail infrastructure must achieve 100% by 2022)

Since it is not yet apparent what specific DDA compliance will be required for legacy fleets, it has not been considered further in this report. Other than to note, there is an increased risk of modifications being required for greater life extension periods.

6.0 Structural Analysis and Residual Fatigue Life Calculation

6.1 Methodology

Package 1 – Finite Element Analysis and Structural assessment of the Carbody

The residual fatigue life and structural analysis has been undertaken by Design and Analysis Ltd of the UK by conducting a Finite Element Analysis (FEA) study of the carbody.

After careful consideration during the tender phase it was decided that the fatigue analysis and structural study should be split into two distinct phases. The Phase 1 component of the FEA work included a fatigue analysis of the carbody using standard load cases described in BS EN 12663 as well as utilising a series of input data from previous projects completed by Design and Analysis and those available for the A-series and the PTA urban network. The Phase 2 element of the FEA study encompassed a validation of the analysis of the carbody based on track test data in order to verify the initial load cases.

The results of the Phase 1 study are included in this report, whereas the work associated with Phase 2 is not.

The methodology implemented to carry out the scope of work for FEA fatigue and structural analyses to generic rail load cases, was as follows:

1) Generation of Load Case Document

A fatigue load case document has been generated that summarises all the applicable load cases defined in BS EN 12663 and GM/RT2100, as well as the input loads available for the PTA urban network and technical data for the A-series trains. The document specifically describes how the force values are derived for this vehicle and how they are applied to the FEA model.

2) Generation of Finite Element Analysis Model

An FEA model has been generated of the DMA car. The DMB car is passed by comparison with the DMA car. This is based on the following; the DMA car as a significantly higher mass than the DMB car, the DMA car has the pantograph well which is considered a weaker structure than the continuous roof of the DMB car and the DMA car has additional underframe mounted equipment and support bracketry.

The model has translated the 2D detail drawings into a 3D FEA model. The FEA model is mainly constructed from thin shell elements to represent the stainless steel sections used in the carbody construction. The FEA software used will be the Altair Hyperworks suite of software, with the model solution conducted in Optistruct and NX Nastran.

3) Model Solution

Load cases were applied and then the model was 'debugged' to achieve a successful solution for each load case. Validation of the model was undertaken via interrogation of reaction loads with respect to applied loads.

4) Post Processing

Interrogation of the model results was conducted to determine the maximum and minimum principal stress levels for each fatigue classification presented within the design. Finally, manual fatigue calculations were carried-out based on either BS7608 or Eurocode 3 to predict vehicle life.

Practical verification was recommended (Phase 2) of the results presented following Phase 1 of the study and the work associated with Phase 2 requires intrusive work to be undertaken on an A-series railcar requiring the installation of accelerometers and strain gauges. The optimum installation of which would be inside the passenger area of an operational railcar. It was proposed that the Phase 2 element would be postponed until the results of the Phase 1 FEA study were available in order to cause minimal disruption to PTA's services. The detailed methodology AECOM prepared for Phase 2 is provided in Appendix D.

6.2 Assumptions

Table 12 identifies the list of assumptions regarding the fatigue model input loads. The table identifies the source of the input, an explanation for its inclusion, and comments on a means to improve accuracy. Detailed input assumptions are prescribed in the Fatigue Load Cases Document for the A-series Railcar (Report Number C3263-001 Issue D).

Table 12 FEA fatigue model input sources and explanatory notes

Input description	Basis of assumption	Further comments
Train build reflective of drawings	Drawings	On inspection railcar 236 found to have what appeared to be a 15mm toe dressed weld instead of 3mm fillet on door pillar to sole bar joint
Car tare masses	Specification	Weighed masses should be used
Car mass centre of gravity	Only vertical CoG provided, lateral and longitudinal CoGs estimated	CoGs based on weighed masses should be used
Underframe component mass	4 of 30 masses retrieved from drawings or during inspection.	Other underframe component masses estimated using Class 465 data
Underframe component mass centre of gravity	Estimated as centre of volume from drawings	Could be measured through accurate weighing
Passenger loadings/passenger mass conditions	Estimated from Smartrider data	Adjusted to use data from Smart Rider
Passenger loading/unloading cycles	LU standard 2-01202-025	Adjusted to use data from Smart Rider
Passenger loading/unloading number	Estimated from Smartrider data	Previously LU standard 2-01202-025
Vertical inertia	BS:EN12663	BS:EN12663 might reflect high cycle frequency compared to A-series network (previously LU standard 2-01202-025)

6.3 Inputs

6.3.1 FEA model and fatigue calculation data

The FEA model is constructed from 2D shell elements with a global mesh size of 25mm, although in high stress areas the mesh size has been refined to 7.5mm to increase accuracy. The FEA model has been generated from drawings and is an accurate representation of the data supplied. The FEA model has been checked and applied load reactions also checked. All loads represent the loading outlined in the load case document.

Load cases analysed: LNG 1-4, LAT 1-4, VRT 1-4, PAS & TWS, (see C3263-001-Issue C for details)

Stress extraction: Eurocode 3 requires the nominal stress to be used; this has been taken one element away from stress concentration.

Cumulative Damage calculated for Eurocode 3 Fatigue Detail Categories:

- Category 36: Root cracking of fillet welds
- Category 80: Toe cracking of full penetration welds

Stress levels have been factored by $\sqrt{2}$ at the Category 36 features to account for throat thickness. The vertical load case was assessed against a reduced total cycle number of 10×10^6 cycles as opposed to the 110×10^6 cycles stated in the load case document C3263-001-issue B. The 10×10^6 cycles now used is a value specified in BS EN 12663. Imagery of the FEA model is presented in Figure 22.

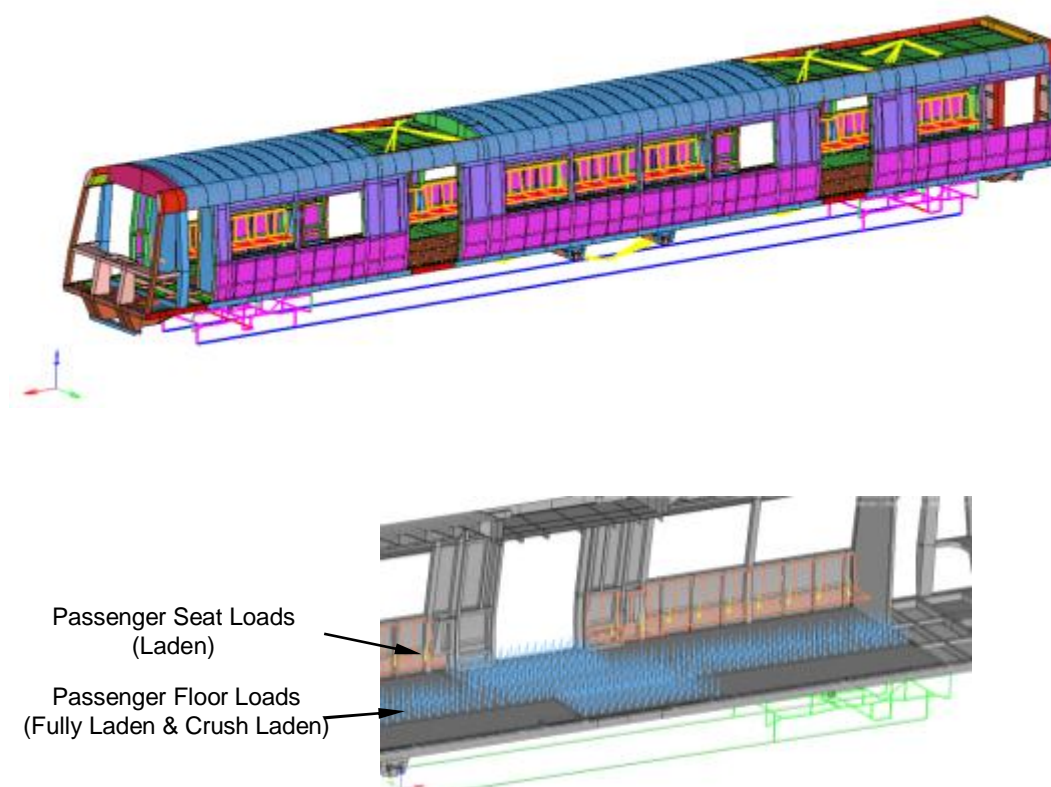


Figure 22 FEA model carbody complete and cutaway section of carbody

6.4 Results

A total of 14 load cases have been analysed:

- Longitudinal Tare (LNG 1)
- Longitudinal Fully Laden (LNG 3)
- Lateral Tare (LAT 1)
- Lateral Fully Laden (LAT 3)
- Vertical Tare (VRT 1)
- Vertical Fully Laden (VRT 3)
- Passenger Loading/Unloading (PAS)
- Longitudinal Laden (LNG 2)
- Longitudinal Crush Laden (LNG 4)
- Lateral Laden (LAT 2)
- Lateral Crush Laden (LAT 4)
- Vertical Laden (VRT 2)
- Vertical Crush Laden (VRT 4)
- Track Twist (TWS)

Typical stress plots with exaggerated deflections are shown in the Appendix H.

6.4.1 Structural steel framework and surface panelling

From the results it can be seen that the majority of the carbody is lowly stressed. However, there are six areas of the carbody that have been identified as not achieving a fatigue life of 30 years. Of these six areas Table 13 identifies the lowest life found in each area.

Table 13 Summary of fatigue life results for framework and panelling

Location	Location	Weld Class	Worst Load Case	Cumulative Damage	Life (Years)
1	Door Corner Bottom	36	VRT 2	27.02	1.1
2	Cab Back Wall Bottom	36	LAT 2	17.60	1.7
3	Waistrail	36	VRT 2	12.43	2.4
4	Window Stiffener	36	VRT 2	9.72	3.1
5	Door Corner Top	80	VRT 2	9.66	3.1
6	Body Side Column	36	VRT 2	8.60	3.5

6.4.2 Spot welds

The vehicle external skins are spot welded to the supporting structural steel framework using thousands of 6mm spot welds. In total the FEA model contains 12,979 spot welds. The forces in each of the spot welds were returned from the FEA for all 14 load cases.

In total 10 spot welds were found to have a life of less than the 30 year design life requirement. These spot welds were centred on two areas of the vehicle. Of these two areas Table 14 identifies the lowest life found in each area.

Table 14 Summary of fatigue life results for spot welds

Location	Weld Class	Worst Load Case	Cumulative Damage	Life (Years)
Door Corner Top	125	VRT 2	4.86	6.2
Roof Stiffener	36	VRT 2	1.98	15.2

6.4.3 Bolted joints

Two bolted joints have been assessed as structurally critical to the safe operation of the vehicle and therefore requiring fatigue assessment. The critical bolted joints which were considered structurally critical to the vehicle are:

- Centre pin bracket to bolster joint
- Coupler mounting joint

A fatigue analysis of the critical bolted joints has been undertaken. The results suggest that all bolted joints meet the 30 year life requirement.

6.5 Discussion

The high stresses identified in the analysis are in locations that are typical of this type of design of carbody. The A Series carbody design suffers from having welds exactly where the geometrical stress concentrations are likely to be. A number of these critical locations are where fillet welds have been used. These welds fall into the lowest weld classification designated by Eurocode 3 of Class 36 for a failure from the throat of the weld.

This design is representative of other carbody designs of the same era. This stress concentration, combined with factors necessary when assessing welds, results in very low life predictions. These vehicles were designed prior to the widespread use of Finite Element Analysis as an engineering tool and today these design features would be avoided.

AECOM has conducted a preliminary inspection to the weld between the base of the door pillar to the solebar (Location 1 see Figure 23). It was observed that there appeared to be a toe dressed weld of approximately 15mm throat width instead of a 3mm fillet. If the weld throat size becomes significantly larger than the plate thickness then failure through the weld throat becomes unlikely and failure from the weld toe becomes more likely. Based on the geometry we have in this rail vehicle, failure from the weld toe falls into a higher category of Class 80. Changing the classification of the welds from a design specified Class 36 to be re-categorised as Class 80 welds (if confirmed) will return a significantly higher fatigue life.

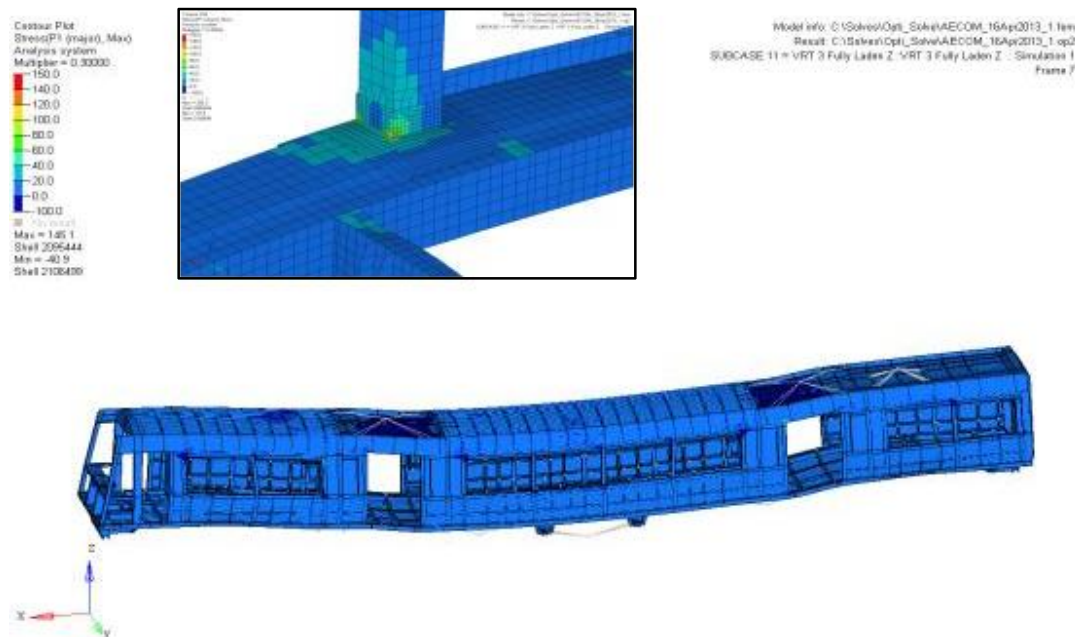


Figure 23 FEA results Location 1

For this vehicle, the predicted life is very low in the locations identified. Why then, given that the vehicles have already served a 22 year life, have the predicted cracks not appeared, or the train failed catastrophically? There are five possible explanations:

- 1) The train manufacturing does not reflect the design;
- 2) The FEA model does not represent the actual vehicle;
- 3) The loading is too severe, meaning the actual A Series carbody does not see the loadings applied;
- 4) There are cracks present in the vehicle structure but they have not been noticed; or
- 5) The fatigue analysis methodology is too conservative.

6.5.1 The train manufacturing does not reflect the design

It has been observed during an asset inspection that the fillets welds at Location 1 (only 2 welds observed for railcar 236) are not to drawing and are in reality larger than a 3mm fillet, see Figure 24.



Figure 24 Railcar 236 welded joint between door pillar and solebar

It has yet to be confirmed whether the weld is consistent with design, however, if it were the case then this would increase the weld classification to a class 80 for a likely failure through the weld toe instead of the weld root. The weld throat was crudely measured at approximately 15mm at the throat rather than 3mm as prescribed in the design if this were the case this weld would no longer be of concern. Closer inspection of the welds suggests they are toe-dressed and are of a substantially higher strength than identified in the design. It is not yet possible to inspect the welds of Location 2 due to panelling and covers in the door aperture. Figure 25 illustrates the difference which an amendment to weld classification can make to the result.

Fatigue Eurocode 3		Stress [Mpa]			Damage	Damage
		Max	Min	Worst	Class	Class
		Prin	Prin		36	80
LNG 1	Longitudinal Tare	0.1	-6.5	6.5	0.00	0.00
LNG 2	Longitudinal Laden	0.1	-6.9	6.9	0.00	0.00
LNG 3	Longitudinal Fully Laden	0.3	-6.9	6.9	0.00	0.00
LNG 4	Longitudinal Crush Laden	0.3	-6.9	6.9	0.00	0.00
LAT 1	Lateral Tare	34.36	-0.6	34.4	0.22	0.00
LAT 2	Lateral Laden	34.4	-0.7	34.4	3.74	0.00
LAT 3	Lateral Fully Laden	32.0	-0.7	32.0	0.28	0.00
LAT 4	Lateral Crush Laden	30.8	-0.7	30.8	0.03	0.00
VRT 1	Vertical Tare	47.2	-1.6	47.2	0.56	0.01
VRT 2	Vertical Laden	54.6	-1.7	54.6	14.97	0.21
VRT 3	Vertical Fully Laden	74.7	-2.3	74.7	3.57	0.09
VRT 4	Vertical Crush Laden	84.6	-2.4	84.6	0.65	0.02
PAS	Passenger Loading/Unloading	124.4	-2.8	124.4	1.57	0.00
TWS	Track Twist	0.4	-54.2	54.2	1.43	0.02
BLD	Lateral Damper	0.1	0.0	0.1	0.00	0.00
Cumulative damage					27.02	0.35
Years					1.1	86.2

Figure 25 Effect of weld classification on fatigue life

6.5.2 The FEA model does not represent the actual vehicle.

The FEA model has been checked and is believed to be a true representation of the drawings/information supplied, with a mass distribution in accordance with the mass data supplied. It would be evident in the photo imagery that exists if there is significant additional structure on the vehicles that is not represented in the drawings and there appears to be no such evidence

6.5.3 The loading is too severe, meaning the actual A-series carbody does not see the loadings applied

It is possible that the track condition is sufficiently good and is maintained to such levels throughout the vehicle life, such that the inertia loads experienced in reality are much lower than that stated in the European standard

It is also possible that the vehicle does not experience the patronage levels which were input to the modelling simulation. AECOM has been able to consider the effects of differing the passenger loadings and passenger mass distribution on fatigue life.

It is understood that any reduction in stress to the carbody will have a cubic effect on the damage incurred. Therefore accuracy of inputs is critically important.

Previous				New Data				
Load Case	Mass Condition	Acceleration	Number of cycles	Load Case	Mass Condition	Acceleration	Number of cycles	
1	Tare	±0.15g	3.1 x 10 ⁶	1	Tare	±0.15g	0.5 x 10⁶	
2	Laden	±0.15g	3.0 x 10 ⁶	2	Laden	±0.15g	8.6 x 10⁶	
3	Fully Laden	±0.15g	3.0 x 10 ⁶	3	Fully Laden	±0.15g	0.8 x 10⁶	
4	Crush Laden	±0.15g	0.9 x 10 ⁶	4	Crush Laden	±0.15g	0.1 x 10⁶	
			Total Cycles				Total Cycles	10 x 10 ⁶

Previous				New Data				
Load Case	Mass Condition	Vertical Acceleration (Z-Axis)	Number of cycles	Load Case	Mass Condition	Vertical Acceleration (Z-Axis)	Number of cycles	
PAS 1.1	0.33 x Crush	- 1g	1 x 10 ⁶	PAS 1.1	0.33 x Crush	- 1g	1.98 x 10⁶	
PAS 1.2	0.50 x Crush	- 1g	0.5 x 10 ⁶	PAS 1.2	0.50 x Crush	- 1g	6.80 x 10³	
PAS 1.3	0.66 x Crush	- 1g	0.3 x 10 ⁶	PAS 1.3	0.66 x Crush	- 1g	5.40 x 10³	
PAS 1.4	0.83 x Crush	- 1g	0.12 x 10 ⁶	PAS 1.4	0.83 x Crush	- 1g	2.20 x 10³	
PAS 1.5	1.00 x Crush	- 1g	0.08 x 10 ⁶	PAS 1.5	1.00 x Crush	- 1g	1.00 x 10³	
			Total Cycles				Total Cycles	2 x 10 ⁶

Figure 26 Adjustment to passenger mass and passenger loading

The results of the adjustments presented in Figure 26 show a marginal improvement in fatigue life:

- Location 1 – Life increase to 1.1 years from 0.7 years.
- Location 2 – Life increase to 3.3 years from 2.6 years.

The reduction has arisen due to the reduction in the higher passenger density values; however, there has not been a significant reduction as the total number of cycles has not reduced.

The following inputs are likely to impact the result of the fatigue life study:

- Unit mass and distribution;
- Underframe component mass and location;
- Vertical inertia accelerations; and,
- Number of cycles.

6.5.4 There are cracks present in the vehicle structure which have not been noticed

It is possible that cracks are present and have not been noticed. The cracks may have relieved the concentrated initial stresses and propagation has not been as excessive since. It should be noted that, it is possible for cracks to have developed in the door corners without propagating to a significant extent once the initial stress concentration has been relieved. These cracks may not noticeably affect the overall structural performance of the vehicle.

The Central Line 92TS experienced greater than expected loading during the first years of operation. It incurred fatigue cracking to the door aperture corners and saloon window surrounds. Cracks appeared during the first 5 years of operation and the fleet was put on a frequent monitoring programme although it continued in operation. The 92 TS is still in operation today and carries far greater load than its design had ever intended. London Underground is considered to be a particularly cautious and conservative operator and have not seen evidence of crack propagation to the extent that railcars should be removed from service. It is believed that the initial cracking which occurred relieved the concentrated stresses without catastrophic failure.

It is understood that the Locations 1 and 2 as identified in this results section have not been closely inspected for cracks and many railcars may never have had the panelling around the doors removed as it is not required for any of the planned maintenance or overhaul interventions.

6.5.5 Fatigue analysis methodology is too conservative

SN curves contained in Eurocode 3, [Ref. 2], have an inherent amount of conservatism built in to ensure safe design. Part of the SN curve conservatism stems from the fact the standard needs to cover all types of steel. In this case stainless steel is modelled which has a high ultimate tensile strength to yield ratio and may therefore be more resistant to crack initiation and propagation.

6.5.6 Further actions

Actions to identify the correct explanation or combination of explanations are:

- 1) Identify those highly stressed areas which are life limiting for each of the study Option life spans.
- 2) The proposed work outlined as Phase 2 in the project plan is embodied. This will allow the high stress areas of the carbody identified during this analysis to be strain gauged so that more accurate life predictions based on actual vehicle loadings can be made. The findings of this work will also allow adjustment of the FEA based load cases if the on track loadings are significantly different to those estimated.
- 3) The areas of the vehicle where this report has identified a life lower than the 30 year design life should be subject to inspections and non-destructive testing for the presence of cracking. This includes the spot welds.
- 4) It is recommended that a thorough dimensional investigation using a weld gauge is carried out for the critical welds identified in this report. This may allow the Class 36 welds to be re-categorised as Class 80 welds, which will return a significantly higher fatigue life in these areas.
- 5) Review the input assumptions and seek to better the accuracy through improved measurement or calculation techniques.

6.6 Market Analysis

During the course of the study feedback was sought regarding the asset life potential of stainless steel rolling stock fleets. Discussions were held with the operators, engineers (present and former) and other persons knowledgeable in fleet operation. Research suggests that rolling stock employing stainless steel carbodies are observed generally to exceed the intended design life.

QR EMU

A sample corrosion assessment report of the QR EMU fleet has been reviewed and it is reported that the results show that the structural areas of the undercarriage of the car and metallic integrity is excellent. Test results show that none of the side sills, head stocks, bolsters show signs of corrosion. The floor did show signs of corrosion particularly in the area of the headstock and backing bar, however these areas are not reported to be of structural importance to the railcars. The QR EMUs are in the order of 34 years old and since a new rolling stock order has not yet been placed, the railcars are likely to remain in operation until they are in the order of 40 years old. Recommended treatments are patch repairs to the corroded carbon steel areas of floor and headstock, as well as installation of secondary retention systems to the underframe equipment boxes.

It is known that the A-series design uses a greater proportion of stainless steel in the exterior panelling and for the underframe too. Whilst the QR EMUs are reported to be in a good state of health for the age, corrosion of the underframe is evident (see Appendix I). Corrosion of the underframe is not expected to pose a similar risk to the A-series railcars due to the incorporation of stainless steel throughout the underframe and an argument could be made that the railcars would achieve a better service life by comparison as a result of this and the less precipitous conditions in Perth by comparison to Brisbane.

Philadelphia Area Transit Company (PATCO)

Companies Budd and Vickers built 120 stainless steel cars in the late 60's/early 70's comprising of single cars, married cars, and Budd English cars. A refurbishment was recently undertaken where the scope was largely driven by obsolescence in equipment such as the braking logics, traction systems, EP braking system and also by the necessity to improve reliability, maintainability, and availability.

The inspection of railcars found:

- The stainless steel carbody in good condition with no corrosion despite extreme temperatures, high salinity levels due to gritting and road salt and high moisture levels.
- The carbody welding was not to design standards, some ring welding at brackets on side and centre sill show signs of crack propagation but not significant
- NDT performed on bogies to confirm continued use
- The secondary structure had bridging plates inserted. Huckling/pop riveting was performed instead of welding to protect the carbody

The life extension expectancy is a further 15-20 years of operation post refurbishment.

It should be noted that railcars manufactured by Budd in the United States are known to be heavily built units of unreserved strength and mass.

VIA Rail Diesel Cars

The Rail Diesel Car (RDC) overhaul project formed part of a US\$907 million VIA Rail capital investment project.

The RDCs operate as 2 three car units and they are constructed of stainless steel carbodies. The RDCs were built in 1949 – 1962 by the Budd Company of Philadelphia, Pennsylvania and have been operating far beyond their intended design life of 30 years. The railcars are used in low density, short passenger/commuter areas. The RDC Fleet Rebuild Project is considered the first major overhaul project where the cars were stripped back to the carbodies and structural assessments were performed. Major system enhancements were also undertaken.

Structural evaluation revealed that the stainless steel carbodies were considered in good condition for their age with no signs of corrosion despite Canada's harsh conditions of snow, rain and extreme temperature differences. Fatigue cracking to the side sill was found and it was determined this had been mainly caused by conducting poor weld repairs and lack of temperature control. It was noted that the structural members of the cars were constructed with stainless steel of 201 and 301 types. To prevent future propagation of cracks due to welding, stainless steel splices were reinforced by huck bolts at critical locations.

The design life of the cars following the refurbishment/life extension works is expected to be 40 – 50 years, compared to an estimated 40 year design life for carbon steel or aluminium replacement railcars.

6.7 Conclusions

The following conclusions are made in light of the FEA fatigue modelling which has been undertaken:

- The fatigue life of the A-series trains has been predicted to be extremely short at just over one year for the worst case location;
- The present life of the A-series railcars far exceeds the predicted fatigue life from the FEA analysis;
- The carbody design concentrates stresses in the jointed areas;
- The majority of the carbody is lowly stressed; and,
- The following explanations are given for the distinctly short fatigue life result generated by the fatigue life modelling:
 - Manufacturing processes have differed from design;
 - Inaccuracy in the FEA model;
 - Inaccuracy in the model inputs;
 - The A-series railcars have already experienced fatigue cracking; and,
 - The fatigue analysis methodology is too conservative.

6.8 Recommendations

These recommendations are made on the basis of the results retrieved:

- Inspect the carbody for cracks in the locations identified;
- Validate the accuracy of the input loads by the following courses:
 - Train mass and CoG – accurate weighing of railcars;
 - Component underframe masses – accurate weighing of masses;
 - Vertical inertia – acceleration testing as described in Phase 2;
 - Experienced stresses and strains – strain gauge testing; and,
 - Measurement of the weld sizes in high stress locations.
- Non-destructive testing of high stress areas such as dye pen and ultrasonics for surface and sub-surface cracks

7.0 Part Two - Options Analysis and Discussion

The following sub-sections of the report discuss the alternative options available for the A-series fleet. A concise comparison of each of the Options with one another is provided in Section 9 which considers cost, strategic risk and schedules as well as other factors.

The items discussed and opinions expressed in this section of the report are based on the analysis conducted and findings outlined throughout Part One of the report.

The Options being considered are as follows:

- Straight replacement at end of service life;
- Life with existing technology and or minor enhancements of the railcar; and,
- Re-engineering life.

The implications of these Options on the design life of the railcars are provided in Table 15, below:

Table 15 Options definition

Option Number	Ref	Title	Duration of extension (years)	Operating life	Year extended to
Option 1	1	Design life expiry	N/A	30	2021
Option 2	2a	Life extension (Minor mods)	5	35	2026
	2b	Life extension (Minor mods)	10	40	2031
Option 3	3a	Life extension (Re-engineering life)	20	50	2041
	3b	Life extension (Re-engineering life)			

All costs obtained during the course of this study should be considered as 'budget estimates' accurate to $\pm 30\%$. A comprehensive list of the assumptions which apply to the costs presented in this report in Section 3 .

Each of the options is discussed in the following areas:

Assumptions – those specific to the Option and which costs or schedules are based;

Asset health – those recommendations which are pertinent to maintaining a consistent level of asset health at the same level as currently found on the fleet;

Market analysis – those findings from research and case studies which are relevant to the Option;

Reliability, availability and target meeting – how the Option is expected to perform in future;

New rolling stock introduction – the impact of new rolling stock introduction on the Option; and,

Cost analysis – an appraisal of the cost of the Option.

It is assumed where there are works which are expected to be included in the existing scope of works for the maintenance contractor they are presented as nil cost to PTA in the following sections. Where ultimate contractual responsibility is unclear for any of the Options (PTA or maintenance contractor), the values for those scope activities have been applied to the PTA cost model to maintain a reasonable level of conservatism.

7.1 Option 1 – Straight Replacement at End of Service Life

The first 43 railcars of the A-series fleet were delivered from 1991 and are over twenty years in to their intended design life. If there is no extension to the operation of the A-series, a planned replacement at the end of the intended design life is likely to take place in a further 8-10 years.

Since the results of the Phase 1 FEA study suggest that the carbody has already exceeded its fatigue life, continued operation of the A-series should be undertaken with due diligence. The recommendations presented in Section 6 should be carried out in order to validate the desk top fatigue life analysis and determine the level of risk inherent with continued operation of the A-series.

7.1.1 Assumptions

The following assumptions are made in the context of replacing the A-series at the end of its design life:

- Rolling stock capacity expansion (New rolling stock) will be required from 2018. Replacement railcars are phased in with replacement rolling stock – New rolling stock;
- New rolling stock will require new maintenance facilities;
- Both the first and second batch of the A-series railcars will be decommissioned in the same programme;
- The A-series will be life expired from 2021, decommissioning is necessary before this date.

7.1.2 Asset health

During the completion of this study AECOM has conducted a series of asset inspections, and completed discussions with reliability, fleet engineers and maintainers from PTA and the Maintenance Service provider. Further reliability analysis has been undertaken in order to understand the present state of health of the A series and the likely future performance.

It was deemed an objective to identify the initiatives and practices which would most likely maintain the existing reliability with low financial investment to complete the period of operation associated with Option 1.

AECOM understands that the overhaul activities, as listed in Table 16 are likely to be undertaken during the remaining term of the maintenance contract:

Table 16 Overhaul activities in current contract

Overhaul Activity	
Main circuit breaker	Dampers
Pantograph	Brake disc, motor & trailer
Gearbox	Bogie, motor & trailer
HVAC	Air compressor
Power/Brake controller	Air boxes
Driver's console	Air dryer
Traction control system	Brake calliper
External passenger doors – heavy (door leaf not included)	EBC5 brake rack
Gangway doors – heavy (bellow not included)	Brake system - valves, cocks, general
Cab doors (door leaf not included)	Auxiliary converter
Driver's seat	Automatic coupler
Main transformer	Semi-permanent coupler
Thyristor converter	Auxiliary transformer / reactor
Contact box (does not include overhaul of internal components)	PFC unit
Auxiliary relay box (does not include overhaul of internal components)	Wheelsets
Brake resistor	Traction motor – rewound on condition basis

Based on the information provided to AECOM during the course of this study, it is believed the total material and labour cost for the activities described in Table 16 over the contract life is in the order of AU\$36 million which is believed to be absorbed by the maintenance contractor under the terms of the existing maintenance contract.

An overhaul programme projection is presented in Figure 27. It can be observed that the overhauls conducted during the 2014 to 2015 period will alleviate the planned requirement for heavy maintenance until 2018/2019 in the case of the traction motors and later still for the other train systems.

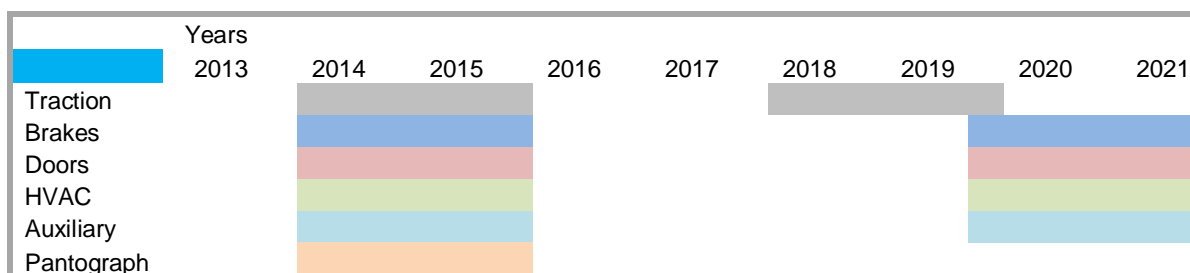


Figure 27 Projected overhaul programme to be conducted by maintenance contractor

From the analysis conducted AECOM is able to propose that the following programmes be considered in the event that the railcars are to be decommissioned at the end of the design:

Recommendations

- Avoid deferring maintenance, specifically component overhauls;
- Conduct a RCM programme in order to identify appropriate maintenance periodicities;
- Initiate a periodic fleet check (including ultrasonics) for bogie cracking;
- Initiate a periodic fleet check of underframe equipment case integrity ;
- Initiate a periodic fleet check (including NDT and ultrasonics) of Transformer and Auxiliary case brackets and fixings ;
- Rectify manufacturing quality/design issues with door leaf design;
- Gearbox oil sample testing on a routine basis;
- Conduct sample checks of electrical insulation;
- Conduct structural analysis through NDT and strain testing of a sample carbody;
- Inspect motor pinion shaft for pitting, score marks and damage as part of the gearbox overhaul;
- Undertake sample NDT testing and ultrasonic analysis of bogie structure; and,
- Improve traction motor overhaul programme time through sourcing from an expanding supplier network.

Detailed findings of the asset health assessment are described in Section 5.7 Technical Summary and Appendix B.

7.1.3 Market analysis

The QR EMU fleet is nominally 10 years older than the A-series and there is commonality in some system design, technology and performance. The QR EMU is considered to act as a reasonable projection of potential future issues which could be experienced by the A-series. A full case study of the QR EMU life extension was provided as part of this study for review and consideration. A few key points which should be reviewed in the context of the A-series railcar study are summarised below, and these should be considered by PTA when developing programmes for continuing operation of the A-series:

- There is commonality in the carbody structure and service duty, QR EMUs show no evidence of fatigue in the carbody structure which would typically be evidenced by cracking;
- Bogie frames differ between the fleets, however QR reports no fatigue issues;
- Gear box leakages confined to only one railcar;
- Door issues are consistent with age and those experienced on the A-series (see Appendix B);

- Traction motors are clean and in good condition, modifications have been made to brush springs to improve reliability;
- Large quantity of capacitors leaking and/or melting;
- Traction control relays and electronic control equipment are now obsolete, investigations for replacements are being undertaken;
- Some problems experienced with battery charger (experienced also with A-series);
- New compressors are being installed;
- Minor corrosion evident on roof, extensive surface corrosion to underframe (notably the QR EMUs feature carbon steel underframes);
- Underframe fixings experiencing extensive wear and bending; and,
- Corrosion present inside HVAC ducting.

7.1.4 Reliability and availability target achievement

Predictions for future reliability are difficult to make based on historic performance data. The maintenance contract has been in place for a 12 month period and reliability targets are not yet being achieved. It is understood that the maintenance service provider is undertaking a series of reliability improvement plans and initiating a component overhaul programme to rejuvenate system performance. It is predicted reliability will steadily increase over the next five years until targets are achieved and then experience steady state til the end of the current maintenance contract in mid-2019. This prediction is illustrated with the predicted reliability curves in Figure 28 for the A-series.

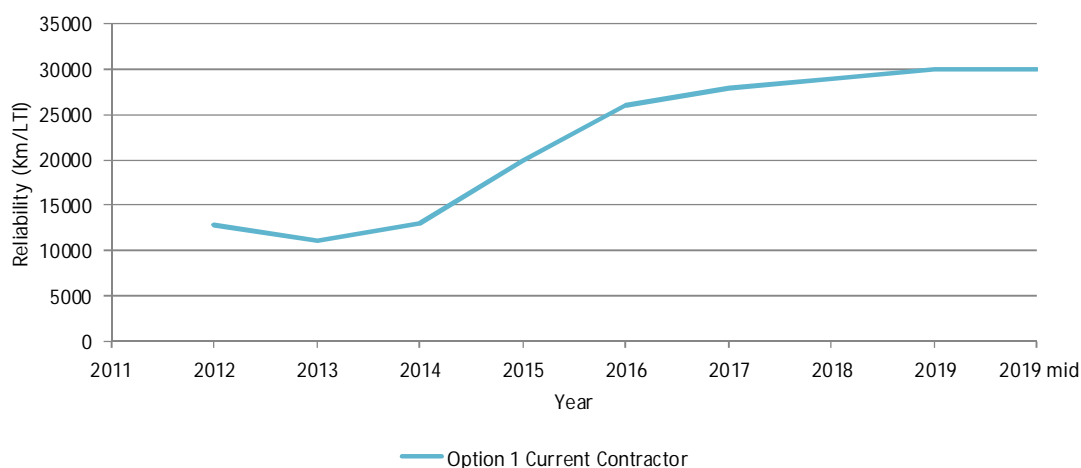


Figure 28 Option 1 (Replacement mid-2019) Expected Reliability under Current Maintenance Contract

An indicative reliability curve has been projected for the A-series in Figure 28 during the remaining period of the assets design life. The curve tracks what is expected to be the likely achievable reliability growth of the A-series based on the works being undertaken and forecasted for the assets (as discussed in Section 5.4).

The subsequent effect of achieving the current and the forecasted 30,000 km per LTI is displayed in Figure 29 for ≥ 4 mins.

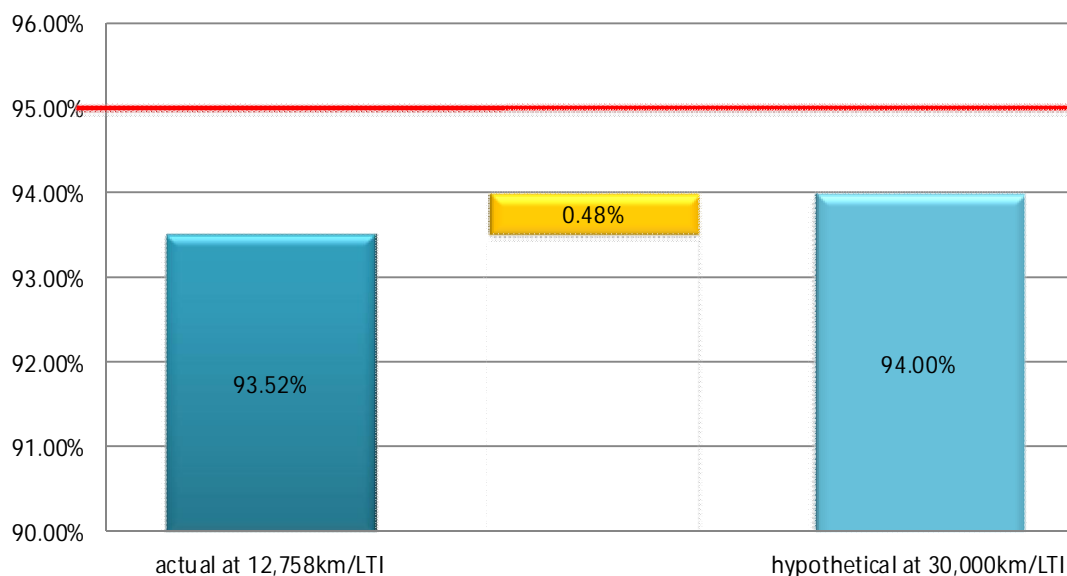


Figure 29 Effect of Reliability Improvements on Operational Performance (LTIs measured as ≥ 4 mins)

It is evident that achieving a reliability of 30,000 km for the A-series rolling stock is not sufficient for a target of on-time running of 95% to be accomplished.

7.1.5 Maintenance contract

In order to adhere to the intended design life of the assets, the A-series fleet would commence decommissioning from 2021. The existing maintenance regime includes a contractual break option period in June 2019, whereby the contract can be terminated by PTA or continued for another 7.5 years (PTA is required to provide the maintainer with its intentions six months prior to the maintenance contract break point). Comparing the timescales for the maintenance contract and design life of the A-series it is apparent that the two do not align. There are two reasonable alternatives for fleet decommissioning listed below:

Alternative 1 Decommission the fleet at 30 years of service; and,

Alternative 2 Decommission the fleet prior to 30 years of service.

Alternative 1 leads to a period of 1.5 years or greater whereby the A-series maintenance will need to be supported by a contract or party different than that which is presently employed. Contractual complexity, availability of maintainers, training and other issues may discourage this tactic.

Alternative 2 means that the full design life of the asset is not achieved, however the risks associated with continued maintenance support of the railcars are avoided if the A-series is phased out during the existing maintenance contract.

7.1.6 New rolling stock introduction

PTA has reported that a new rolling stock fleet will be required to serve the growing service demand in the future.

The introduction of new rolling stock to the network could provide a reasonable opportunity for PTA to decommission the A-series fleet. The two main capital investments associated with new rolling stock introduction are typically:

- The railcars; and,
- The railcar maintenance facilities (where required).

Both items above inherit additional risk if the A-series fleet's operation is continued in parallel with new rolling stock. In the case of the procurement of new rolling stock, more sizable order quantities are likely to return better financial terms for PTA due to economies of scale. In the case of the maintenance facilities, a future depot would require facilities and plant which would preferably be compatible with both rolling stock types, A-series, B-series and new rolling stock. These issues are mitigated by phasing out the A-series fleet during the commissioning of a new rolling stock fleet.

7.1.7 Schedule of works

A schedule of these activities is demonstrated in Figure 30.

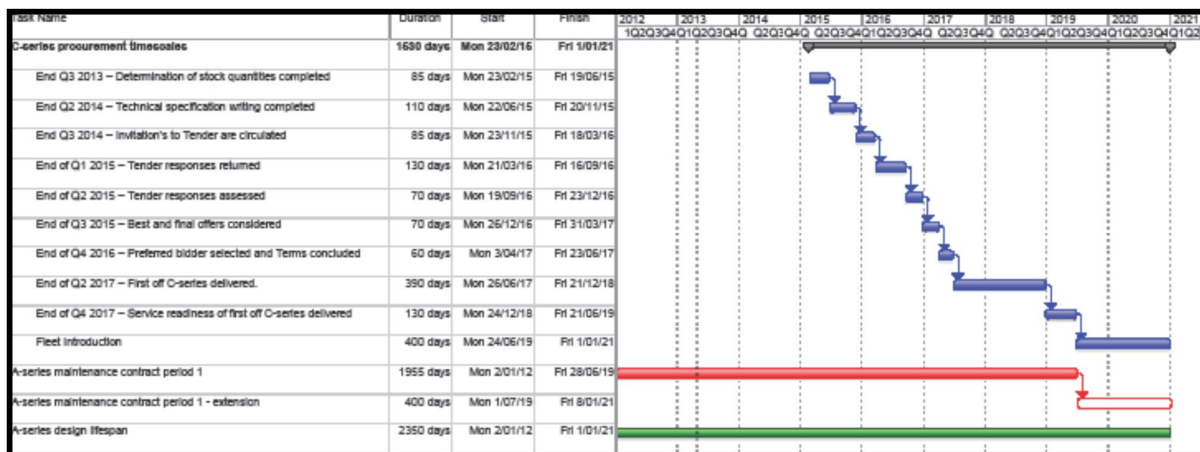


Figure 30 Projected schedules for Option 1

7.1.8 Cost analysis

It should be noted that due to the conditions of the existing maintenance contract, that many of the initiatives discussed in Section 7.1.2 is likely to be undertaken by the maintenance service provider under the terms of the existing maintenance regime. Indicative costs for Option 1 are presented in Table 17

Table 17 Indicative costs for Option 1

Option 1 Maintenance contract	Indicative cost for maintenance contract (\$AUD)	Notes on costing assumption
Completion of the contract to mid-2019 including contingency	\$102,362,050	Based on current maintenance contract option pricing and all other works being undertaken by maintenance service provider
Completion of the maintenance contract to 2021	\$38,982,750	Extension of maintenance contract cost for 18 months
Total	\$141,344,800	

7.2 Option 2 – Life with Existing Technology and or Minor Enhancements of the Railcar

During discussions with PTA, Option 2 – life with existing technology and or minor enhancements is considered to mean the operation of the assets beyond the specified design life until such time the units are reasonably expired and is to be achieved through minimal financial investment. To this end a life extension of five to ten years is considered a reasonable term for continued operation of the A-series with low financial investment in performance and asset health modifications.

Two particular life extensions were selected for Option 2 since they coincide with planned major maintenance intervals, maintenance contract duration and other such events.

- Option 2a – 5 year extension beyond 30 years (life expiry 2026)
- Option 2b – 10 year extension beyond 30 years (life expiry 2031)

The directive for Option 2a is that an extension to design life of five years is achieved by undertaking critical investments to sustain the operation of the A-series railcars through maintaining safety systems and realising satisfactory reliability levels succinct with on-time running targets.

The directive employed for Option 2b is that a longer asset life extension to 10 years beyond design life (40 year service life) would warrant modifications to improve the A-series image and public perception through aesthetic improvements as well as undertaking the works required to maintain appropriate safety and reliability levels.

The results of the Phase 1 FEA fatigue life study are set aside during the discussion of this Option. The results will ultimately have significant bearing on the feasibility of Option 2, but validation of the results should be sought through practical testing before omitting Option 2 from consideration entirely.

7.2.1 Assumptions

The following assumptions are made in the context of a minor (5-10) year life extension of the A-series railcars:

- B-series railcars currently on order will facilitate rolling stock capacity expansion in the near future and new rolling stock procurement can be postponed until 2025;
- New railcars are phased in with the decommissioning of A-series rolling stock;
- New rolling stock will require new maintenance facilities;
- It is assumed that both the first and second batch will be decommissioned in the same programme; and,
- Option 2 employs the same reliability predictions as used for Option 1 until 2021, thereafter further analysis was undertaken to predict future events.

7.2.2 Asset health

Section 7.1.2 describes the recommended practices to maintain good asset health for the period of operation up to 2021 (end of intended design life of the A-series). Option 2 is broken down into two possible sub-options, and the recommendations for continued operation and justification for inclusions are further defined below.

7.2.2.1 Option 2a – 5 year life extension

The objective of employing the recommendations below is to preserve the reliability of the railcars for a short to medium term period.

In addition to the recommendations and requirements prescribed in Option 1, the following practices should be applied:

Recommendations

It is recommended the following activities should be implemented in addition to the activities outlined in Option 1:

- All DC traction motor armatures should be re-wound with new main and equaliser coils. During overhaul it is recommended that traction motors undergo motor pinion shaft inspections and testing in order to verify longevity of the motors.
- The auxiliary converters are of an age where it would benefit from regular minor overhauls between major overhauls resulting in an improved reliability of the system for an additional 5-10 years beyond design life. The materials required in supporting this programme are currently in stock at Claisebrook.

- The fan motors and control components of the HVAC system be replaced to maintain the life of the system. Condenser coils should be replaced on a condition basis.
- Smoke detection (VESDA) on board has been investigated previously, but not implemented. This is a result of development of system design over time resulting in various challenges for VESDA installation such as enabling communication between railcars. PTA has informed AECOM that it is their present understanding that smoke detection is not a requirement of DDA compliance on legacy rolling stock. However provision of VESDA should be revisited for the A-series fleet, since it is becoming a standard installation on modern rolling stock including the B-series. It will reduce asset loss risk from arson, increase passenger safety from fire, and reduce service disruption caused by overheating electrical equipment.
- LED saloon and dashboard lighting will generate improved illumination in comparison to the current incandescent lighting used which should in turn improve passenger and driver comfort. CAPEX costs associated with LED fittings are likely to be countered by a far greater lifespan and reduced energy usage leading to reduced OPEX costs. Custom fit LED saloon and cab lighting are readily available. Diffusers should also be replaced and are available from the OEM.
- The emergency door release is currently located above the passenger doors and may require relocation to provide better accessibility to people with reduced mobility. The DDA requirements are subject to interpretation and PTA is recommended to approach the DDA council to seek clarity.
- The current AM/FM radio has always had reception issues as a result of the overhead wiring; replacement with better reception should enhance driver comfort and may indirectly reduce driver related LTIs (cost not sought).
- Condition based replacement of underframe equipment cases for those suffering exceptional corrosion and/or significant wear. For those boxes being replaced it would be advisable to integrate a secondary retention system into the equipment case design.
- It is assumed that for this Option an interior refurbishment will be required. The scope of the interior refurbishment is assumed to form part of the existing maintenance scope and thereby nil cost is incurred by PTA. However, it is noted that the period of extension associated with Option 2b may require further modifications to the interior in order to comply with relevant DDA requirements.

Table 18 shows the individual and cumulative total cost for the modifications and practices recommended above.

Table 18 Option 2a - Life extension of 5 years

Minor upgrades and modifications with existing technology	Indicative cost to PTA for materials and labour (\$AUD)	Notes on costing assumption
Re-wind existing DC traction motors fleet wide*	\$4,752,000	Scope of maintenance contract
Perform minor overhaul of auxiliary systems every 840,000km. To include replacement of capacitors, circuit breakers, thyristors, and circuit discs	\$192,000 (Material only)	Assumed that maintainer will bear labour costs and PTA to provide equipment. Schedule aligned with brake system overhauls leading to shared gains for both parties.
On HVACs, replace fan motors and control components fleet wide, and replace condenser coils where necessary	\$287,000	Assumed that maintainer will bear labour costs for removing and attaching HVAC unit, and PTA to provide equipment and offsite labour costs. Schedule aligned with brake system overhauls leading to shared gains for both parties.
On board smoke detection – Very Early Smoke Detection Apparatus (VESDA)	\$576,000	\$6000 material per VESDA, 80 labour hours per railcar
LED saloon lighting	\$493,000	Quotation supplied by ART (see Appendix G) 5 hours per railcar – to confirm cost with supplier

Minor upgrades and modifications with existing technology	Indicative cost to PTA for materials and labour (\$AUD)	Notes on costing assumption
LED dashboard lighting	\$116,000	Quotation supplied by ART (see Appendix G) 90 minutes per railcar using two technicians.
Relocation of the emergency door release	\$348,000	Relocated to the side of door and 32 hours for installation per railcar
Condition based replacement of underframe equipment boxes	\$317,000	Assume 2 boxes replaced per year suffering exceptional corrosion over last 5 years, 80 hours per box
Contingency at 15%	\$1,066,000	
Total Additional Cost to PTA	\$8,172,000	

* The cost associated with the traction motor re-wind covers 30% of the fleet, since an estimated 70% of motors are provisioned for in the F-service presently.

Improvements to the activities recommended in Option 1, which should feature in a standard scope of works for a 5 year life extension are identified below:

- Conduct structural analysis through NDT and strain testing of carbody this should also include destructive testing of welded joints to determine S-N curves;
- Conduct testing of the motor pinion shaft to analyse structural integrity; and,
- Conduct fatigue life analysis of bogie.

7.2.2.2 Options 2b – 10 year life extension

Recommendations

Option 2B builds upon the enhancements and improvement programmes defined for Option 2a and seeks to enhance the aesthetic impression of the railcars through low cost initiatives to improve passenger perception of the aged railcars.

This is a process which was fundamentally applied by New Zealand Rail Limited from 1993 upon acquisition of the ADL class DMU fleet formerly of Perth. The railcars, originally manufactured in the early 1980's were purchased by NZR in 1993, in 2002 the railcars received a refurbishment focussed on enhancing the aesthetic appearance of the railcars through facelifting the frontage (new GRP), new seat moquettes, new interiors (grab poles and flooring), electric destination displays and painting of exterior body shells. The investment of approximately \$8.8 AU (\$8.5M NZ in 2003, allowing for exchange rate and inflation adjustments) for the refurbishment works, the railcars were received by the public as if they were new trains.

The recommendations for modifications and improvement programmes pertinent to extending A-series life by 10 years of service operation are identified below:

- Installation of a cab HVAC will provide conditioned air directly to the cab, improving the climate control of the cab environment and improving the ambience for driver comfort. This may also prevent associated workers union disputes in regards to this issue particularly throughout summer periods.
- Traction brake controller upgrade to improve sensitivity. The controllers are reported to be 'notchy' and inconsistent between railcars and during the course.
- Modernisation of the cab frontage will improve and enhance the aesthetics of the fleet markedly. It may also give rise to increased patronage and acknowledgment of the PTA in their role of provider of public transport to the community. The estimates for cab frontage development are based on the values available for the B-series GRP.
- The A-series design does not incorporate anti-climbers on the carbody/cab. Anti-climbers are a safety feature inherent in the design of most modern rolling stock which aid in reducing the risk of one car riding over a second car during collisions subsequently reducing the risk of injury to passengers during such events.
- It is understood that vacuum circuit breakers (VCB) have not been overhauled since commissioning and should be replaced or overhauled periodically due to their age under this option.

- Fleet wide installation of secondary retention to the underframe equipment cases to improve security of equipment cases (cost not sought).
- It is expected that only minor modifications to the headstock and solebars will be required and this work could be incorporated into the development of a modernised cab frontage.

Table 19 Option 2b - Life extension of 10 years

Minor upgrades and modifications with existing technology	Indicative cost for materials and labour (\$AUD)	Notes on Costing Assumption
Option 2A 5 year minor upgrades and modifications	\$7,324,000	Accounts for additional Auxiliary Converter minor overhauls (\$218k)
New cab frontage	\$5,360,000	Labour at 80 man-hours per cab end
Installation of cab HVAC	\$2,144,000	Excludes ducting materials and assumes 155 hours per HVAC unit
Anti-climbers	\$696,000 (material cost only)	Does not account for potential additional modification to sole bar
Vacuum Circuit Breakers	\$2,008,000	3 hours per unit, to be done during planned maintenance
Traction controller	\$2,328,000 (material cost only)	Excludes installation cost
Contingency at 15%	\$2,979,000	
Total Cost to PTA	\$22,839,000	

7.2.3 Market analysis

The QR EMU fleet was introduced from 1979 and are approaching 35 years of service operation. The fleet will continue in operation until replacement rolling stock is sought. 75 six-car units are expected to replace the existing EMUs, though new rolling stock is not expected to be available until the beginning of 2017 at the earliest if a contract is commissioned in late 2013. By this time the existing QR EMU fleet will be approaching 40 years of age. There is no indication that timescales for new rolling stock procurement are being hurried due to degraded condition of the existing stock. Due to the similarities existing in the QR EMU fleet and the A-series it would be reasonable to assume that the A-series should achieve a similar lifespan. It is known that the A-series design uses a greater proportion of stainless steel in the exterior panelling and certainly for the underframe. Whilst the QR EMUs are reported to be in a good state of health for the age, corrosion of the underframe is evident (see Appendix I). Corrosion of the underframe is not expected to pose a similar risk to the A-series railcars due to the employment of stainless steel throughout the underframe and an argument could be made that the railcars would achieve a better service life by comparison as a result of this and the less precipitous conditions in Perth by comparison to Brisbane.

The reliability of the QR EMU fleet is noticeably less than that of the A-series EMU fleet which is perhaps partly due to the fleet's age. The QR EMUs achieve in the order of 8,000 km per LTI (where an LTI is a delay even of greater than or equal to five minutes).

7.2.4 Reliability and availability target achievement

It is unlikely the works proposed for Option 2a will require railcars to be off line for any period of time significant enough to immediately impact availability. Instead it is likely that the scope can be incorporated into down time for the railcars. The works should not require facilities other than those already available at Claisebrook.

It is considered a reasonable assumption that as the fleet ages, the reliability of the railcars will become increasingly difficult to maintain and will therefore decrease over time. The train systems are expected to incur further mechanical wear, electrical degradation and interferences associated with ageing componentry. This has been reflected in the reliability forecasting for the future operation of the railcars. The future forecasts presented in Figure 31 account for the recommendations outlined in Section 7.1.2 (those which relate to reliability rather than aesthetics in relation to the scope of work for Option 2b), and employment of a rigorous maintenance and overhaul programme which avoids deferral of or omitting of overhaul. The reliability forecasts also assume that maintainer asset knowledge is not lost in the future.

It is worth noting that if PTA packaged work up and incorporated it into a maintenance contract as currently employed, PTA is able to have reliability 'guaranteed' even if it isn't actually achieved.

Figure 31 demonstrates the predicted reliability curves for the fleet during the periods of continued A-series operation associated Option 2a and 2b. Figure 31 also shows the potential effect of the introduction of a new maintenance contractor for the second maintenance contract period. Reliability is observed to decrease for a period of time before stabilising to a more gradual decline. The two stages of reliability reduction are associated with the initial lack of knowledge of the maintainer and the inevitable wear and tear incurred by the fleet which is unlikely to be compensated through the installation of minor upgrades.

The prediction of future reliability until 2021 is largely based on the data presented in Section 7.1.4 for Option 1.

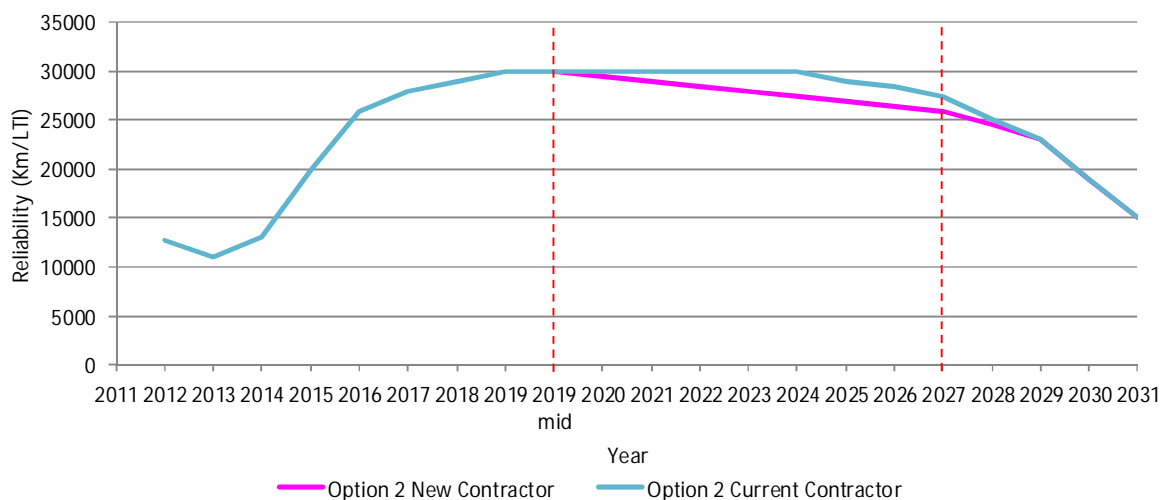


Figure 31 Option 2a/b (Replacement at end of year 2026) Expected Reliability over Time

The works associated with Option 2b are likely to have a slightly greater impact on train availability by comparison to Option 2a, nominally due to the nature of the work for replacing the cab front end. The heavy maintenance facilities in the DMU shed will suffice to complete the works. It is estimated that the replacement of the cab frontage will be the longest linear duration of works and the remainder of the scope can be undertaken synchronously. It is expected that five days is a conservative estimate for the duration works in completing the scope of Option 2b. It should be noted that the programme assumes working Monday to Friday working Saturday's and Sunday's available as contingency.

7.2.5 Maintenance contract

There is an option with the existing maintenance contract to continue with the existing supplier for a second term of 7.5 years after the completion of the first term (also 7.5 years). The second phase would expire on December 31, 2026. It is apparent that the timescales for the maintenance contract are largely succinct with end of service life for Option 2a. Therefore there exists an opportunity to decommission the fleet leading up to the completion of the maintenance contract in a similar way as described in Option 1. A potential schedule for decommissioning is presented in Figure 32.

It is worth noting that PTA is not obligated to proceed with the second phase of the maintenance contract and has the option to end the contract after completion of the first period is complete. In this event two alternatives are considered workable. The first is that PTA takes ownership for maintenance delivery of the A-series in-house. The second alternative is that another maintenance service provider is employed. In this instance it would appear most practicable that the selected supplier of new rolling stock receives a novated maintenance contract. It is thought that there are greater levels of risk inherent with the first options (discussed further in Section 8). If the PTA chooses to end the existing maintenance contract, the break period in between Phase 1 and Phase 2 of the contract is a prudent time, especially if the preference is for novating the lease to a new rolling stock manufacturer.

Since Option 2b requires the railcars remain in operation for 10 years beyond the intended design life (until 2031), which is a period of years after the completion of both phases of the existing maintenance contract. This means there is no influence from the existing maintenance contract impacting the schedule for decommissioning.

The costs associated with extending a maintenance contract over the remaining 5 year period of operation for Option 2b are provided in Table 20. The costs have been escalated by 20% to account for the age of asset and potentially degenerated condition. There is also a risk that a maintenance service provider takes a more pessimistic view of the asset health and increases fees according to the perceived risk.

Table 20 Option 2b Maintenance contract cost to PTA

Option 2B Maintenance contract	Indicative cost for maintenance contract (\$AUD)	Notes on costing assumption
40 year operating life	\$ 349,708,000	Based on current maintenance contract option extension pricing and escalation consistent with asset age

The indicative cost for maintaining the A-series fleet for the period of operation associated with Option 2b is based on the existing maintenance contract rates for Phase 1 and Phase 2 and a 5 year extension of the contract with a 20% premium applied for the final five years of operation. The escalated rate represents the additional maintenance and materials expenditure associated with the ageing fleet. The cost has not been adjusted for inflation or net present value.

7.2.6 New rolling stock introduction

It is assumed that new rolling stock will be required irrespective of current fleet sizes due to growing patronage and a need to serve capacity expansion. It is also assumed that the introduction of new rolling stock will supplement the A-series fleet for a period eventually replacing it or cascading the B-series trains.

In the event that procurement of new rolling stock can be postponed until 2025, the schedule for undertaking Option 2a appears very favourable as illustrated in Figure 32.

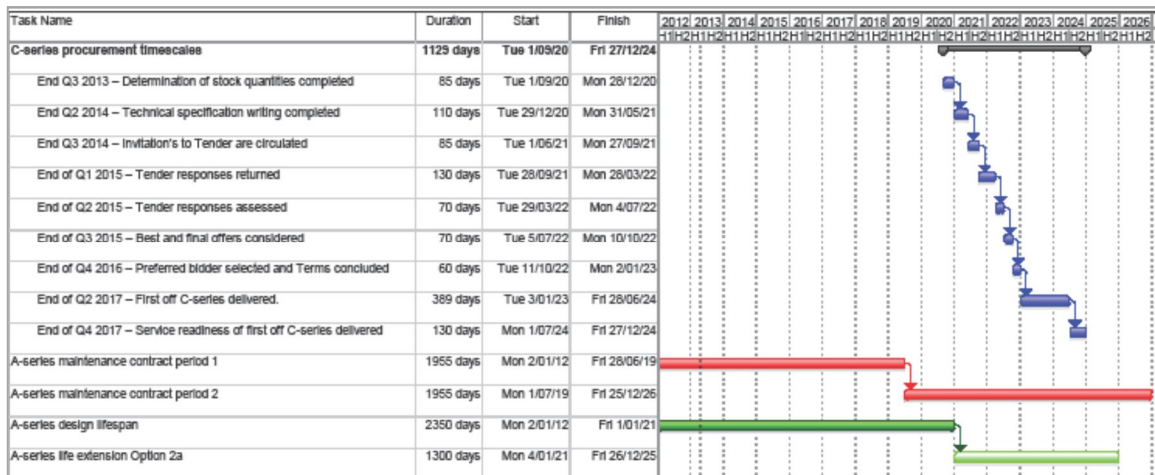


Figure 32 Indicative schedules for Option 2a

It is highly likely that the A-series fleet will not be sufficient to serve a growing ridership demand through to 2031 (life expiry of railcars according to Option 2b) without supplementation. It is likely a new rolling stock order will take place before 2031 and it is therefore likely the decommissioning of the A-series will only be co-ordinated with a 'follow-on' order. Either alternative is less favourable than that described for Option 2a. A further point worth noting is that an additional rolling stock maintenance depot is most likely to be required for a New rolling stock. Continuing to operate the A-series synchronously will require the upkeep of two maintenance facilities.

7.2.7 Cost analysis

Table 21 presents the indicative maintenance contract costs for Option 2a. The existing maintenance contract price has been projected over the schedule term for Option 2a with the direct costs of the minor modifications and enhancements outlined in Section 7.1.2.

Table 21 Indicative costs for Option 2a

Option 2a Maintenance contract	Indicative cost for maintenance contract (\$AUD)	Notes on costing assumption
Continue with existing maintainer until end of service life	\$ 239,776,500	Estimate based on Schedule 16 in Maintenance Agreement
Technical enhancements	\$ 8,172,000	Table 18
Total	\$ 247,948,500	

Life extension for a further 10 years as defined for Option 2b may require the deployment of an additional five year maintenance contract. The alternatives already described remain relevant, the existing maintenance supplier could continue to maintain the fleet, PTA may select to return maintenance to an in-house operation or a new maintenance supplier could be employed.

Indicative costs for Option 2b are presented in Table 22.

Table 22 Indicative costs for Option 2b

Option 2b Maintenance contract	Indicative cost for maintenance contract (\$AUD)	Notes on costing assumption
40 year operating life	\$ 349,708,000	Based on current maintenance contract option extension pricing
Technical enhancements	\$ 22,839,000	Table 19
Total	\$372,547,000	

7.3 Option 3 – Re-engineering Life

The objective applied to the development of a model succinct with the scope requirements for Option 3 has been to identify those modifications and activities which will enable continued operation of the A-series railcars on the Perth urban network for a sustained period of time.

Since there is likely to be a significant capital investment required to re-engineer the A-series to fulfil the objective, the lifespan of the railcars is extended to 20 years for Option 3 which optimises the time available for realising a return on the investment.

In conducting the investigations for suitable re-engineering schemes, it was decided that the traction system should be the focus of the analysis in this Option due to the likely cost for modifying the system. Two scenarios were investigated comprehensively which were; retain DC traction motorisation or replace DC motors with an AC traction system. These scenarios become:

Option 3a – Retain and upgrade DC traction system, operate railcars for 20 years beyond design life

Option 3b – Install an AC traction system, operate railcars for 20 years beyond design life

A broad range of other system enhancements and modifications were considered and are further discussed in this section but their application or feasibility is not altered by the application of a DC or AC traction system.

The results of the Phase 1 FEA fatigue life study are set aside during the discussion of this Option. The results will ultimately have significant bearing on the feasibility of Option 3, but validation of the results should be sought through practical testing before omitting Option 3 from consideration entirely.

7.3.1 Assumptions

The following assumptions are made in the context of a major life extension:

- New rolling stock procurement can be postponed until 2025;
- Works will occur during the period of the first phase of the maintenance contract and disruption to the contract is considered manageable;
- New rolling stock will require new maintenance facilities;
- It is assumed that both the first and second batch of the A series will be decommissioned in the same programme;
- Reliability predictions are based on Options 1 and 2 in addition to achievements of fleets in the UK;
- Re-engineering works will not be able to be undertaken on any existing PTA site;
- DC traction and AC traction modernisation costs have been provided by Alstom Transportation and in accordance with the assumptions and exclusions specified in Appendix G, with the exception of labour rates;
- Labour rate costs have been adjusted to account for the utilisation of local Western Australian workforce and overheads associated with leasing facilities suitable to conduct the scope of the re-engineering; and
- The Traction re-engineering costs provided by Alstom Transportation were benchmarked against those provided by Vossloh Kiepe.
- Comprehensive analysis of the power consumption of the A-series rolling stock has been conducted during the course of this study. It has been identified that the total power consumption of the A-series rolling stock is in the order of \$10.1 million per year (based on 2012 statistics).
- It is assumed that the train interiors will be maintained under the conditions of a maintenance contract to the current standards and are excluded from PTA's cost estimate.

7.3.2 Asset health

Section 7.1.2 describes the recommended practices to maintain good asset health for the period of operation up to 2021 (end of intended design life of the A-series). This section identifies the modifications associated with Option 3a and Option 3b, and provides a summary of the recommended modifications, works and initiatives which should be undertaken independently of traction system upgrades. The generic modifications are identified in the subsection for Option 3a and are assumed to carry-over for Option 3b.

The recommendations for modifications and improvement programmes pertinent to extending A-series life to 50 years of service operation are identified in the following sub-sections.

7.3.2.1 Option 3a

The recommendations which are made herein are considered to support sustained operation of the A-series beyond the intended design life and for an extended period of time.

The recommendations made below are expected to optimise the safety, reliability and investment in the assets. Some recommendations will overwrite or supersede previous recommendations for Options 1 and 2a. This has been accounted for in scope costing.

It is advised that the recommendations as prescribed by Option 2b should be undertaken and deployed on a fleet wide basis where not already recommended, as well as the following items:

- The DC traction motorisation is retained and enhanced through the integration of a DC regenerative braking system. This will involve replacement of the rectifying thyristors with IGBT to improve voltage waveform and power factor. It is important to note that the DC regenerative braking system control proposed by the supplier is an unproven system for service operation, though extensive laboratory testing has been conducted. In laboratory testing conditions it has been able to generate up to 35% energy savings through regenerated energy returned to the main power supply, however it is considered that a more appropriate value for energy saving is 20% (systems in Europe have been reported to return between 18-22% usable energy to a system. Refer to the Appendix G for a full system proposal made by Alstom Transportation. The DC traction modernisation scheme should encompass as a minimum a traction motor re-wind so that motor condition is known for installation.
- New brake system components should be installed. The callipers are in a non-uniform state and subsequently the OEM refuses to overhaul the callipers and accept warranty responsibility. As a result fleet wide replacement of callipers is recommended. Polymeric bushings on callipers can also be replaced with those that have steel pinions for improved longevity, or an alternative that is optimised for the application. There is an opportunity to integrate new wheel slip/slide protection with the installation of new brake control unit enabling improved integration between the two systems and enhanced fault diagnostics from a new BCU. This enhancement will reduce obsolescence risk of the braking system in future.
- Oil free compressors are recommended and are becoming common as retrofit systems in aged fleets which will remove oil contamination in components (doors, brakes) and should reduce the compressor maintenance burden.
- Modern HVAC systems incorporate improved automatically adjustable temperature control making them more sensitive to passenger thermal energy and distribution. This makes them more energy efficient. Long term running and maintenance cost savings are expected with an upgraded HVAC asset. It would be feasible to develop a split cab/saloon HVAC system with installation of additional ducting to the cab. Existing ducting should be checked for corrosion and replaced where necessary. If HVAC system replacement is not affordable, pipes, hoses perishable or corroded items should be replaced.
- Communication upgrades to improve passenger safety through CCTV enhancements with live wireless offload of captured CCTV footage at multiple locations along the route and upgrade of the PA/Intercom system. This feature may be expanded to provide better train condition monitoring performance (costs not sourced).
- Provided the current ATP system continues to be operated in the long term, it is recommended PTA upgrade the cabling and transmission racks. These have been changed fleet-wide and on condition basis since first implemented in 1990 -1994, however there are a high volume of transmission faults monitored up to early 2012 and are still been experienced, and should be further investigated by PTA. Upgrade to the protocol of the system should be suspended until a system wide decision is taken on the future operation of ATP or an alternative is sourced. A new passenger door system with an intelligent DCU capable of self-learning closing, opening profiles and door obstruction system may reduce station dwell times. Obstacle detection systems are not recommended unless mandated in future by DDA or other standards. If necessary door overcurrent devices are recommended rather than sensitive edge technology or similar, which have proven to be very unreliable on other rail systems. Improved diagnostics should enable more accurate fault detection and location identification. Passenger counting detection through sensory door equipment can also be incorporated to better monitor train loadings against capacity.
- Hearing augmentation in the form of hearing aid frequency induction loops will require extensive modifications to the current interior as discussed in Section 5.7 (DDA section). PTA will need to discuss this requirement further with the DDA to determine its necessity given life extension of 20 years.

- NDT and ultrasonic testing of the autocouplers and drawbars should be undertaken. It is likely that the electrical coupler heads will have degraded to a state where their replacement becomes necessary due to worn flexible components and seals or damaged electrical contacts. Unless evidence of fatigue is presented in the findings for the coupler mechanical testing the continued operation has been assumed.
- It is likely a new train management system will be required to incorporate the above mentioned ATP and control unit upgrades. Additionally, a new TMS will provide better integration protocols, faster transfer of data, increased functionality and a modern driver's interface.
- Train aesthetics are improved through the installation of a new GRP cab frontage as described by Option 2b, the passenger environment would benefit from an enhanced infotainment system. Existing PIS and communications systems can be improved upon by replacing dot matrix displays with LCD systems and renewed announcement units. Provision of Wi-Fi and even on-board entertainment could be made available through the installation of LCD/LED screens on interior panels. A-series railcars do not suffer from significant graffiti and advertising revenues would go some way to covering the APEX and OPEX investment.

Costs associated with the upgrades are provided below in Table 23.

Table 23 Option 3a Life extension of 20 years with DC regenerative braking

Major upgrades	Indicative cost for materials and labour (\$AUD)	Notes on costing assumption
Option 2b 10 year minor upgrades and modifications	\$15,161,000	Accounts for additional Auxiliary Converter minor overhauls, removal of replacement of HVAC fan motors (incorporated in New HVAC system replacement), and excludes 30% traction rewind
DC traction modernisation with a new traction system allowing regenerative braking	\$21,014,016	Price excludes new motors and re-winding of existing traction motors. Quote from Alstom will entail two years for fleet upgrade
Re-wind DC traction motors for fleet	\$12,960,000	Assumes maintainer is not incentivised to conduct partial re-wind programme due to traction upgrade and all motors are re-wound in upgrade programme.
New brake and air system	\$8,106,000	
New HVAC system for the saloon	\$6,144,000	
Upgrade ATP system	\$680,000	Includes only cables and transmission racks. Excludes system cards or a system wide upgrade
New passenger door system	\$2,688,000	
Hearing aid loops in line with DDA requirements	\$1,048,000	For railcars 1-43, 44-48 have been fitted already. PTA would need to review necessity of equipment with DDA.
Replace electrical coupler heads on condition	\$2,560,000	Assumes 60% of couplers will be replaced over the 30 years
New train management system (TMS)	\$8,606,000 (materials only)	Exclusive of labour
Contingency at 15%	\$11,845,050	
Total Cost to PTA	\$90,812,050	

It is worth noting that the price for DC traction modernisation assumes the existing traction motors can be retained. A fixed price for a fleet wide overhaul of the DC motors incorporating a rewind is included in the price of this Option. Alstom has indicated that the estimated cost of a motor overhaul and rewind can be completed for approximately AU\$45,000 per motor if a fleet-order is placed. Alstom also indicated during discussions an estimated cost of \$60,000 for a new DC motor for a fleet order. On this basis the DC traction modernisation could escalate. For the purposes of comparison the indicative estimates provided by Alstom Transportation for new DC motors are presented in Table 24.

Table 24 Option 3a DC motor re-wind and re-motorisation costs

Option 3a Maintenance contract	Indicative cost including DC motor re-wind	Indicative cost including new DC motors
Technical enhancements	\$66,007,000+ \$12,960,000*	\$66,007,000+ \$17,280,000**
Contingency	\$11,845,000	\$12,493,000
Total	\$90,502,000	\$95,780,000

*Accounts for re-wind of DC motors for whole fleet

**Accounts for new DC motors for whole fleet

7.3.2.2 Option 3b

Option 3b retains the recommendations made for Option 3a above, however the DC motorisation will be replaced with an AC regenerative tractive system. The AC system proposal is further described in the Appendix H, but in summary it involves the following works:

- Replacement of the DC traction motors with AC motors
- Removal of:
 - Main converter
 - Main reactor
 - Power factor correction unit
 - WSP
- Introduction of:
 - Traction control unit
 - Brake resistor
 - WSP

Renewal of the auxiliary converter and battery charger could be undertaken also to further enhance system performance and based on the existing performances this is also recommended. However, the prices for these items have not been sought and are not included in the estimates presented.

Table 25 Life extension of 20 years with AC regenerative braking

Major upgrades	Indicative cost for materials and labour (\$AUD)
Option 3a 20 year major upgrade excluding DC regenerative braking	\$44,993,000
AC regenerative braking system upgrade	\$79,390,000
Contingency at 15%	\$18,657,400
Total cost to PTA	\$143,040,400

*Given the age of the fleet, a higher risk premium is likely to be requested from the maintainer in this scenario

Regenerative braking is more commonly proven with AC traction systems. AC traction systems require less maintenance in comparison to the DC counterpart with commutator and contact brushes often being problematic. Also introduction of an AC traction system removes the potential risk of failure of the original casing and pinions used in the re-wound DC traction motors. Energy savings from the regenerative braking are likely to be consistent than those discussed for the DC traction option (in the order of 20% energy saving).

Table 26 below conveys the indicative cost for an additional 20 year life extension beyond design life. The maintenance contract cost in Table 26 below is equivalent to that in Option 3a. However, the maintenance costs for Option 3b could, in reality be slightly lower since it is broadly accepted in industry that AC traction systems are less maintenance intensive than the DC counterparts. To remain conservative in the estimation a cost saving has not been incorporated into the indicative contract pricing.

Table 26 Option 3a/b - Maintenance contract cost to PTA

Option 3A and 3B Maintenance contract	Indicative cost for maintenance contract (\$AUD)	Notes on costing assumption
50 year operating life	\$545,360,000*	Based on current maintenance contract option extension pricing – linearly adjusted

*Given the age of the fleet, a higher risk premium is likely to be requested from the maintainer in this scenario

The maintenance contract cost is based on the existing contract cost and allows for cost uplift for the extended asset life. A 40% premium above Phase 2 of the existing maintenance contract has been applied for the life extended period beyond Option 2b. Note the maintenance contract costs do not factor in inflation or net present value.

7.3.3 Schedule

PTA has indicated that in order to maximise the benefits of the modifications that the re-engineering works would be undertaken in the near future if it is the preferred option. It is reported that the programme for the traction modernisation packages is consistent for each option. The programme of works is provided below in Figure 33 and assumes a commencement during the current maintenance contract period.

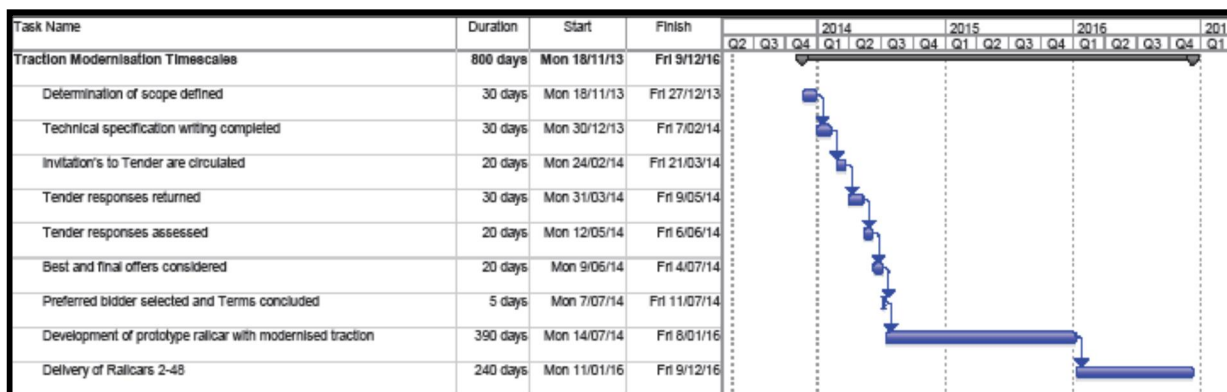


Figure 33 Indicative schedule of works for traction modernisation (AC or DC)

The programme assumes there is a scope development period for PTA and a tendering period up front. The schedule of works for the traction modernisation was provided by the supplier as part of their budget estimate and technical proposal. The programme projects a development time of 14 months for development of the solution and a first off prototype, thereafter the railcars will be completed in a two week cycle rate.

It is expected that the generic scope of re-engineering work can be accommodated in the programme length of traction modernisation works.

The programme of work requires two railcars off line at any period of time with a one week phase shift in the works. The railcar availability required to meet this programme will impact on the PTAs system requirements currently for releasing 45 of 48 railcars in peak times (with the spares being allocated to maintenance and overhaul). It is highly likely therefore that this programme will impact on the network services.

7.3.4 Reliability and availability target meeting

There is an assumption that the re-engineering works will be undertaken in the near future to enable the greatest return on investment to be realised through having the modernised railcars in operation for as long a period as feasible.

The schedule in Section 7.3.3 forecasts an introduction of equipment to take place from June 2016. It is expected that there will be a period of reduced reliability during the first few years whilst integration and compatibility issues are resolved. After which a period of improved reliability is seen reflective of the new train systems. A

conservative estimate of 20% increase in reliability measured as improved LTIs per kilometre. Figure 34 illustrates the forecasted estimate of reliability.

It is expected given the present condition of the A-series and international market analysis that an improved reliability is achievable. Reliability figures for the UK were considered in the long term predictions of the A-series. EMUs of a similar age to that of the A-series are achieving between 22,000 km (9,000 miles) per LTI (where an LTI is measured as mean distance between 3 minute delays) and 65,000 km per LTI.

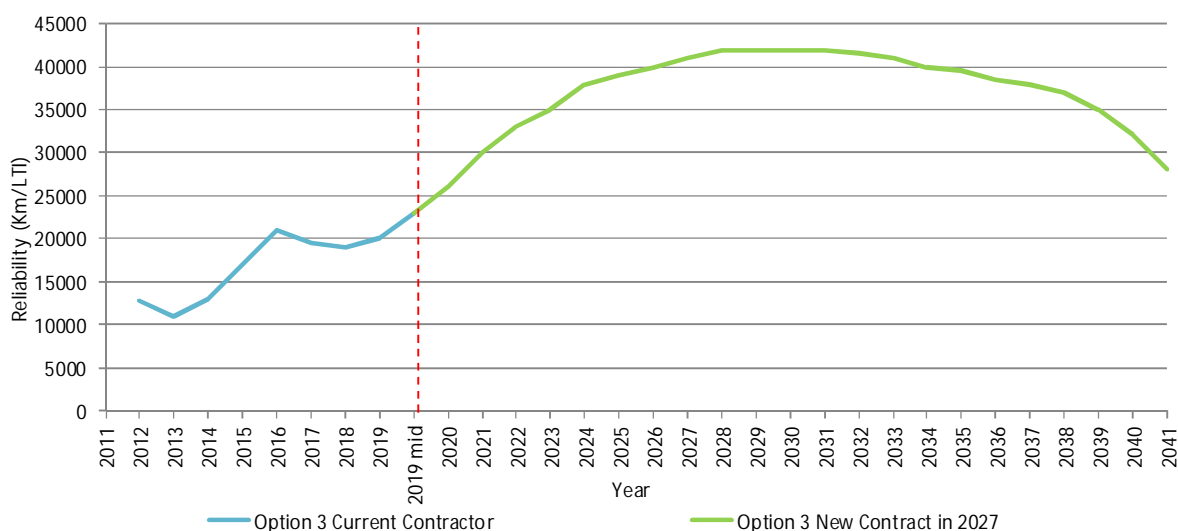


Figure 34 Option 3a/b (Replacement at end of Year 2040) Expected Reliability over Time

The supplier has informed AECOM that there will be negligible difference in reliability between the AC and DC traction modernisation schemes.

The curves in Figure 34 follow the reliability growth expectations presented for Option 1 and build in an improved reliability for the new system installation. It can be observed that there are expected to be some initial issues with integration and compatibility of new and old systems immediately after installation before reliability can be improved upon. Inevitably though, it is expected that train reliability will decrease with age due to the effects of newly installed ageing componentry and the existing unmodified equipment becoming life expired over a long period of operation.

It is evident that the introduction of the new train systems enables the railcars to remain at a higher level of reliability for an extended period of time, though there is a period of underperformance initially, associated with integration and compatibility issues.

7.3.5 Maintenance contract

Due to the schedule of modifications it is likely that the existing maintenance contract will require amendment to reflect the modifications to the rolling stock. Maintenance contract values were assumed to remain constant since there would be shared benefits for both PTA and the maintenance services provider associated with the implementation of the enhancements.

The maintenance contract continuation period ultimately depends on the schedule for new rolling stock. It has already been identified a new maintenance depot will be required for the provision of servicing to new rolling stock. It has also been discussed that the future of Claisebrook is unclear. If new rolling stock is required to increase service capacity on the Heritage lines before the decommissioning of the A-series, it would be prudent to maintain the fleets at a single depot and arrange for the maintenance to be conducted by a single provider to avoid industrial disputes or other such risks.

It is recommended that PTA avoids attempting to synchronise the re-engineering works of the A-series, delivery of new rolling stock and completion of the maintenance contract and that the programmes for each activity are phased methodically to reduce risk of low availability.

7.3.6 New rolling stock introduction

It is concluded in the previous subsections that it would be preferable to coincide the decommissioning of the A-series with the completion of the Maintenance Service Contract which is completed at the end of Q2 2019 or the second maintenance contract completion in 2026, the timescales for the procurement of the New rolling stock are unlikely to benefit the programme of works of either Option 3a or 3b.

It is noted that the PTA might incur additional cost in the procurement of new rolling stock if it continues to operate the A-series and is unable to realise the benefits of economies of scale through bulk purchasing in a new rolling stock order.

7.3.7 Cost analysis

Table 27 and Table 28 present the indicative maintenance costs for Options 3a and 3b respectively, together with the capital investments associated with the re-engineering (technical enhancements) scope for these Options.

Table 27 Indicative costs for Option 3a

Option 3a Maintenance contract DC traction modernisation	Indicative cost for maintenance contract (\$AUD)	Notes on costing assumption
Continue with existing maintainer til end of service life	\$545,360,000	Estimate based on Schedule 16 in Maintenance Agreement
Technical enhancements	\$90,812,050	Table 23
Total	\$636,172,050	

For the purposes of estimating Option 3a assumes a fleet wide traction motor re-wind is undertaken in the traction modernisation scope.

Table 28 Indicative costs for Option 3b

Option 3b Maintenance contract AC traction replacement	Indicative cost for maintenance contract (\$AUD)	Notes on costing assumption
Continue with existing maintainer til end of service life	\$545,360,000	Estimate based on Schedule 16 in Maintenance Agreement
Technical enhancements	\$143,040,400	Table 25
Total	\$688,400,400	

It was suggested by Alstom Transportation that both the DC and AC traction modernisation schemes identified in this study are able to achieve in the order of 30% energy savings for the rolling stock. A value of 30-40% was promoted by Vossloh Kiepe regarding energy savings attributable to regenerative braking technology.

The total energy consumption attributed to the A-series was estimated to be in the order of AU\$10 million per year. If it is assumed that the railcars reduce energy consumption by 20% per year and the reduction in energy is directly proportional to a reduction in the energy cost, a reasonable estimation for the energy saving over the duration of the asset life following installation is AU\$44 million at 2012 energy prices, assuming installations are complete for 2019.

The net effect of the energy saving from the regenerative braking is factored into Table 29.

Table 29 Indicative costs for Options 3a and 3b including value of energy saving attributed to the regenerative braking

Cost description	Option 3a costs – DC modernisation	Option 3b costs – AC traction replacement
Maintenance cost	\$545,360,000	\$545,360,000
Technical enhancements	\$90,812,050	\$143,040,400
Energy saving value	-\$44,000,000	-\$44,000,000
Total	\$592,172,050	\$644,400,400

7.3.7.1 Further notes on cost analysis for Option 3b

A comprehensive quotation was provided by Alstom Transportation for the works scope associated with the traction modernisation works both DC and AC upgrades for Options 3a and 3b. The full quotation together with assumptions and exclusions are included in Appendix G.

The costs provided by Alstom were benchmarked against those estimations provided by Vossloh Kiepe a supplier base in Europe and UK. Labour rate adjustments were made to provide a better comparison.

It was noted that a significant exclusion of both cost estimates was the lack of provision of facilities to undertake the works. AECOM identified two potential suppliers with appropriate facilities in the Perth region:

- UGL Rail Ltd
- Gemco Ltd

AECOM was able to acquire a quotation for utilisation of UGL's facilities on the basis they would be involved in a programme of works. The quotation was provided for a series of labour rates which included the overheads associated with the use of a venue and its facilities appropriate to conduct the aforementioned scope.

Utilisation of existing workshops and facilities to conduct the major re-engineering works in this way was thought to be more cost effective than It is expected to be economically beneficial than having a dedicated facility constructed.

8.0 Strategic Risk Assessment

During the course of completing this study AECOM held two internal Strategic Risk Workshops. The purpose of the workshops was to identify the future business risks posed to the PTA pertaining to the options discussed in Section 7. Therefore this risk assessment focuses not on the specific technical risks but more so, on the risks presented to the PTA business. However the risk assessment has not entirely excluded technical risk since there were a series of technical issues identified during the workshops which presented broader business risk to PTA.

A full risk register is presented in Appendix J.

The key strategic risks associated with each of the Options are discussed in the following subsections together with the potential consequences as well as feasible mitigations.

8.1 Results of Strategic Risk Assessment

The PTA Risk Management Policy - 9502_000_001 Rev4.00 has been adopted as the template for the risk analysis conducted during this study. The criteria, ratings and classifications have been adhered to in order to present PTA with risk information consistent with its own documentation and procedures.

8.1.1 Option 1

Figure 35 shows the distribution and seriousness of the risks identified for Option 1. It is noticeable that there are no risks of a Level 15 or over pre mitigation. It is observed that due to the relatively short duration of continued operation of the assets and the presence of the current maintenance contract that much of the risk for Option 1 is either of low impact or offset to the maintenance contractor.

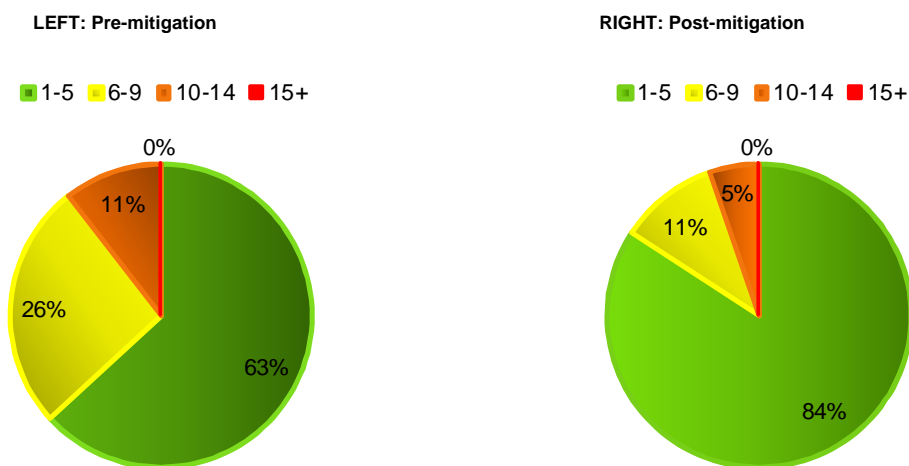


Figure 35 Option 1 Risk analysis

The main risks associated with selection of Option 1 are predominantly driven by the schedules of various works. The existing maintenance contract (Phase 1) and the planned end of design life do not synchronise. A suitable mitigation would be to align the timescales associated with decommissioning and maintenance contracting (with little impact on the terms of engagement) and furthermore the supply (if demand and capacity expansion warrants it) of new rolling stock could also be aligned with termination of a maintenance contract and A-series decommissioning.

A more significant risk is perhaps the failure of the fleet to achieve a desired reliability in line with the terms of the maintenance contract. The risk to PTA is predominantly an impact to reputation resulting from any underperformance. This may occur due to component obsolescence or underperformance of the maintenance contractor. It is thought that the existing maintenance contract provides incentive enough for the maintainer to endeavour to achieve the required level of reliability for the fleet. Furthermore, there is considered to be an increased risk associated with early termination of the existing maintenance contract and commissioning of a new service provider. This is due to the risk of unfavourable terms, increased cost burden as a new maintainer that is more pessimistic about asset health and potentially short to middle term reduced reliability associated with the initial learning curve of the new service provider. Completion of the existing maintenance contract would appear

preferable and should alleviate low reliability risk if the maintainer commits to undertaking a comprehensive maintenance optimisation scheme.

Structural integrity of the carbody and bogies are risks inherent with all Options due to a failure to achieve the desired asset lifespan. Early identification of structural issues should be identified through regular inspections and non-destructive testing of 'at-risk' areas. Structural reinforcements and repairs can be undertaken to weakened elements of the carbody and bogies and many examples of rolling stock undergoing or that have undergone this treatment are available.

8.1.2 Option 2

Figure 36 shows the distribution and seriousness of the risks identified for Option 2. It is noticeable that there are far less risks in the 'acceptable' levels of 1-5 and an increased proportion of risks in the higher bands for both pre and post mitigation.

Structural integrity of the carbody and bogies and failure to achieve the desired asset lifespan exist with Option 2. However, both the impact and likelihood of the risk occurring are increased due to the extended operating life of the asset and the increased financial investment which may have taken place and not be realised.

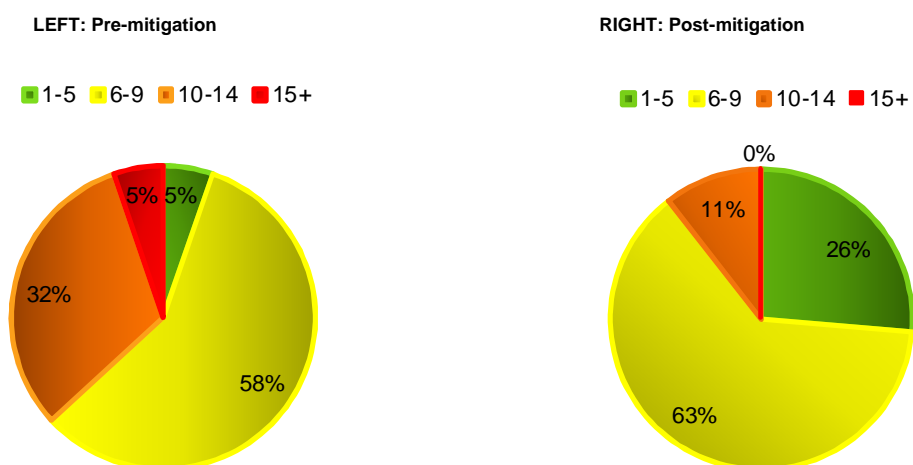


Figure 36 Option 2 Risk analysis

The risks for Option 2 are largely similar to those discussed for Option 1. However due to the extended period of operation the risks are of greater significance due to an increased likelihood and severity associated with the extended railcar operation.

The main areas of strategic risk to PTA for Option 2 result from the lack of enhancements, modifications, and re-engineering that takes place. Seeing as the railcars continue operation for a period beyond the intended design life with a low capital investment it is reasonable for the trains to be at an increased risk of component obsolescence and mechanical wear and electrical failure. The scope of works identified for each sub package is selected to mitigate the greatest of risk but further mitigation necessary to reduce the levels to an acceptable level comes with a significant dollar value which would not likely be justified in a short extension of life.

It is expected that the aesthetic improvements packaged in Option 2b should go some way to improve passenger perception of the railcars and cab HVACs may alleviate some driver complaints and issues, however, it is thought that the scopes associated with Option 2 would benefit a shorter life extension – consistent with that identified for Option 2a.

Whilst the data in Figure 34 does not distinguish between options 2a and 2b, it is logical to assume that the lower capital investment and shorter operational period for Option 2a enables a lower risk profile. Whereas the scope of work associated with Option 2b balances the reduced risk of Option 2a with greater risk levels associated with increased capital investment and a longer period of operation.

8.1.3 Option 3

Figure 37 shows the distribution and seriousness of the risks identified for Option 3. It is noticeable that there are a far greater proportion of risks in the higher bands than for the previous options and this is true for statistics of pre and post mitigation.

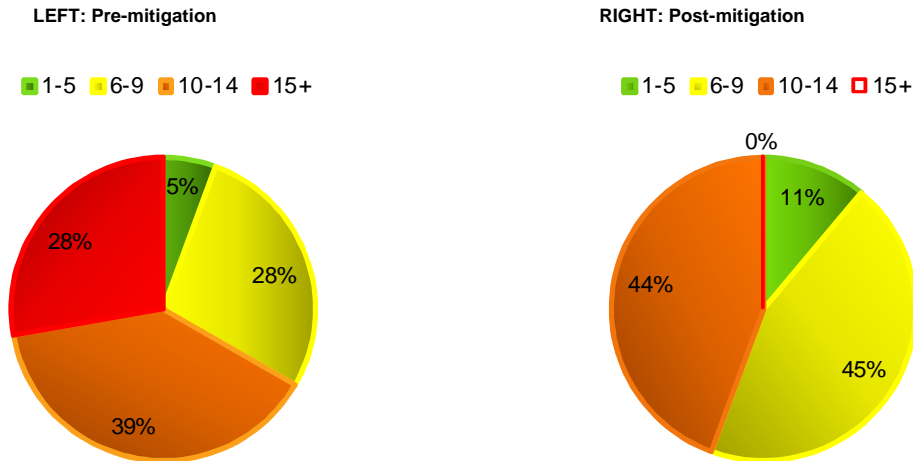


Figure 37 Option 3 Risk analysis

The long-term operation of the fleet potentially poses the greatest risk to PTA. There are many risks inherent with continued operation of the fleet for Option 3 and undertaking recommended works.

Newly installed systems may reduce reliability through compatibility and integration issues may lead to less than desired reliability which ultimately reduces the availability of trains and ultimately impacting on train services and operations. Benefits from improved reliability, energy saving, reduced maintenance may not be realised and a failure to do so may negatively impact the reputational credibility of PTA. Extensive prototype testing and proven product selection is recommended to reduce the risk. DC traction modernisation incorporating regenerative braking is thought to be of greater risk in this instance than an AC traction modernisation since regenerative braking systems are more common on modern rolling stock.

Whilst the A-series interiors are of an excellent condition and the exterior stainless sheeted bodyside panels show little signs of age, it is expected that the cab frontage of the railcars may be poorly perceived by the public in the middle to long term (Option 3a did not include aesthetic enhancements). Similarly so, without a focus on enhancing the cab environment there is a risk of driver disputes over ageing interiors lacking the ergonomic design of more modern driver stations.

The network preference is to avoid operating the A-series fleet on the North-South lines. The existing design of the A-series railcars inhibits some of the network flexibility, as a result of the lower maximum operating speed, the 2-car configuration and interior design elements.

The timescales for decommissioning the fleet for this Option are likely to be in advance of the requirement for new rolling stock, therefore there is no opportunity to align the decommissioning of A-series railcars with the commissioning of replacement rolling stock order. This may lead to reduced purchase power of new rolling stock through low procurement volumes. There is also a financial risk associated with ensuring future maintenance facilities remain compatible with A-series railcars and new rolling stock.

Most of the risks inherent with the two previous Options are also relevant to Option 3 but likelihoods of occurrence increase due to the greater age of the fleet. This is true of the following technical risks; obsolescence, low reliability resulting from worn components, catastrophic failure of the bogies or carbody, endemic failure manifestation, underframe equipment boxes. Many of the mitigations for these risks will result from expanding the re-engineering scopes and conducting further train modifications though this ultimately will have a cost penalty attached.

9.0 Options comparison

9.1 Fatigue life analysis

The results of the finite element analysis study of the fatigue life suggest that the A-series carbody has a very short fatigue life and should have already experienced fatigue cracking around door and window aperture corners if the inputs are assumed to be accurate representations of the loadings experienced by the A-series. Inspection for cracks has not been feasible during the course of this study. However it is known that the railcars have never experienced a catastrophic failure of the carbody. There are examples of fatigued railcars in operation on other rail systems long after cracks appeared on the carbodies and research suggests that stainless steel carbodies are particularly resilient.

On the basis of the results generated to date it would be prudent not to pursue a life extension to the A-series (Options 2a, 2b, 3a or 3b). However, the results of the fatigue life study warrant further investigation through practical verification before definitive conclusions can be drawn regarding the residual life of the rolling stock.

9.2 Financial impact

This section of the report summarises the key points of the Options discussion and presents them together for the purposes of enabling the audience to benchmark and compare the advantages and disadvantages of each Option at a very high level.

Table 30 provides the financial investment required for each option and the level of strategic risk.

Table 30 Options Comparison

Option	Life extension period	Decommissioning date	Indicative total cost	Strategic risk level
1	0	2021	\$141,344,800	Low
2a	5 years	2026	\$247,948,500	Medium
2b	10 years	2031	\$372,547,000	Medium/High
3a	20 years	2041	\$592,172,000*	High
3b	20 years	2041	\$644,400,400*	High

*The regenerative braking energy reduction is factored in at AU\$44 million.

The rate of maintaining the A-series fleet increases over time. The rate of increase is not proportional to the passage of time and instead increases at a greater rate.

Little investment is required for Options 1 and 2a in addition to that which is expended on the existing maintenance contracts.

The scope of refurbishment, enhancement and re-engineering grows with time in order to reduce the risk of component obsolescence, low reliability and endemic failures.

The cost of modernising the traction systems in line with the scope of Options 3a and 3b is offset by a degree when the value of the regenerative braking energy savings are factored into the cost of continued operation.

For the purposes of comparison, indicative estimates have been presented for the costs of procuring and maintaining a new rolling stock fleet in Table 31. Both existing and new rolling stock are assumed to benefit from regenerative energy savings and as such the values are included in the table.

Table 31 Indicative costs for operation of new and old rolling stock

Option	Decommissioning date	CAPEX cost	OPEX cost	Indicative total cost
Matangi	2043	\$153,600,000	\$415,000,000	\$568,600,000
A-Train	2043	\$384,000,000	\$415,000,000	\$799,000,000
Option 3a	2041	\$90,812,000	\$ 545,360,000	\$592,172,000
Option 3b	2041	\$143,040,000	\$ 545,360,000	\$644,400,400

It was reported by associates involved in the GWRC rolling stock renewal programme that the cost of maintaining the new Matangi fleet was over 50% less than that of the Ganz Mavag units they replaced during the first 15 years of operation. Table 31 approximates the OPEX costs for the new fleet rolling stock by applying a 50% reduction to the existing maintenance contract values for a period of 15 years summed with 100% of the value of the maintenance contract values for the remaining 15 years of an assumed 30 year life – representative of an aging fleet. Inflation and net present values are not factored in the other costs presented in the table.

It can be observed from Table 31 that the cost of procuring new rolling stock varies significantly depending on the origin. It can also be seen that the cost of the DC re-engineering works is substantially less than the cost associated with new rolling stock procurement (even the inclusion of new DC motors at a cost of approximately AU\$17 million is unlikely to affect this). However, the cost of the AC motorisation upgrade is similar to the value of a replacement Matangi fleet. Furthermore the operating costs for the new rolling stock are substantially less than those of the A-series projections even after the re-engineering is factored in and regenerative braking energy efficiencies are accounted for in the A-series. The table suggests there is not only a business case but potentially a whole life cost saving (attributed to maintenance) associated with commissioning a new rolling stock fleet.

This is a high level and crude cost summary and further consideration of a new rolling stock versus A-series should be considered in more depth before determining the most appropriate course of action for continued operation of the A-series.

9.3 On-time running performance

It is observed from the data presented in part one of the report that given the current system performance an on-time running target of 95% is not being achieved. Improvements to rolling stock reliability alone are insufficient to enable a 95% target to be achieved. This is true of both existing rolling stock and following the introduction of new rolling stock. A reliability of approximately 2,000,000km per LTI would be necessary for an on-time running target of 95% to be achieved, where all other factors remain constant. 2,000,000km per LTI is not a realistic reliability target. Other factors such as 'weather' and 'passenger' are far greater contributors to the on-time running performance.

It is evident that of the Options discussed in this report the greatest improvement to reliability is likely to come from the implementation of Option 3 (either a or b), however the cost implications associated with this are significant as already discussed.

It is believed a significant reliability improvement can be achieved through the implementation of a reliability centred maintenance regime and avoidance of overhaul deferrals. It is expected that reduced down time of railcars, achieved through maintenance exam balancing and maintenance task blocking, will lead to greater availability of assets. This process can be undertaken with minimal financial impact.

9.4 Summary

The feasibility of continued operation of the A-series is uncertain given the results of the initial FEA study. However, there are many factors which allude to the retirement of the A-series fleet occurring in the short to middle term being preferable.

10.0 Conclusions

The A-series can be considered in a good state of repair given their age. However there are a series of technical issues which were identified during the course of this study that should be addressed. Reliability has been maintained at a level lower than that normally expected of a similar aged fleet. Availability of trains in terms of on-time running performance is below target but the contribution of rolling stock incidents to the network performance is relatively small by comparison to other factors such as 'weather'.

The finite element analysis results for the fatigue life estimate suggest that the A-series railcars have a very short fatigue life due to the high concentrations on welded joints and may already have experienced fatigue cracking. Sensitivity analysis showed that small adjustments to the modelling impart a significant effect on the stresses experienced and ultimately the damage incurred and residual fatigue life of the carbody. It is feasible that the input assumptions are overly conservative and have produced an unexpected result. Further validation of the inputs is necessary before planning for continued operation of the A-series railcars.

Continued operation of the A-series rolling stock was investigated exclusive of the fatigue life study. Five packages of work were identified for each of the following scenarios:

Option 1 – Straight replacement at end of service life

Option 2a – 5 year life extension with minor enhancements/existing technology

Option 2b – 10 year life extension with minor enhancements/existing technology

Option 3a – 20 year life extension re-engineered systems with DC traction

Option 3b – 20 year life extension re-engineered systems with AC traction

From a financial perspective, values associated with the packages range from AU\$141 million to AU\$645 million and typically the period of life extension drives the investment. However, these values should be taken into consideration given the depth of analysis and the scope of work.

It is apparent that the strategic risk exposure to PTA also increases with the term of life extension.

Based on the analysis conducted in this report, the following conclusions are made:

- LTIs relating to rolling stock contribute only 13% of the total LTIs and improvements to rolling stock reliability are insufficient to enable a 95% on-time running target to be achieved. If PTA strives to achieve an on-time running target of 95% rolling stock reliability improvement should form part of a broader system improvement plan which aims to improve the LTIs resulting from Weather, Passenger, Electrical, Driver and Special Events.
- It is expected that the deployment of a comprehensive maintenance optimisation scheme which coordinates the results of RCM studies, exam balancing and maintenance blocking and avoidance of overhaul deferrals will contribute to improved asset reliability for the A-series.
- The results of the FEA study suggest that the fatigue life of the carbody are very low and if the manufactured railcars reflect design they could have already experienced fatigue cracking localised to the door and window aperture corners. The results of the FEA fatigue study are likely to be comprehensive and many of the assumptions and inputs are expected to benefit from practical validation.
- The level of risk inherent with continuing the operation of the A-series increases with the extension of operable time
- Market analysis suggests that Australian rolling stock is far more expensive than that available from the rest of the world and valued in the order of AU\$4 million per vehicle, whereas stainless steel alternatives are available from Korea (Hyundai Rotem) for approximately AU\$1.6 million per vehicle or aluminium vehicles from Europe at approximately AU\$1.8 million per vehicle.
- The works necessary to re-engineer the A-series consistent with the requirements of long term operation of the assets are likely to make Option 3 cost prohibitive when comparing the re-engineering costs against the cost of internationally available new rolling stock.
- Option 1 appears to present a relatively low risk to PTA and the projected timescales associated with decommissioning the A-series consistent with Option 1 align well with the end of the first phase of the maintenance contract and the introduction of a new rolling stock fleet.

- Similarly so, Option 2 has relatively low risk and the suggested schedule for decommissioning aligns with the completion of the second phase of the maintenance contract, postponed introduction of new rolling stock and continued operation with minimal financial investment.
- The A-series lack some modern safety features, such as energy absorption elements of the carbody design and anti-climbers. The railcars preceded the construction of the Mandurah line, as such their current performance and design makes the B-series a more preferable asset to operate on the North-South lines. However major re-engineering of the A-series may improve performance deficits and enhance their overall versatility and network compatibility.

11.0 Recommendations

In addition to the recommended packages of work associated with each of the Options, the following recommendations are made in light of the conclusions of this study:

- The areas of the vehicle where this report has identified a life lower than the 30 year design life should be subject to inspections and non-destructive testing for the presence of cracking .This includes the spot welds.
- Conduct a comprehensive maintenance optimisation programme which identifies appropriate maintenance periodicities and tasks through reliability centred maintenance investigations, balancing of exams to avoid extensive maintenance durations and maintenance blocking is incorporated into services to further improve efficiencies.
- Conduct component and system overhauls at the prescribed periodicities and avoid deferring heavy maintenance work.
- Improve traceability of component or system overhauls – this may result from an enhanced configuration management system.
- Conduct validation of the FEA assessment by undertaking practical testing of accelerations and loads as well as component and railcar masses and CoG analysis. This will allow the high stress areas of the carbody identified during this analysis to be strain gauged so that more accurate life predictions based on actual vehicle loadings can be made. The findings of this work will also allow adjustment of the FEA based load cases if the on track loadings are significantly different to those estimated.
- It is recommended that a thorough dimensional investigation using a weld gauge is carried out for the critical welds identified in this report. This may allow the Class 36 welds to be re-categorised as Class 80 welds, which will return a significantly higher fatigue life in these areas.
- Review the FEA input assumptions and seek to better the accuracy through improved measurement or calculation techniques.
- Seek to improve on-time running performance through improving all aspects of the network, of which rolling stock is a factor.
- Evaluate the requirements for new rolling stock in terms of quantities and timescales.

12.0 References

12.1 Fatigue Life Analysis

- Fatigue Load Cases Document for the A-series Railcar C3262-001 – Issue D.
- Eurocode 3: Design of steel structures- Part 1-9: Fatigue BS EN 1993-1-9:2005
- 3EAM 0-0052 “Description of Traction Control System for Perth EMU”
- PTA Drawing 60232 issue B & 60234 issue B, “Outline Drawings for Railcars”
- PTA A-series Floor Area Diagrams, (included as appendix A of [Ref. 1])
- Excel Spreadsheet from AECOM “FEA Mass Inputs as at 270213.xlsx”
- Walkers Ltd Drawing: Layout, Misc Under frame Eqt B1-W45104
- BS EN 12663, Railway applications. Structural requirements of railway vehicle bodies
- BS7608:1993 “Fatigue Design and Assessment of Steel Structures”.
- Maddox S J: 'International conference on the performance of dynamically loaded structures'. IIW 50th Annual Assembly Conference 1997

12.2 Study

- Personal correspondences as received from PTA
- Various data received from PTA, including but not limited to:
 - 2010051 A Series Depot License Final 21 Jul 11;
 - 2001-09 Measurement EMU Bogie Rubber Components Report01;
 - A-series Perth EMU Body and Interior Equipment manuals;
 - Westrail EMU Maintenance Guide;
 - Perth EMU System Description DR 89514PERTH;
 - A-F Service sheets;
 - A-service - Form No. 4030-109-001.3 Rev. 25;
 - B-service - Form No. 4030-109-001.4 Rev 29;
 - C-service - 4030-109-001.5 Rev 43;
 - D-service - Form No. 4030-109-001.6 Rev 40;
 - E service - Form No. 4030-109-001.7 Rev 40;
 - F service part 1 - Form No. 4030-109-001.9 Rev. 32;
 - F service part 2 - Form No. 4030-109-001.9 Rev. 32;
 - F service part 3 - Form No. 4030-109-001.9 Rev. 32;
 - Narrow Gauge Mainline Code Of Practice Document No. 8190-400-002 Rev 2.01;
 - Reliability data downloads from EMU asset management system
 - The Western Australian Government Railways Commission Contract No. 2299 for the Design, manufacture, Supply and Delivery of 21 Electric Multiple Unit Car Sets for use on 25 kV a.c. 1067 mm Gauge Suburban Railway
 - Smartrider ridership data
 - Train timetables
 - A-series Maintenance Agreement
 - Delay Minutes

- Vehicle parameter list
- Strategic Review of the A Series Railcar Fleet's Future, Report No.ITPLR/TA2010/1
- QR EMU Report

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Appendix A

Preventative Planned Maintenance Gap Analysis

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GAP ANALYSIS - PLANNED PREVENTATIVE MAINTENANCE SERVICES

EQUIPMENT	Service Periodicities (months)												COMMENTS
	OEM - BT/ED	PTA	OEM - BT/ED	PTA	OEM - BT/ED	PTA	OEM - BT/ED	PTA	OEM - BT/ED	PTA	OEM - BT/ED	PTA	
	A	A	B	B	C	C	D	D	E	E	F	F	
OLD CONTRACT / NEW CONTRACT AS AT 25/10/11	3	4	9	12	36	36	72	72	144	144	288		New F Service is first major service and refurbishment
1 ROOF EQUIPMENT													
1.1 Main Circuit Breaker			x	x			x						B services the same, Old D service not performed in New services - these include testing operation, changing the interruptor, and cleaning the air filter
1.2 Pantograph			x	x			x			x	x	x	B services the same except Old B service does not state to change carbons if worn to 5mm thickness. Old Service D delayed til New Service E - removing dust boot and inspecting cylinder for corrosion. Old F service more rigorous than New "F" Service - ie replace components and more detailed inspection
1.3 Earthing Switch							x	x					D services are the same
1.4 Surge Arrester				x	x								Cleaned more frequently than in the past (Old C service vs New B service)
1.5 Voltage Transformer			x	x									B services the same
1.6 Current Transformer			x										No Current Transformer maintenance mentioned in New Services
1.7 Air Conditioning Unit	x	x	x	x	x	x					x	x	A services the same, B services the same, C services the same, F services the same - component change outs if deemed necessary
1.8 High Voltage Filter			x	x			x						Carsets 44-48 only. Unknown description of Old B and D services. Only New B service identified involving repairing/renewing cracks or chips on porcelain, cleaning insulator surface and resistor and fuse surfaces, and measuring resistance over the fuse link
2 CAB EQUIPMENT													
2.1 Direction/Power Control	x	x											A services the same - checking brake cylinder pressure and movement of handles
2.2 Driver's Console	x	x			x								New A service includes both Old A and C requirements - ie ensuring all pushbuttons are in working order
2.3 Horn/Wiper/Washers/Doors etc		x	x	x			x						New A service includes Old B services - ie, greasing door locks. Horns excluded in New A service. Cab door seals checked in New B service compared to 72 months in Old D service.
2.4 Traction Control System			x	x	x	x					x		B services the same, New C service is Old F service - ie o/h the computer fan or replace, Old C service of checking that the wheel diameter setting corresponds to the diameter of the wheels of axle 7 is unidentified in new maintenance periodicities
3 PASSENGER EQUIP.													
3.1 Emergency Switches				x	x								Passenger Emergency Intercom tested in New B Service, not done in Old C Service which only checks Emergency buttons
3.2 Door Controls	x	x	x	x								x	New A service includes Old B services - ie, checking tracks air locks, door operational timing. No Old F service, New F service includes refurbished saloon doors and door control modifications to incorporate door and brake status monitoring and one-shot door operation.
3.3 Seats	x											x	Major refurb of seats - including conversion to longitudinal for cars 01-19, renewal and replacement of noryls on seat frames and handrails, new carpet
3.4 Communications/CCTV				x									Not provided with Old Services. New B service to check PEI systems
4 UNDERFRAME EQUIPMENT													
4.1 Main Transformer	x	x	x	x			x	x			x		New A service includes Old B services - ie, silica gel in the dehydrating breather. C services the same except new C service also includes Old F service of testing of the oil.
4.2 Thyristor Converter					x	x					x		The same C service. Replace all sprung finger contacts in old F services not identified in new F service.
4.3 Contactor Box					x					x	x	x	Old C service performed at New E service, ie checking the traction motor over current relays for correct calibration. Contactor doors replaced with stainless steel and new seals in New F service, also any corroded areas replaced
4.4 Auxiliary Relay Box							x	x					D services are the same

4.5 Brake Resistor	x	x		x	x	x				x	x	The same for A service, New B service includes Old Service C of removing the bottom cover of resistor enclosure and inspect. New C service includes Old D service - examine condition of cable terminations on the resistor and measuring of resistance. Old F service to replace end bearing units, whilst New F service to replace complete units with O/Hauled units.	
4.6 PFC Unit						x	x					x	D services are the same. PFC assembly replaced at New F service, which is not detailed in Old Services
4.7 Power Supply Unit	x	x	x		x	x	x	x				x	The same for A, C, and D service, Old B service performed in New C service - measuring 50V DC supply and 200Hz supply. Thorough cleaning of unit in New F service.
4.8 Auxiliary Converter					x							x	Old C service has extended periodicity to New D service - cleaning, checking, and lubricating components. Old F service replaces all sprung finger contacts - not stated in new services
4.9 Battery System		x	x	x	x								New A service at 4 months implemented for checking of battery water level compared to been done in Old B service of 9months. Additional block lubrication in New B service. Old C service of checking all components for tightness not mentioned in New Services. New "F" Service includes cleaning box out and lubricating hinge door
4.1 Automatic Coupler	x	x			x	x	x					x	The same for A and C services. New C service includes Old D service of checking position of coupler boxes in relation to coupler face. Old F service included in New "F" service.
4.1 Aux. Transformer/Re	x			x								x	Old service was initially done every 3 weeks and then as required, New B service periodicity fixed. Involves inspection and cleaning. Unit changed to stainless steel in New F service and thorough inspection performed.
5 BOGIE EQUIPMENT													
5.1 Wheels and Axlebox	x	x	x	x							x		The same for A and B services. Old E service of removing end cover, then cleaning and greasing of axle box bearings not mentioned in New Services.
5.2 Traction Motor	x	x					x	x	x				The same for A service, except New A service excludes inspection of commutator and cables, New C service has additional greasing areas from Old D service and profiling of traction motors, New D service accounts for insulation testing as in Old D service
5.3 Gearbox			x									x	Gear box inspection, oil change, and o/h services not mentioned in New Services
5.4 Earth Brush			x				x						Old B service is more rigorous inspection of earth brushes than New C service
5.5 Suspension	x			x									Primary and secondary suspensions checked/inspected less frequently with New B service compared to Old A service
5.6 Hydraulic Dampers			x	x				x				x	The same for B service, removing all dampers and testing of dampers in Old D service as well as o/h in Old F service not mentioned in New Services
5.7 Disc Brakes	x	x									x		The same for A service. Disassembly of brake caliper mechanism in Old service E not mentioned in New Services
6 COMPRESSED AIR SYSTEM													
6.1 Main Compressor	x	x			x	x	x	x				x	The same for A service, C service, D service and addition to D service is to change the cooler pre-filter assembly. New F service to include fitting of new conical spacers and hex head bolts to thermostatic bypass valve cover plate, and more rigorous cleaning
6.2 Auxiliary Compressor	x	x	x		x	x	x						The same for A service, except New A service includes the replenishing of oil which is part of Old B service, C services similar except New includes Old 72wk D service of Valve inspections and removals. Checking of motor brushes in New C service not in old services
6.3 Air Boxes			x								x		
6.4 Air Filter/Dryer	x	x		x	x	x	x				x		The same for A service, New B service includes checking of Air Reservoir and filter drain cocks to identify if there is any excessive water build up which would indicate failure of the filter dryer which would need rectification. C services the same
6.5 Braking System	x		x		x		x					x	New F service replaces Auxiliary Brake unit assembly with overhauled assembly for both cabs. Old services not yet identified in New services.

Appendix B

Train System Study

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Appendix B Train System Study

Overview

The development of this appendix has relied on a number of information sources, including train data, site visits and technical discussions.

Reliability data were compiled based on the following files as provided by PTA:

- AEA-AEB railcar Delays in Traffic 2000 to 2012.xlsx – this set of data contains information of train sub-system faults that have resulted in train delays. It should be noted that full data for 2012 is unavailable. Hence data were compiled over 12 years from 2000 – 2011.
- Work done on railcars 2000 to 2012.xlsx – this set of data contains information of faults and observations as recorded by the drivers that may or may not have caused a train delay. It also contains information regarding work carried out across the fleet from 2000 to 2012.
- EMU A Series Components.xlsx – this data contains information of train components installations and removal.

Observations made and issues identified were based on a number of site visits. Visual inspections of the A-series railcars 236 and 246 whilst undergoing General Overhaul and several other railcars (namely 201, 247, and 237) whilst in for routine inspections, A or B exams, were conducted on the following dates:

- 25th January 2013
- 14th February 2013
- 8th April 2013
- 18th April 2013

Traction and traction control

System description

The power configuration for the A Series fleet consists of 75% motorisation of the 2-car units. That is each 2-car unit has 6 traction motors distributed amongst the two cars. The units use axle mounted 195kW DC traction motors, with current drawn from the 25kV overhead electrification system.

The units have the following car configuration:

- The first car, driver motor car (DMA) with 1 x pantograph and 4 x 195kW DC traction motors; and
- The second car, driver motor car (DMB) with 2 x 195kW DC traction motors.

Distribution of traction is illustrated in Figure 38.

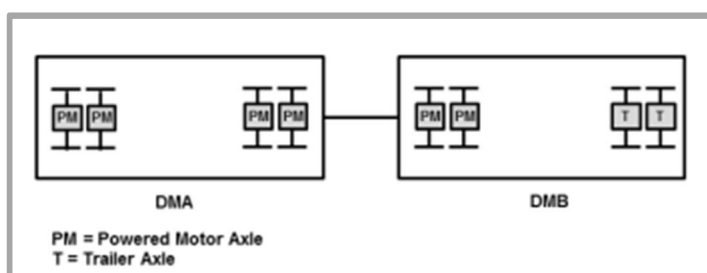


Figure 38 Traction motors of the 2-car units

Observations and issues identified

Table 32 outlines the observations made and issues identified on the EMU traction and traction control system during site visits to Claisebrook train maintenance depot.

Table 32 Traction and traction control observations and issues identified

Components	Observations or Issues Identified
Traction control system	<ul style="list-style-type: none"> - System is old and experiencing a number of faults such as leaking capacitors, ageing and worn insulation, thyristor failures. - It was noted that PTA had purchased a sizable amount of semiconductors and capacitors spares prior to contract handover to BT/Downer.
Converter	<ul style="list-style-type: none"> - Converter experiencing micro-arcing issues resulting from poor insulation of coils and this has contributed to a number of earth faults. - Insulation failures have occurred. It is understood failures result from the original insulation material being too voluminous and not enabling sufficient heat to transfer to the outer heat sink.
Traction motor	<ul style="list-style-type: none"> - Typical overhaul is every 8 years. Reactive maintenance program is currently being carried out where motors are re-wound. -
Line reactors	<ul style="list-style-type: none"> - Experiencing earthing faults due to poor insulation performance resulting from age. - Reactors were re-varnished without re-winding of copper wire.
Semi-conductors	<ul style="list-style-type: none"> - Replaced on failure. - Semi-conductors are experiencing heat sink conducting issues.

Reliability issues

Traction Control System

Traction control system failures amount to 3% of the fleet total number of failures during the 12 years of data analysis, refer to Figure 39. The current system is approximately 20 years old and the trend for increased faults is likely due to the aged system.



Figure 39 Total traction control system faults across entire fleet



Figure 40 Image of traction control unit and thyristor converter

Faults of the traction control system are contributed to, by a number of sub-systems, refer to Figure 41.

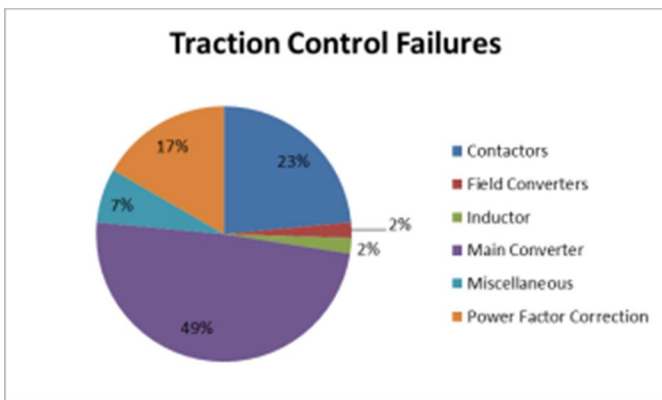


Figure 41 Traction control sub-systems faults

Main converter failures contributed to 48% of the total traction control failures, refer to Figure 42. The overall trend in failures is increasing with the maximum number of faults recorded in 2010.

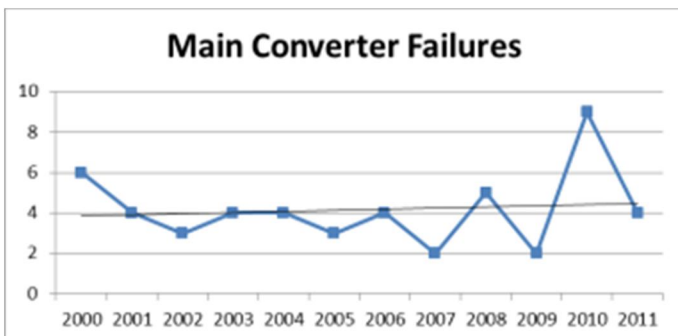


Figure 42 Total main converter faults across entire fleet

Contactors faults amount to 23% of the total traction control failures, refer to Figure 43. The overall trend for failures is increasing and closer examination of data reveals that a large proportion of faults were related to forward and backward contactor faults. Typically the faulty contactor was replaced during service. Other faults such as broken switch springs were noted and these were rectified by spring replacements.



Figure 43 Total contactor faults across entire fleet

Traction Motor System

Traction motor failures amount to 9% of the fleet total number of failures over the past 12 years of data, refer to Figure 44. The data shows that the overall trend of failures increase with time and the maximum number of faults occurs in 2011.

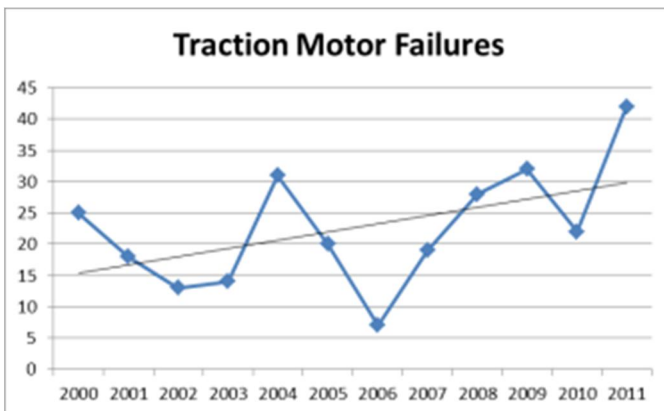


Figure 44 Total traction motor faults across entire fleet

The total traction motor faults are comprised of the breakdown illustrated in Figure 45.

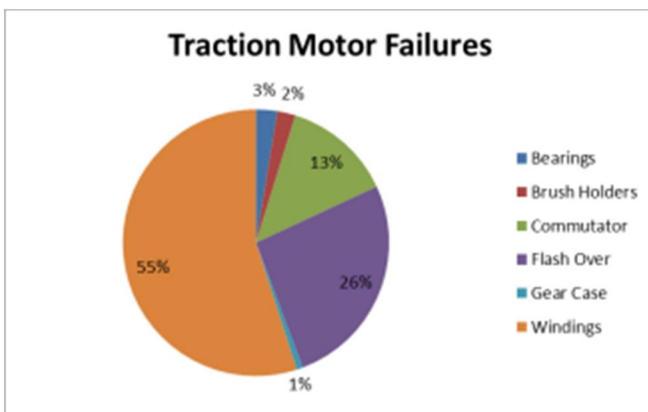


Figure 45 Traction motor sub-systems faults

Winding faults contributed to 55% of the traction motor failures, examination of data reveals that large proportions were apportioned to earth faults.



Figure 46 Total windings faults across entire fleet

Figure 46 shows an increased number of earth faults in 2004 and a number of traction motors were replaced to rectify the issue. This may have contributed to the improved reliability during 2004 – 2006 as reflected in Figure 44.

Reliability of traction motors worsened during 2006 – 2009 and this trend is also reflected in the installation data. From the discussion with PTA, it was understood that decreased reliability was likely due to the running of A Series railcars on the Mandurah and Clarkson train line. The increase of failures may have been due to traction motors being at higher running speeds for sustained periods of time on North-South line, where the units operated at 110km/h compared to 90km/h on the Fremantle line. It is understood from discussions held between AECOM and PTA that the number of traction motor flashover reports increased whilst the A-series was in operation on the Mandurah-Clarkson line during 2008-2009. Flashovers are not reportedly endemic with operations on the East-West lines.



Figure 47 Image of traction motor and a burnt traction motor that occurred during operation

Air and brakes

System description

The A series fleet employs an electro-pneumatic disc braking system manufactured by Faiveley (formerly Davies and Metcalf). The EMUs also have rheostatic braking capabilities.

The key brake components are:

- Compressor
- Air reservoirs
- Brake pipes and hoses
- Brake cylinders
- Brake blocks
- Brake valves

Observations and issues identified

Table 33 outlines the observations made and issues identified with the brake system during site visits and discussions with PTA.

Table 33 Brake system observations and issues identified

Components	Observations or Issues Identified
Park brakes	<ul style="list-style-type: none"> - The rubberised spring covers are aged and show signs of UV degradation through material splits and cracks. - Fleet wide park brake replacement was carried out 3 years ago. - Some brake ratchets are experiencing corrosion, causing some brakes to remain on when the release mechanisms are actuated.
Brake manifolds	<ul style="list-style-type: none"> - Corrosion identified during overhauls and maintenance services - causing air leaks.
Callipers	<ul style="list-style-type: none"> - Calliper design lacks bushing and suspension support on bracketry to aid shock absorption. Noise issues have been noted.
Air dryer	<ul style="list-style-type: none"> - Experiencing obsolescence issues and oil leaking into the desiccators.
Bearings	<ul style="list-style-type: none"> - The steel bearings have been replaced by polymer bearings under direction of OEM, reduced longevity from polymer bearings.
Electronics	<ul style="list-style-type: none"> - Ageing system and require replacement.
Main air compressor	<ul style="list-style-type: none"> - Experiencing oil carry over issues. - Overhaul of compressors commenced from 1999 and was only completed in in 2009. - 6 pole motor was installed due to low duty cycle and this induced milky water to the system.

Reliability issues

Brake System

The brake system amount to 15% of the total EMU faults. The trend is increasing with significant increase of faults during 2006 – 2008 as illustrated in Figure 46. This is further investigated and discussed below.

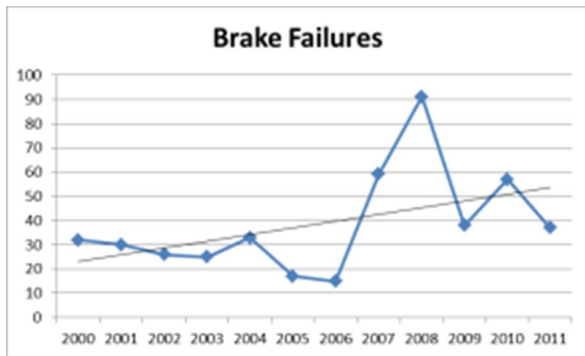


Figure 48 Total brake faults across entire fleet

The recording of brake system faults comprises a number of sub-systems, with the highest contributors being active component faults and electronic faults, refer to Figure 49.

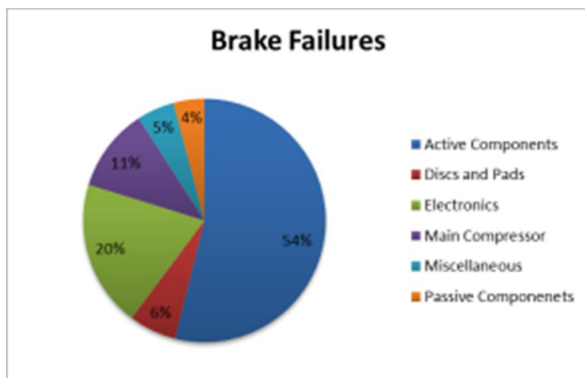


Figure 49 Brake sub-systems faults

Active components comprising of brake assist, traction control systems and electronic stability control systems amount to 54% of the total brake system faults, refer to Figure 50. Reliability worsened during 2006 – 2008, examination of data reveals that a large proportion of faults were associated with park brakes remaining ‘on’ despite release being selected. It was noted that a park brake replacement scheme was initiated during 2008/2009 and this is reflected as a decrease in the number of faults during 2009 to 2011. Other main contributors to decreasing reliability were related to Wheel slip/Slide Protection (WSP) system and smoke resonating from the brake pads. A program of WSP system resets and brake pad renewal mitigated much of these issues.

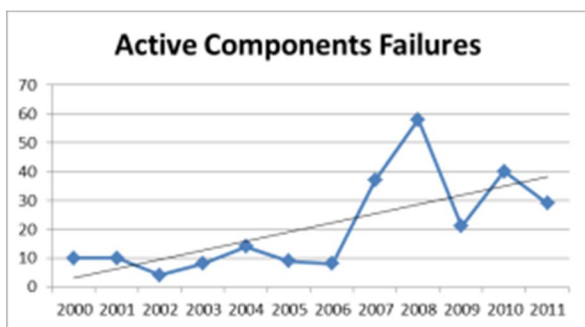


Figure 50 Total active components faults across entire fleet

Electronic faults comprising of electrical brake control system amount to 20% of the total brake faults, refer to Figure 51. Although the trend in electronic brake failures is decreasing with time, the highest number of faults occurred in 2012. Close examination of 2012 faults data revealed that large amounts of faults were associated with electronic brake control system (EBC 5). This issue is rectified when the system is re-set by the driver and was further investigated during train service. This observation is supported by discussions held with maintenance personnel during depot visits in that issues with ageing electronics are present.

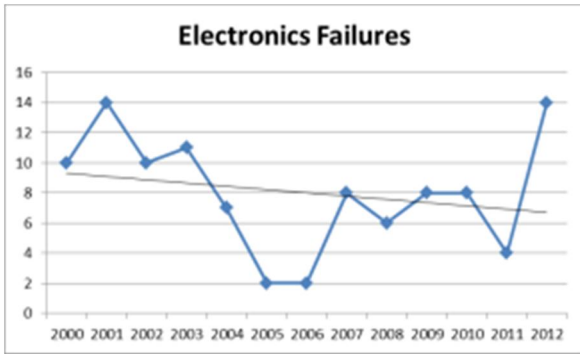


Figure 51 Total electronics faults across entire fleet



Figure 52 Image of brake control unit

Main compressor faults amount to 11% of the total brake faults, refer to Figure 53. The trend is increasing and examination of data reveals a large proportion of faults were associated with tripping of the compressor motor.

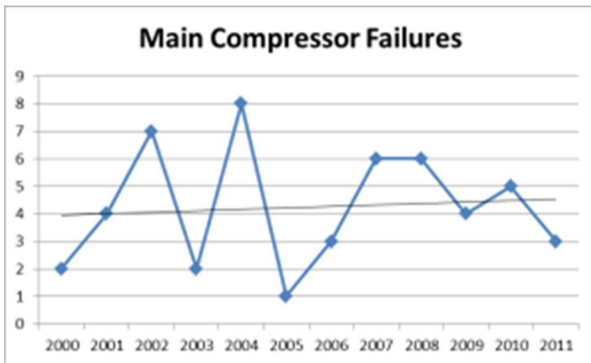


Figure 53 Total main compressor faults across entire fleet



Figure 54 Image of main compressor of brake system

Faults related to brake discs/pads amount to 6% of the total brake faults, refer to Figure 55. There was a significant increase in the number of faults in 2007 and 2008; examination of data reveals that the majority of faults can be attributed to reports of air leaking from the brake cylinder. Reliability improved significantly in 2009. Brake pad replacements are ongoing as part of the A service. All brake cylinders were replaced as part of a special program in 2008/2009

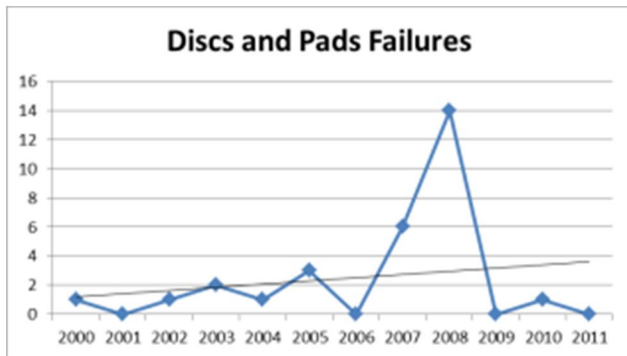


Figure 55 Total brake disc/pad faults across entire fleet



Figure 56 Image of brake disc and calliper



Figure 57 Image of brake resistor and fan

Dynamic Brake System

Dynamic brake faults amount to 1% of the total EMU faults, refer to Figure 58. The overall trend is decreasing and faults are generally related to earthing faults, many of which are rectified by renewing the dynamic brake grid. Reports of high temperature of the dynamic brake resistors were also noted.

The highest number of faults occurred during 2002 - 2004. Material usage data revealed that a number of dynamic brakes were installed/exchanged during 2005 and 2006, which may have contributed to a more consistent reliability performance during the period 2006 – 2011.

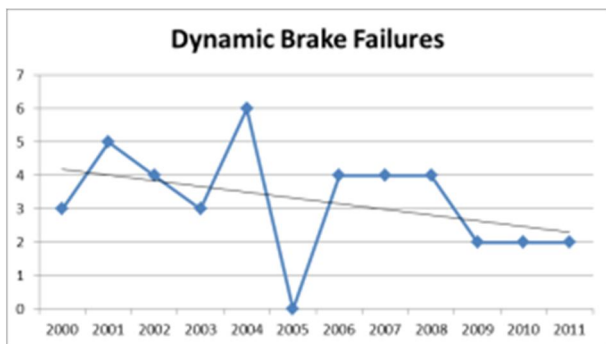


Figure 58 Total dynamic brake faults across entire fleet

Bogies

System description

The A series bogie consists of the following key components:

- H-frame structure
- Two wheel sets per bogie
- Chevron spring primary suspension
- Airbag and damper secondary suspension
- Outboard pneumatic disk brake system
- Cylindrical roller bearings
- Two motors and two driven axles per bogie (motor bogie)

Observations and issues identified

Table 34 outlines the observations made and issues identified with the A series bogie during visit to Claisebrook depot.

Table 34 Bogie observations and issues identified

Components	Observations or Issues Identified
Bogie Structure	<ul style="list-style-type: none"> - No instances of structural problems or cracking of bogie frames have been reported. - Bogies were last overhauled in 2008.
Wheels	<ul style="list-style-type: none"> - Wheel turning takes place on an 18 months periodicity - Hollow tread is typically the reason for wheel turning, rather than flange wear or other wheel wear symptoms. - Wheelsets are currently being changed out on an 8 year cycle, however it is understood that wheels may last up to 12 years. - A consistent wear rate has been observed across fleet. - Wheel slide issues are experienced and believed to originate primarily from driver errors during braking, poor weather conditions or unsuspended axle probe.
Bearings	<ul style="list-style-type: none"> - No issues observed.
Primary suspension	<ul style="list-style-type: none"> - Rubber is degraded and extensively cracked due to UV exposure and requires replacement. - No issues reported with the condition of the springs.
Secondary suspension	<ul style="list-style-type: none"> - An airbag replacement programme was undertaken where a Phoenix secondary suspension system was installed. Refer to Figure 59.



Figure 59 Image of bogie and secondary suspension

Reliability issues

The bogie system amounts to less than 1% of the total EMU faults refer to Figure 60. Further examination of data indicates that the majority of faults are related to air suspension issues such as loud noise and blown airbags. Examination of material usage data indicates that a number of bogies were overhauled in from 2002 to 2011. There are conflicting reports that 5, 18, or 24 bogies were overhauled during this period by PTA.

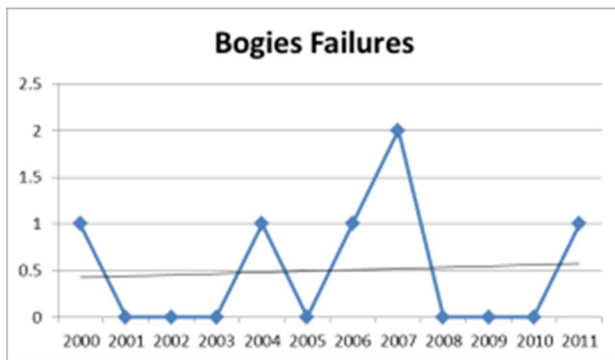


Figure 60 Total bogies faults across the entire fleet

Figure 61 shows the number of work orders completed across the entire fleet for primary suspension. The trend is decreasing and the works carried out were related to air bags splitting and vibration issues. The type of work performed on the primary suspension correlates to the faults identified on bogies.

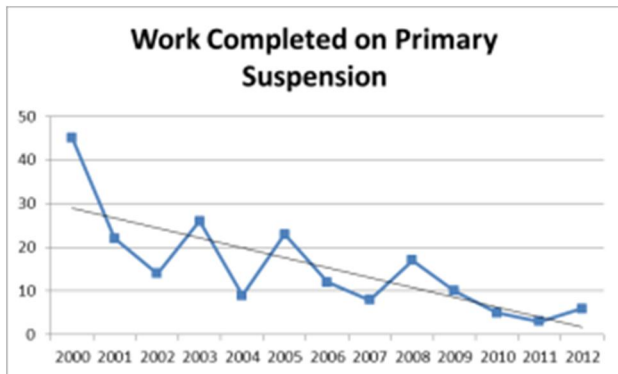


Figure 61 Total primary suspension work done across entire fleet



Figure 62 Image of primary suspension

Axle and wheel faults amount to less than 1% of the total EMU faults. Very few axle and wheel faults were noted which provides indication of their robustness and the appropriateness of the maintenance regime for this system.

Auxiliaries system

System description

The auxiliaries system is used to power all on-board systems except for the traction motors. The main components of the auxiliary system are the:

- Converter
- Batteries
- Compressor

Observations and issues identified

Table 35 outlines the observations made and issues identified with the A series auxiliaries system during visit to Claisebrook depot.

Table 35 Auxiliaries system observations and issues identified

Components	Observations or Issues Identified
Converter	- Capacitor leakage has been observed.
Batteries	- Batteries have been replaced within the last 2 years.

Reliability issues

Auxiliary system faults amount to 5% of the total EMU faults, refer to Figure 63. Reliability seems to be consistent over the years; however reliability seems to have worsened between 2009 and 2010. This will be further discussed below.

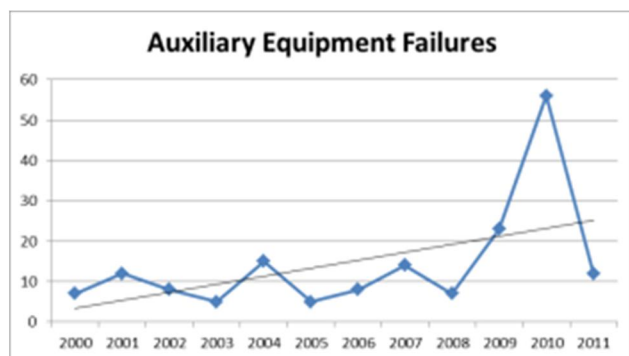


Figure 63 Total auxiliary equipment system faults across entire fleet

The recording of auxiliary equipment system faults comprises a number of sub-systems, refer to Figure 50.

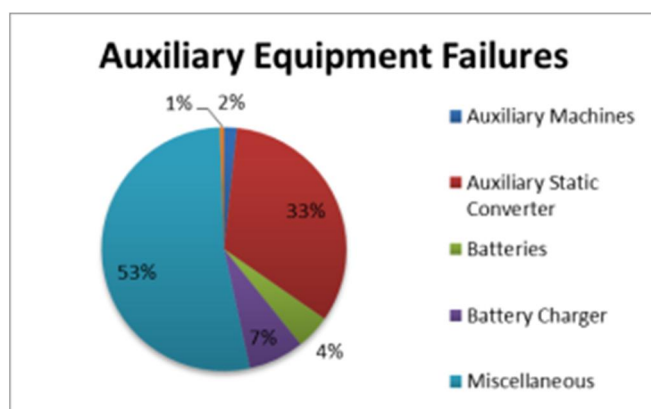


Figure 64 Auxiliary equipment sub-system faults

Miscellaneous amount to 53% of the total auxiliary equipment faults, refer to Figure 65. There is a significant increase in the number of faults in 2010. Examination of data reveals that a large proportion of faults were related to reports of ‘two cabs–activated’ faults. This issue was rectified by renewing the relays, However it was later reported that the relays were not at fault but drivers complaints instead... A number of motor contactor faults were also noted.

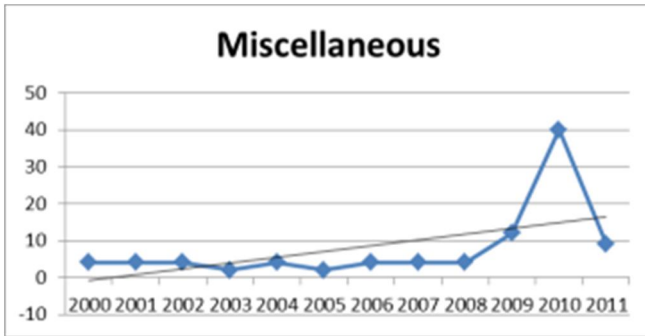


Figure 65 Total miscellaneous faults across entire fleet

Auxiliary static converters amount to 33% of the total auxiliary equipment faults, refer to Figure 66. Though the number of faults fluctuates historically, the overall trend is increasing. Examination of data reveals that these are related to internal fault of the auxiliary converter, converter disc faults and tripping of the circuit breaker.

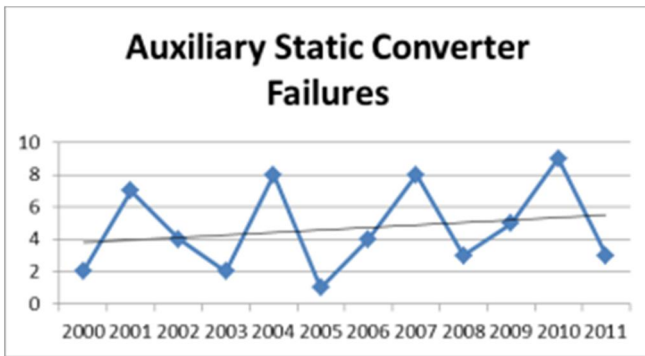


Figure 66 Total auxiliary static converter faults across entire fleet



Figure 67 Image of auxiliary converter, capacitors and contactor, leaking capacitor, damaged plastic backing

Faults of the battery charger amount to 7% of the total auxiliary equipment faults, refer to Figure 68. Close examination of data reveals that the majority of faults are related to defects occurring on the charger leading to battery's not being charged.

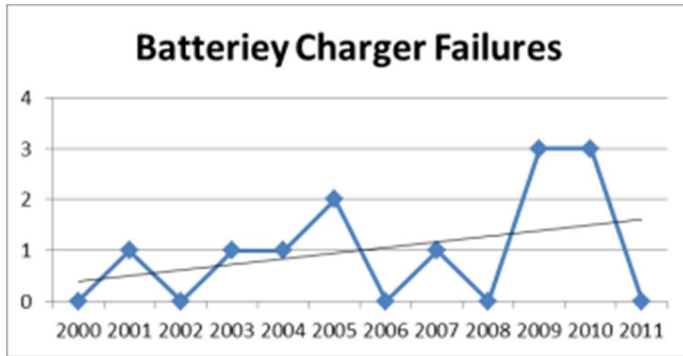


Figure 68 Total battery charger faults across entire fleet



Figure 69 Image of battery bay

Passenger doors

System description

The A series EMUs consist of two door pairs per car, which are air (pneumatic) operated sliding door. The doors are operated by passengers with door pushbuttons. The closing operation is initiated in the driver cab.

Observations and issues identified

Table 36 outlines the observations made and issues found on the passenger doors during discussions held during visits to Claisebrook depot.

Table 36 Passenger door system observations and issues identified

Components	Observations or Issues Identified
Door operating mechanisms	<ul style="list-style-type: none"> - Door tracks and leafs are 20 years old and showing signs of wear. Tracks are warping and difficulties in door opening and closing are being experienced. Door tracks are being replaced on condition during the General Overhaul programme. Refer to Figure 70. - Breaking of door runner causing the leaf to fall away. - Door track material break-out and material thickness decreased. - Door piston needs to be renewed. - Substantial contamination around door piston and tracks resulting from oil leakage
Passenger emergency door release button	<ul style="list-style-type: none"> - Unreachable for passengers with reduced mobility.
Door leafs	<ul style="list-style-type: none"> - De-laminating skins affecting door operations. - Honey comb construction of aluminium covered by stainless steel panels. - Honeycomb structure degenerated and heavily corroded. - Corroded doors are replaced on condition.
Door cylinder	<ul style="list-style-type: none"> - Door cylinders are renewed or replaced as part of an F service.
Door control	<ul style="list-style-type: none"> - Replaced on average every 5 to 6 years. Refer to Figure 72. - Serial bus system results in taking longer to notify driver of door situation. On occasion, door closed is not recognised. <p>Door control units installed for railcars 201-243 starting in 2000 and completed in 2010. Earlier units are now due for replacement due to obsolescence. Railcars 244-248 already equipped with DCUs at time of commissioning, however will also be due for replacement.</p>

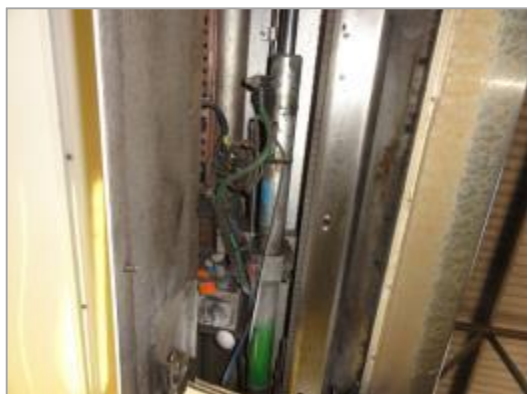


Figure 70 Image of EMU door mechanism



Figure 71 Image of door push button release and de-lamination of leaf aluminium skins



Figure 72 Image of door control unit

Reliability issues

Saloon door failures amounted to approximately 8% of the total number of failures over the past 12 years of data, refer to Figure 73. The number of faults is high in comparison to other systems, which is not unusual for a commuter rail system.

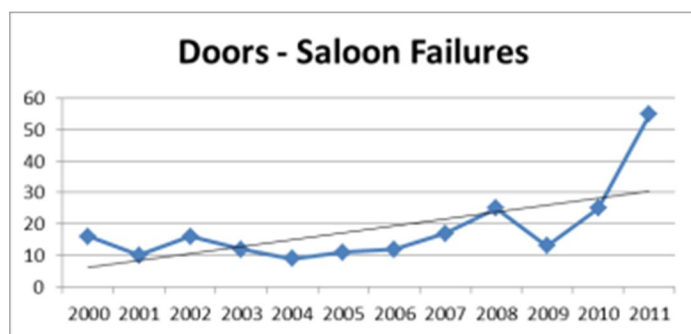


Figure 73 Total saloon door faults across entire fleet

The overall trend for failures shows an increase during 2011 the number of faults has approximately doubled in comparison to the previous year. It has been noted that the majority of faults were related to mechanical failures of the door control system such as sticky doors and door opening/closing failures.

Problems with the platform detection system were also experienced. From the discussions held with PTA on 15/02/2013, it is understood that the increase in faults during 2011 was due to the introduction of the platform detection system and a series of introduction and integration issues were experienced.

Air conditioning (HVAC)

System description

Each A Series EMU car incorporates two heating, ventilation and air conditioning (HVAC) units on the roof. The units provide temperature controlled air and ventilation for passengers. There is a ventilation system which recirculates conditioned air from the saloon into the drivers cab. The HVACs for each railcar unit has synchronised on and off control, however temperatures are set locally to each HVAC and there is no synchronised temperature control across the unit.

Observations and issues identified

Table 37 outlines the observations made and issues found on the HVAC system during discussions held during visits to Claisebrook depot.

Table 37 HVAC system observations and issues identified

Components	Observations or Issues Identified
Compressors	<ul style="list-style-type: none"> - Experience electrical faults that are difficult to trace such as earth faults. - Electrical obsolescence issue and mechanical fatigue issues will likely lead to overhaul of compressors soon, possibly change to rotary compressor. Overhaul is generally on average 8 to 10 years. - Experiences oil carry over from the crankcase occasionally. - Piping shows signs of age.
Cab Fan	<ul style="list-style-type: none"> - Additional blower fans were installed in between the cab and saloon to increase the air ventilation for the driver; however drivers report the modification has not been effective in providing cooling air to the cab. - Fans are experiencing earthing faults of the 3 phase system.
Refrigerant	<ul style="list-style-type: none"> - Currently undertaking gas change over from R22 to R134A. - Refrigerant leaks have been experienced.



Figure 74 Image of HVAC unit

Reliability issues

HVAC failures amount to less than 1% of the total fleet failures, refer to Figure 75. The overall trend for failures is decreasing and examination of data reveals that the majority of faults were mainly related to earth faults of the 3 phase system.

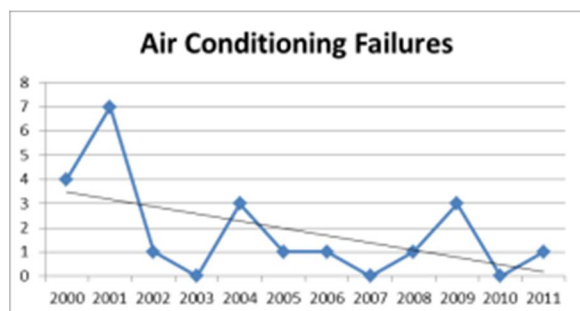


Figure 75 Total HVAC faults across entire fleet

Automatic train protection (ATP)

System description

The A Series fleet uses the L10000 ATP system manufactured by Ansaldo STS (formerly known as Ventura Projects, who were Australian agents for SRT Sweden).

Observations and issues identified

Table 38 outlines the observations made and issues identified with the ATP system during visit to Claisebrook depot.

Table 38 HVAC system observations and issues identified

Components	Observations or Issues Identified
ATP System	<ul style="list-style-type: none"> - Mechanical failures such as damaged buttons on drivers cab panel. - Transmission rack is experiencing signal problems with the antenna. Refer to Figure 76. - A number of transmission faults occurring at the DMA end. - Card and cables were originally fitted during 1990-1994 and have been replaced on fleet wide and condition basis. - Currently experiencing issues due to aging equipment.



Figure 76 Image of ATP antenna

Reliability issues

ATP system failures amount to 14% of the fleet total number of failures, refer to Figure 77. The overall trend is increasing where reliability decreased from 2004 – 2008. Examination of data reveals a large proportion were ‘H2’ faults which correspond to ATP recording unit faults. This issue is rectified by re-setting the system by the driver and was further investigated during train service. It was noted that a number of ATP antenna, driver display panel and ATP console were renewed during 2008 and 2009.

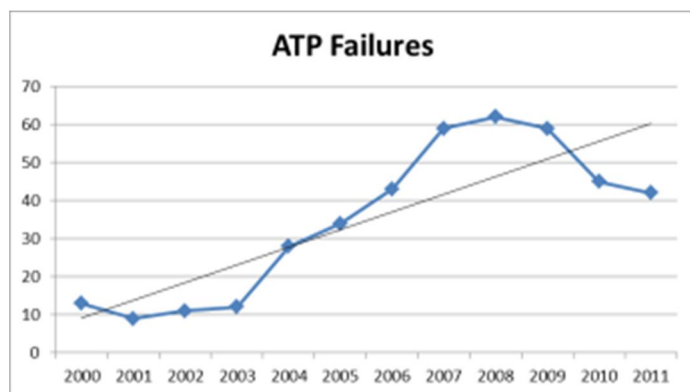


Figure 77 Total ATP system faults across entire fleet

ATP failures data provided by PTA is shown below in Figure 78. The overall trend is also increasing with the highest number of faults reported in 2011. Panel faults appears to have increased significantly in 2011, data suggests that these reports result from damaged buttons on drivers cab panel.

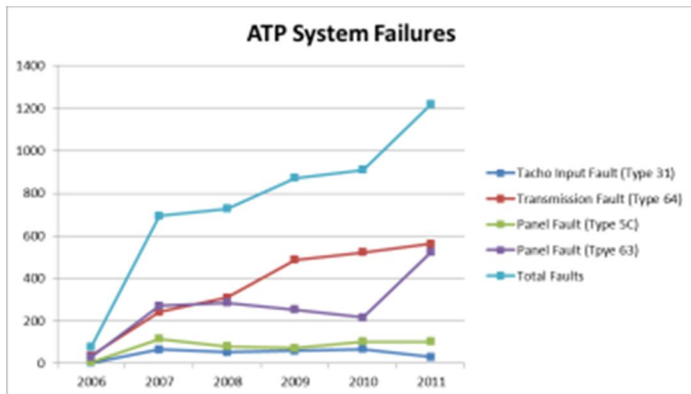


Figure 78 Total ATP system faults from 2006 – 2011

The recording of ATP system faults comprises a number of sub-systems, with the highest contributors being transmission faults and panel faults, refer to Figure 79.

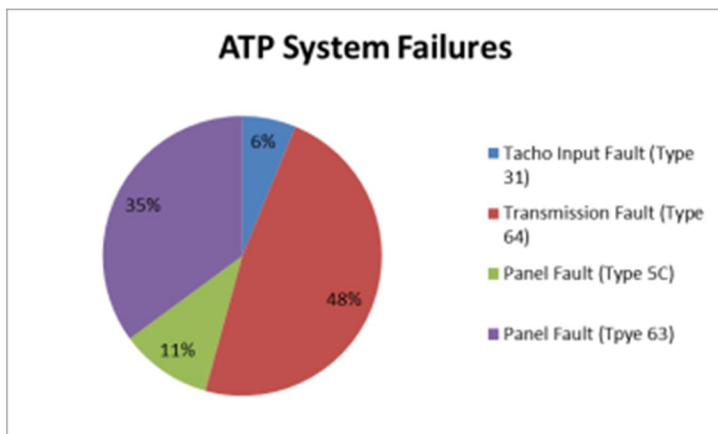


Figure 79 ATP sub-system faults

Communication systems

System description

The Communications units for the A Series consist of the following key sub-systems:

- Exterior destination displays on the front and back of each 2-car set
- Public address (PA) system
- Advertising and network map poster displays
- CCTV

Observations and issues identified

Table 39 outlines the observations made and issues found on the communication and PIS system during discussions held during visits to Claisebrook depot.

Table 39 Communication and PIS system observations and issues identified

Components	Observations or Issues Identified
RAPID	<ul style="list-style-type: none"> - Experiencing system crashes frequently, rectified upon resetting of software. - System displaying and/or announcing incorrect station. - Loss of GPS signal was reported historically, however the GPS system has been replaced to rectify this issue.
Electrical	<ul style="list-style-type: none"> - Motherboard and hard drives are obsolete items. - Costly to replace motherboard, relays are readily available however motherboards are not.
CCTV	<ul style="list-style-type: none"> - CCTV analogue system installed recently, four cameras per 2-car set. Refer to Figure 81.
Radio system	<ul style="list-style-type: none"> - AM/FM radio has interference issues as a result of overhead wiring. - Train radio experiences intermittent failures. - Roof mounted antenna experiences corrosion issues. - Cables degeneration due to constant manipulation.
Mobile phone	<ul style="list-style-type: none"> - Obsolete item and very few spares remaining.



Figure 80 Image of EMU showing external destination display



Figure 81 Image of EMU CCTV camera

Reliability issues

Failures related to Communication and PIS system amount to 7% of the total number of fleet failures, refer to Figure 82. It is evident from Figure 81 that the number of PIS and communications related failures is growing with time, significant increases in failures are visible in in 2007 and 2010.

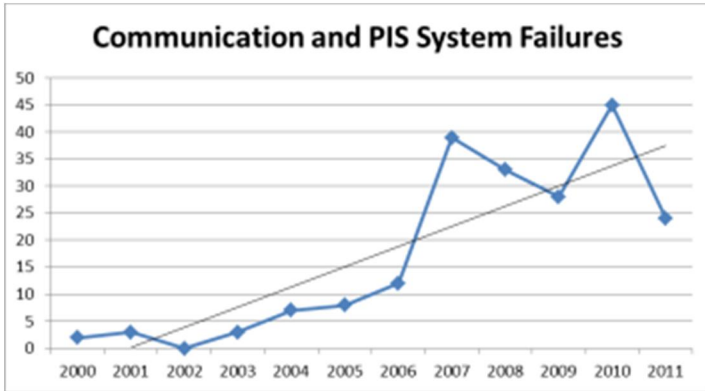


Figure 82 Total communication and PIS system faults across entire fleet

The communication and PIS system faults comprise a number of sub-systems, with the highest contributors to low reliability being the RAPID system, passenger intercom and radio system, refer to Figure 83.

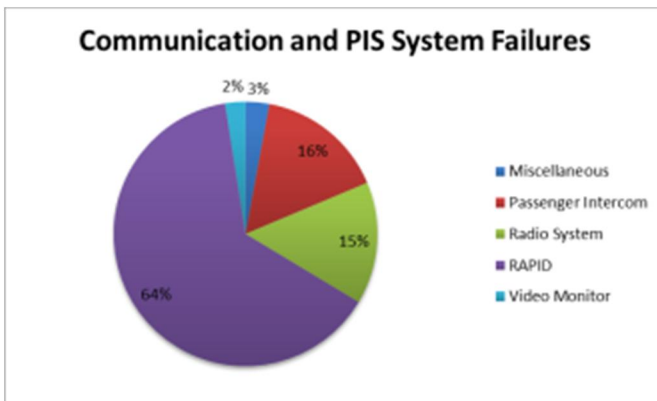


Figure 83 Communication and PIS sub-system faults

RAPID system amounts to 64% of the total communication and PIS system faults, refer to Figure 84. The system was introduced in 2005 – 2007 and the trend appears to be increasing. It was understood from meeting with PTA on 15/02/2013, that the increasing trend of faults from 2006 was due to introduction and integration issues. Examination of data reveals that a large proportion of faults are related to RAPID system crash and faulty PA system. This observation is supported by the discussion held with PTA and maintenance personnel during site visits.

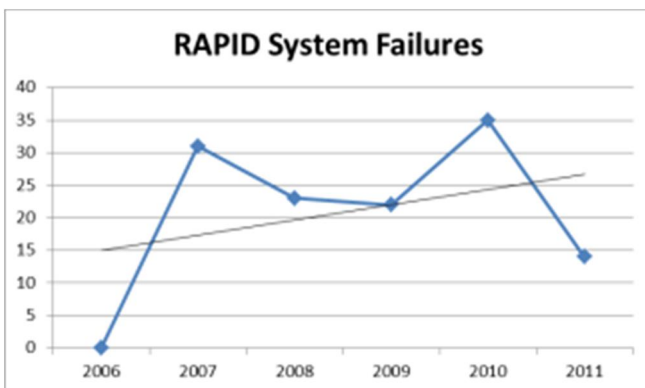


Figure 84 Total RAPID system faults across entire fleet from 2006 to 2011

Passenger intercom system amounts to 16% of the total communication and PIS system faults, refer Figure 85. The worst reliability years for passenger intercom system occurred in 2006 and 2010 and a high proportion of them were related to the faulty message announcement system and lack of door gongs.



Figure 85 Total passenger intercom faults across the fleet

Carbody

System description

The A-series carbody comprises of a stainless steel carbody shell and stainless steel sheeting on the exterior. The structure includes inter-carriage gangways and inter-car doors for passenger movement between each car. Most major train systems (with the exception of the HVAC and pantographs) are hung from the underframe of the carbodies using bolts inserted to the threaded lugs welded to the carbody underframe.

Observations and issues identified

Table 40 outlines the observations made and issues identified with the A-series carbody during site visit to PTA depot.

Table 40 Carbody observations and issues identified

Components	Observations or Issues Identified
Outer skin	- Stainless steel sheeting is in good condition with no visible signs of corrosion.
Saloon windows	- Corrosion to the aluminium window frames. Window frames and rubber sealing surrounds are replaced currently during general overhaul. Refer to Figure 86.
Underframe equipment boxes	- Much of the bracketry for the underframe equipment is hidden from view. - Where underframe components have been removed no significant corrosion is reported or observed for the mounting lugs. - Generally the mounting of the underframe equipment is in reasonable condition. Interior compartments to the equipment boxes are well painted and in good condition as are door hinge and bracketry. However the exterior of several boxes are beginning to show signs of progressive corrosion. Refer to Figure 88. - Cracks were observed in transformer mounting brackets, it is understood the cracks originate from welding issues. It is not known whether this will become an endemic defect. - Some of the equipment boxes were taken out for re-welding. - Corrosion to bolts and fixings was observed. Refer to Figure 89. - No secondary retention is present for the majority of underframe equipment boxes.
Inter-car gangway	- Original rubber gangway canopies have performed well. Gangways bellows are beginning to show signs of wear due to age. Refer to Figure 87.
GRP cab exterior structure	- Signs of cracking observed. Refer to Figure 92.
Roof panels	- Original panels were welded and riveted. Rivets adjacent to the cab GRP structure were changed to stainless steel for most of the fleet. Some spot welds for the roof panels were showing light corrosion from what is understood to be heavy cleaning on the roof panels with the use of scouring pads and wire brushes. Refer to Figure 90. - Some cars show evidence of roofs warping and corrugations forming.



Figure 86 Image of corrosion residue on carbody structure after aluminium window frames are removed



Figure 87 Image of inter-car gangway bellows

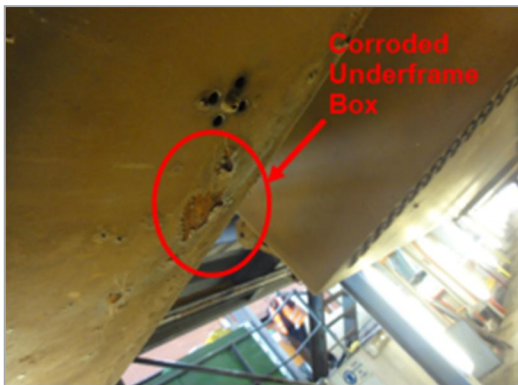


Figure 88 Image showing corrosion to underframe box



Figure 89 Image of corroded bolts of underframe equipment



Figure 90 Image of roof panels

Reliability issues

Failures due to external carbody amount to less than 1% of total EMU failures, refer to Figure 91. Very few failures and issues were noted. Issues such as objects collision and loosened wiper arms were noted. It has been noted that the majority of works performed on the carbody exterior were related to fibreglass cleaning and repairs.

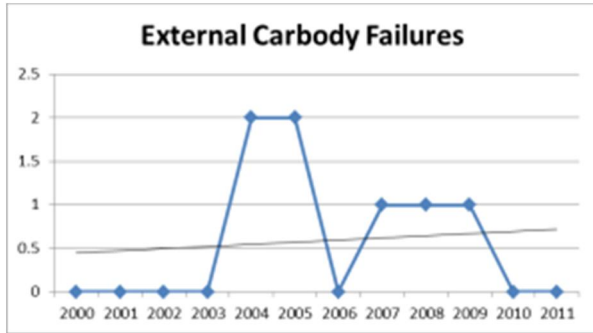


Figure 91: Total number of failures due to external carbody



Figure 92: Image of fibreglass fatigue cracks

Train delays due to vandalism amount to approximately 3% of the total EMU failures, refer to Figure 93. The trend is increasing with the highest number of occurrence in 2007. A large proportion of faults were related to door errors due to activation of emergency release as well as objects interference during door operations. Other issues such as broken/damaged door glass and windows as well as train collision with objects were also noted.

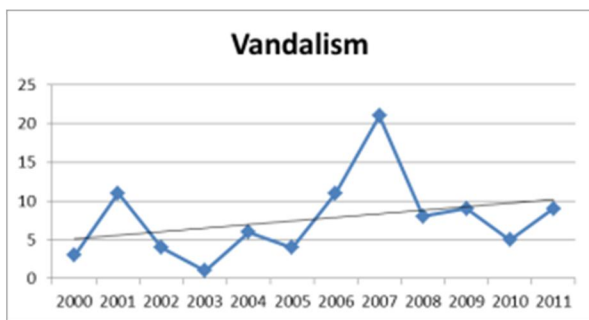


Figure 93 Total number of vandalism causing a train delay

Interior

System description

The A series interior consists of the following key components:

- Seats
- Standing areas with hand rails
- Wheelchair spaces
- Carpet flooring
- Fluorescent lighting

Observations and issues identified

Table 41 outlines the observations made and issues identified with the A-series interior during site visit to PTA depot.

Table 41 EMU interior observations and issues identified

Components	Observations or Issues Identified
General interior	<ul style="list-style-type: none"> - Interiors are in good condition. - Seats are stripped out and replaced on general overhaul.
Lighting	<ul style="list-style-type: none"> - The periodicity for saloon lighting renewal 144 weeks, Saloons are well lit and tubes seem well maintained - Inverters experience earthing faults. - Power supply system for the lighting is being modified currently and it operates on 50V DC at 200Hz. Modifications were undertaken due to inverters failing which caused power surges subsequently tripping the main circuit breaker.
Carpet flooring	<ul style="list-style-type: none"> - Units feature carpeted floors; these are replaced on condition during the general overhaul. A fleet wide replacement occurred from 2002 to 2007.



Figure 94 Image of saloon interior with seats stripped out

Reliability issues

There are few reliability issues on the A series which relate to the car interior. The saloon lighting failures in 2009 were resulted from delayed departure from the depot due to light replacement, refer to Figure 95.



Figure 95 Total saloon lighting failures across entire fleet

Cabs and cab equipment

System description

The EMU cabs contain the following key components:

- Train controller
- Information displays for speed, brake pressure, air pressure etc.
- Switch panel
- Communication equipment
- Destination display control
- PA system control
- HVAC control
- CCTV recording system
- Lighting switches
- Relay boxes
- Driver seat

The driver cabs are located at the 1 and 2 ends of the DMA and DMB cars respectively, allowing it to be driven in either end.

Observations and issues identified

Table 42 outlines the observations made and issues identified with the A-series cab and cab equipment during visit to PTA depot.

Table 42 Cab and cab equipment observations and issues identified

Components	Observations or Issues Identified
Controller	<ul style="list-style-type: none"> - Controller is due for overhaul as the rubber componentry have failed due to age. Overhaul has commenced in 2010, 20 controllers have been changed to date and 28 more to go. - Controllers were initially a 4.5kg force spring and new spring were replaced in 2009/2010 which resulted in decreased number of failures. However drivers find controller is notchy and lacks consistency in operation and this issue is currently being looked with the OEM (Faiveley).
Cab glass	<ul style="list-style-type: none"> - Delamination of cab glass, hinges and seals are fracturing leading to corrosion.
Cab doors	<ul style="list-style-type: none"> - Frames are corroded and loose hinges. - Honeycomb interior deteriorating. - Door locks have no interlocking to the system.
Mobile phone	<ul style="list-style-type: none"> - Obsolete item and low number of spares.
Cab seat	<ul style="list-style-type: none"> - Were replaced fleetwide in 07/08 and then fully overhauled in 2011



Figure 96 Image of EMU cab (unit 36)



Figure 97 Image of relay box within drivers cab (unit 36)

Reliability issues

Failures due to controllers amount to approximately 2% of the total EMU failure, refer to Figure 98. The overall trend is increasing with the maximum faults reported in 2008. Examination of data reveals majority of faults were due to faulty controllers causing park brake to remain on upon release. This issue was rectified by replacing the controller. It was noted that controllers were overhauled/changed in 2009 – 2010 and this may have resulted in the improved reliability.



Figure 98 Total controller failures across entire fleet

General issues

Observations and issues identified

Table 43 outlines any general observations made and issues found on the A series during site visit to PTA depot.

Table 43 General observations and issues identified

Components	Observations or Issues Identified
Couplers	<ul style="list-style-type: none"> - Electrical interface issues were experienced. - Corrosion of the couplers as well as wear was noted. - Couplers are re-lubricated every 12 weeks.
Wiring and looming	<ul style="list-style-type: none"> - Wiring has not been changed on EMUs. - Generally in good condition.
Pantographs	<ul style="list-style-type: none"> - Experiencing wear and tear of the rams and seals as well as corrosion to the copper contactor. - Cracks to the mounting points and centre band fatigues were observed. Cracks may cause the roof to leak during the wet season. - Overhaul of system is planned to be carried out in the near future.



Figure 99 Image of EMU's coupler

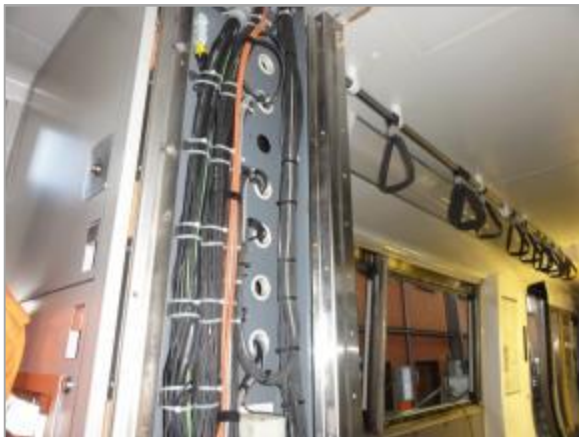


Figure 100 Image of wiring inside the cab



Figure 101 Image of the pantograph

Reliability issues

Couplers faults amount to 1% of the total EMU failures, refer to Figure 102. Coupler faults are generally linked to 'stuck' couplers where there were problems coupling and uncoupling.

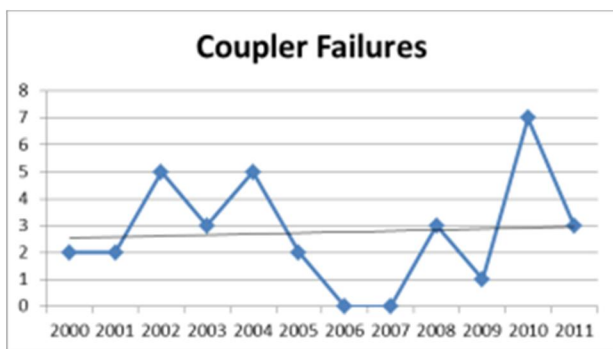


Figure 102 Total number of couplers failures across entire fleet

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Appendix C

Market Analysis

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Appendix C Market Analysis

12.3 NEW Zealand Ganz Mavag

12.3.1 Objective

The Wellington Regional Rail Plan (RRP) titled 2010 – 2035 'A Better Rail Experience' provides for the long term development of the region's rail network. The RRP's objective is to address specific problems facing the Wellington rail network and leverage opportunities to move more people and freight from road to rail transport.

Key issues experienced on Wellington rail network had included; poor reliability, lack of capacity across the network, low frequency of services, ageing train fleet and infrastructure, in which many of these issues are a result of historically inadequate investment in the network.

12.3.2 Background

The Greater Wellington Regional Council (GWRC) unveiled a plan for the upgrade of the Wellington commuter rail system to increase capacity and service frequencies. Part of the RRP involved determining a business case for the procurement of the Matangi units to replace ageing Ganz Mávag rolling stock, which is over 30 years old. As part of determining a business case for these units, an assessment of future investment was conducted, which considered whether heavy maintenance / refurbishment intervention of the existing fleet was preferred over fleet replacement.

Until the recent introduction of the Matangi units, the English Electric units have been operating since 1938 and Ganz Mávag EMUs since 1979 on the Wellington passenger network. A brief history/background of each of fleet is summarised below.

English Electric EMU

The New Zealand DM/D class, also known as English Electrics were a class of Electric Multiple Units (EMU) used on the rail passenger network of Wellington, New Zealand. The railcars were built by English Electric in the United Kingdom between 1938 to 1954. The units entered service in 1938. After 40 years of service, the majority of English Electrics were replaced by EM/ET class, also known as Ganz Mávag railcars in 1982 – 1983.

Due to traffic growth on the rail network, the English Electric cars continued to operate to meet capacity. The remaining railcars underwent life extension refurbishment during 1984 – 1986 and again in the early 2000s. The last English Electric cars were replaced by the Rotem Matangi units in 2012.

Ganz Mávag EMU

The Ganz Mávag railcars were built in 1979 – 1982, a type of EMU that were constructed of 'weather resistant steel'. A total of 44 two car units were introduced into service in Wellington, later only 42 units remained available for operational service due to train collisions.

The fleet was refurbished in 1995 which involved the painting of exterior car body, as well as interior upgrade such as flooring and seat replacement. During the life of the railcars, the electrified infrastructure has never been upgraded and as a result, the electrification system has degraded over time and subsequently caused the motors to degrade at a similar rate.

The fleet has become more sensitive to power surges and susceptible to overloading/blowing motors since the network power upgrade was undertaken for supporting the introduction of the Matangi fleet. As the units have aged, they have ultimately become less reliable (average of 12,000km MDBF at present). There are also significant obsolescence risks with train system componentry.

When Rotem Matangi units were introduced into service from 2010, Ganz Mávag units were either to be replaced or refurbished at the end of its operation life. Four business cases were developed by GWRC to convey cost/benefit analysis of refurbishment versus replacement by Matangi units. In 2010, a prototype refurbishment Ganz Mávag unit was completed to ascertain more accurately the unit costs for a fleet refurbishment and assist with a decision to refurbish/replace the entire fleet.

Matangi EMU

The FP/FT Matangi class are a type of EMU that are currently being introduced for the commuter rail network of Wellington. The Matangi's are constructed with stainless steel carbodies, built by Hyundai Rotem/Mitsui in 2008 and entered into service from late 2010. A total of 48 two car units are currently operating on the Wellington network.

The Matangi units have enabled an increase in the capacity of the Wellington network and have allowed the retirement of the remaining English Electric units. The Matangi units are the preferred units for the bulk of operations both peak and off-peak and will eventually replace the Ganz Mávag units entirely.

12.3.3 Relevance to PTA

There are several aspects which are of specific relevance to the PTA and the life extension study for the A-series railcars:

- Business case investigation involving technical and economic considerations of complete replacement and extension of asset life.
- Purchased new rolling stock to replace the existing EMUs, as EMUs have reached and in some cases exceeded their operational life expectancy.

12.3.4 Work undertaken

GWRC developed business cases comprising of 4 options:

- Option 1: Replace Ganz Mávag fleet at the end of life (present time)
 - The first batch of Matangi units cost is in the order of \$205 million for 96 cars.
 - The second batch of Matangi units cost is in the order of \$140 million for 35-36 two car units (final figures to be announced).
- Option 2: Retain Ganz Mávag fleet and operate for further 5-10yrs
 - This option was unattractive as the units are experiencing a high frequency of failures. It was predicted that future reliability would decrease over the next 5 to 10 years to approximately ~8,000km MDBF.
- Option 3: Retain Ganz Mávag fleet and undertake a mechanical reliability and safety focussed refurbishment
 - The approximate cost is in the order of \$55 - \$65 million across the fleet.
- Option 4: Retain Ganz Mávag and invest in mechanical and interior refurbishment
 - A prototype of this option was carried out.
 - The approximate cost is in the order of \$90 million across the fleet.

The scope of the refurbished Ganz Mávag prototype unit (Option 4) includes the following features:

- Structural integrity and life extension
 - Carbody – replacing corroded material and refresh corrosion protection system; inspect and restore as required the structural integrity of underframe mounting points.
 - Bogies – Non-destructive test (NDT) and ultrasonic test programs were carried out to detect and rectify cracks.
- Reliability improvement
 - Traction control system – full system overhaul was carried out to enable better control of wheel slipping during acceleration and better traction control.
 - Auxiliary power supply – full system overhaul and specific modification carried out to restore and improve the motor/alternator set; replaced existing life expired standby batteries.
 - Brake system – full system overhaul was carried out.
 - Passenger door – additional feature including obstacle detection, passenger door controls and doors opening and closing times improved.
- Safety and accessibility improvement
 - Emergency brake over-ride – new system installed.
 - CCTV – new system installed similar to the Matangi system.
 - Fire safety – improved through the use of better fire performance materials in seat fabric, floor covering and side panel insulation as well as installation of smoke detector.
 - Emergency escape – installation of break window hammers in saloon interior and door step-well lights.
 - Anti-climb device – installation on the cabs to improve passenger safety in an event of collision.

- Cab windscreen – replaced windscreens.
 - Wheel chair spaces – installation of individual flip-up seat arrangement to improve space available for wheelchair parking.
- Passenger/train crew comfort and amenities improvement
- Passenger communications – installation of new Public Address (PA) and Passenger Information Display (PID) system.
 - New passenger seats – installation of new seats with Matangi style seat fabric.
 - Interior fit-out – cosmetic upgrade to be consistent with Matangi units.
 - Driver interface – replaced existing pneumatic wiper with electric wiper; removal of obsolete switches and installation of new controls.
- Vehicle aesthetics/finish
- Painting and branding – painted new to ensure weather tightness; co-branded livery fitted to create consistent feel with the Matangi fleet.

A whole of life cost estimate was developed to compare the continuing operation of the Ganz Mávag beyond their 30 year design life and the maintenance costs of Matangi units. It was estimated that the Ganz Mávag is approximately 2.5 times more expensive to maintain than the Matangi with life cycle cost of Ganz Mávag in the order of \$2.5 million and \$1 million for the Matangi.

12.3.5 Conclusions

The four options in the business case were assessed and the preferred scenario was identified as Option 3 in which it proposed to undertake system modernisation and mechanical upgrade to increase reliability and to ensure safe operation of train. However, the funding of the ongoing maintenance costs of the Ganz Mávag railcars present an issue for the New Zealand Government. After further consideration with operating costs being the drive factor, the final decision was changed to Option 1 being fleet replacement. The capital cost to fund the fleet replacement is justified by the operational savings.

Table 44 provides a summary of the advantages and disadvantages of each option.

Table 44 Advantages and Disadvantages of Options

Options	Advantages	Disadvantages
Option 1 – Replace Ganz Mávag fleet at end of life	<ul style="list-style-type: none"> - Capital gains from increased patronage and ticketing revenue, arising from: <ul style="list-style-type: none"> • Increased reliability; • Improvement in system wide timeliness as a result of improved reliability; and • Improved passenger comfort and amenities. - Standardising on a single fleet type may provide for maintenance efficiencies. 	<ul style="list-style-type: none"> - Uncertainty of project funding as it is unlikely that the Government would be willing or able to meet capital cost. - Capital losses from decreased patronage and ticketing revenue, arising from: <ul style="list-style-type: none"> • Declined reliability of fleet until replacement; • Decreased in system wide timeliness as a result of declining reliability; and, • Unattractive, out-dated interior and seating as well as lack of passenger communication systems would discourage some passenger from using metro rail. - Unplanned maintenance costs would increase due to increasing of mechanical failures.

Options	Advantages	Disadvantages
Option 2 – Retain Ganz Mávag fleet and operate for further 5-10yrs	<ul style="list-style-type: none"> - No financial impact arising from capital expenditure to purchase new railcars. 	<ul style="list-style-type: none"> - Long term capital losses from decreased patronage and ticketing revenue, arising from: <ul style="list-style-type: none"> • Declined reliability of fleet until replacement in 5 – 10 years; and • Decreased in system wide timeliness as a result of declining reliability. - Unattractive and out-dated interior and seating as well as lack of passenger communication systems would discourage some passenger from using metro rail. - Unplanned maintenance costs would increase due to increasing of mechanical failures.
Option 3 – Retain Ganz Mávag fleet and undertake a mechanical reliability and safety focussed refurbishment	<ul style="list-style-type: none"> - Capital gains from increased patronage and ticketing revenue, arising from: <ul style="list-style-type: none"> • Increased reliability; and • Improvement in system wide timeliness as a result of improved reliability. - Capital gains available sooner as refurbishment would be achieved sooner than replacement. - Project funding available as Government has indicated its willingness to co-fund payment. 	<ul style="list-style-type: none"> - Capital gains from patronage and ticketing revenue may potentially be constrained, as passengers would not tolerate: <ul style="list-style-type: none"> • Unattractive and out-dated interior and seating; and • Lack of passenger communication systems. - Passenger may avoid Ganz Mávag railcars by altering their travel patterns. This may lead to overcrowding on Matangi services.
Option 4 – Retain Ganz Mávag and invest in mechanical and interior refurbishment	<ul style="list-style-type: none"> - Capital gains from increased patronage and ticketing revenue, arising from: <ul style="list-style-type: none"> • Increased reliability; • Improvement in system wide timeliness as a result of improved reliability; and • Passenger satisfaction as a result of improved passenger comfort and on-train communication systems. - Capital gains available sooner as refurbishment would be achieved sooner than replacement. - Project funding available as Government has indicated its willingness to co-fund payment. 	<ul style="list-style-type: none"> - Replacement of Ganz Mávag is still required due to life extension design limit to approximately 15 years. - Reliability of refurbished Ganz Mávag trains is still less than the new Matangi fleet. (Ganz Mávag ~35,000km MDBF, Matangi >50,000 MDBF).

In 2012, the GWRC had placed a second order for further Matangi units, a total of 35 – 36 (final figure to be announced) two car units with improved specification such as upgraded traction motors.

The Ganz Mávags are planned to be retired when the next Matangi units enter into service. However a residual 11 – 12 two car units will be retained to be brought out for special events to provide additional network capacity.

Note – costs are based on New Zealand Dollars.

12.4 Hong Kong KCR Metro Cammell EMU life extension project by Alstom.

12.4.1 Objective

Alstom were commissioned by Kowloon-Canton Railway Corporation (KCR), in 2006, later becoming part of Mass Transit Railway Corporation (MTR), to consider the scope of a life extension refurbishment program on the Metro Cammell EMU trains used on the East Line in Hong Kong. The life extension investigation included:

- Assessment of technical and commercial viability of rolling stock for life extension to 40 or 50 years of further service;
- Identification of critical upgrades to meet train service requirements, reliability requirements, improved maintenance and operational costs, and updated legislation for life extension; and,
- Identification of solutions to provide high reliability and low cost.

12.4.2 Background

The railcars were commissioned between 1982 and 1992 forming a fleet of 351 railcars. A refurbishment was undertaken over the period from 1996 to 1999. The refurbishment was performed to increase interior space in order to meet the increased ridership demand. The refurbishment scope included replacement of transverse seating with longitudinal bench seats generating more space for standing passengers, removal of toilets, increasing the number of doorways from 3 per side to 5 per side of each railcar, removal of the freight compartment between driving cab and first class compartment along with the inter-car doors, removal of intermediate driving compartments and the removal of gangway doors excluding first class.

Additional legislative requirements introduced in 1994 required train lengths to be a minimum 12 car configuration. Thus, these particular railcars originally of 3 car configuration were converted to a 12 car configuration.

Safety systems have been enhanced from the original train design with improved Automatic Train Protection systems.



Figure 1 MTR Metro Cammell EMU (DC)

12.4.3 Relevance to PTA

There are items of relevance to the PTA from the QR study conducted by AECOM, they are as follows:

- Required a life extension investigation involving technical and economic considerations of complete replacement and extension of fleet life over a number of different durations.
- Performed Finite Element Analysis (FEA) on the carbody and bogies
- DC traction system and longitudinal seating

12.4.4 Work undertaken

Alstom's study included the following works:

Train structural integrity of carbody and bogies using strain measurement testing and FEA:

FEA of the carbodies included consideration of future changes to passenger mass loadings, and subsequently tested for the service and crush loads for both the current and potentially upgraded Metro Cammell trains. Carbody design fatigue loads were verified using strain measurement testing of door apertures, window surrounds, and the car body frame in both loaded and unloaded states.



Figure 2 Design fatigue loads verified through car body strain measurements

The three cases modelled were the 'design', 'as-built design', 'current operating design', and 'life extended design' with increased passenger loading. Each case was tested using design specified vertical vibration accelerations of $\pm 0.15g$ for 10^7 cycles and the unloaded tare mass case was modelled using design specified vertical vibration accelerations of $\pm 0.30g$ for 10^7 cycles. Each case was also tested using peak vertical vibration accelerations of $\pm 0.22g$ for loaded and $\pm 0.45g$ for unloaded.

The 'life extended design' was modelled with a higher design vertical vibration acceleration equivalent to the current peak vertical vibration accelerations. It was also modelled with an increase in passenger average masses and passenger standing density during crush loading.

Based on the Carbody FEA results presented in Figure 3 below, it was concluded that continuing under the current operation would allow the railcars to achieve an additional 10 years beyond their 30 year design life. Note, the underframe mountings were already being upgraded at the time the FEA was performed and was taken into consideration in the analysis. However, it was also identified that any increase in the passenger loadings presents risk to the railcar of failing to achieve the additional 10 years and would subsequently need to be monitored annually through checking of the car body camber. Under the life extension option, an additional 20 years could be achieved for the railcars provided upgrade works occurred at the end of design life to account for future increases in passenger loading and for increased fatigue life.

	Design Life Years	Design Load	Design Vibration	30 Years	40 Years	50 Years	Over Loading Risk
Original Build	30	57 kg 7 to 8.4 per m ²	± 0.15 g	✓	✓	✗	No
Rolling Stock	30	57 kg 7 to 8.4 per m ²	± 0.15 g	✓	✓	✗	No
Current Operation	30+	62 kg 7 to 8.4 per m ²	± 0.15 g	✓	✓	✗	Yes
Life Extension 2015-2035	40+	65 kg 7 to 9 per m ²	± 0.22 g Recommended	✓	Upgrade needed		

Figure 3 Results from Carbody FEA

The FEA conducted on the bogies required input loadings from on-track testing. The track loadings exceeded those specified in the bogie design limits. At the time of study, the service design life for motor bogies (15 years) and trailer bogies (20 years) had already been exceeded and the bogies were undergoing heavy maintenance and weld repairs to ensure structural composition was maintained. It was identified that to achieve a 20 year life extension of the bogies to match that of the car bodies, post complete fleet inspection of bogies, replacement of the motor frames would be required and the trailer frames would need to be further validated before identifying if they would need replacement.

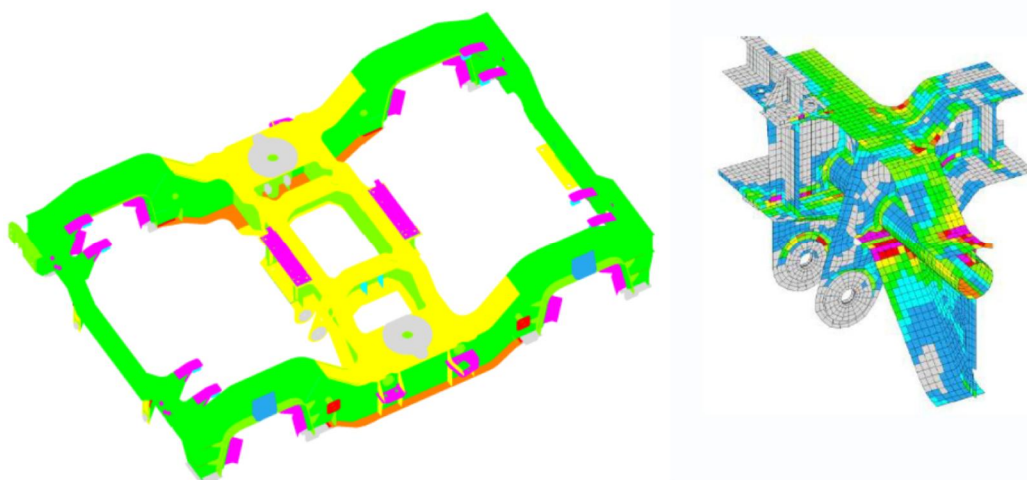


Figure 4 FEA of Bogies

Life extension of cars:

Four life extension options were considered:

- That with the lowest lifecycle cost,
- That with maximum reliability, and
- Replacement at end of life with new train,
- An optimal solution that achieved a balance of reduced lifecycle costs, and improved reliability, and economical period for life extension (or none) before replacement of current trains with new trains.

Key systems for renewal or upgrade were determined based on consideration of the costs and benefits. Benefits included improved structural integrity for life extension, removal of equipment nearing obsolescence, and improving the performance of equipment to achieve better reliability and efficiency. This is outlined in Figure 5 below.

	Key Systems	Cost Incurred For
Structural Integrity	- Car body - Bogie	- Life Extension
Expired Equipment	- Electrical - Interior - Traction	- Routine Maintenance - Overhaul
Equipment Performance	- Doors - Traction - Control	- Reliability - Efficiency

Figure 5 Key systems identified for renewal and upgrade

Phasing of key systems identified for upgrade or renewal for life extension is as below:

	2007-2008	2007-2010	2012-2015
Structural Integrity	- Car body	-Bogie - Bolster	-
Expired Equipment	- Gears	- Power Equip - Axles	- Electrical - Interior - Traction motor
Equipment Performance		- Traction upgrade	- Doors - Control

Figure 6 Key systems to renew or upgrade over a period of 8 years

Of note, AC traction with/without brake boost system was investigated to replace the existing DC traction system. Benefits of AC traction boost included higher accelerations from stop position, maximising regenerated energy with up to 40% energy savings, minimising use of pneumatic brake and brake pad wear by as much as 90%, and the additional circuitry required for AC traction was considered simple and not software based. See Figure 7 below for the capabilities of the AC traction braking system with and without boost compared to DC traction braking and friction braking.

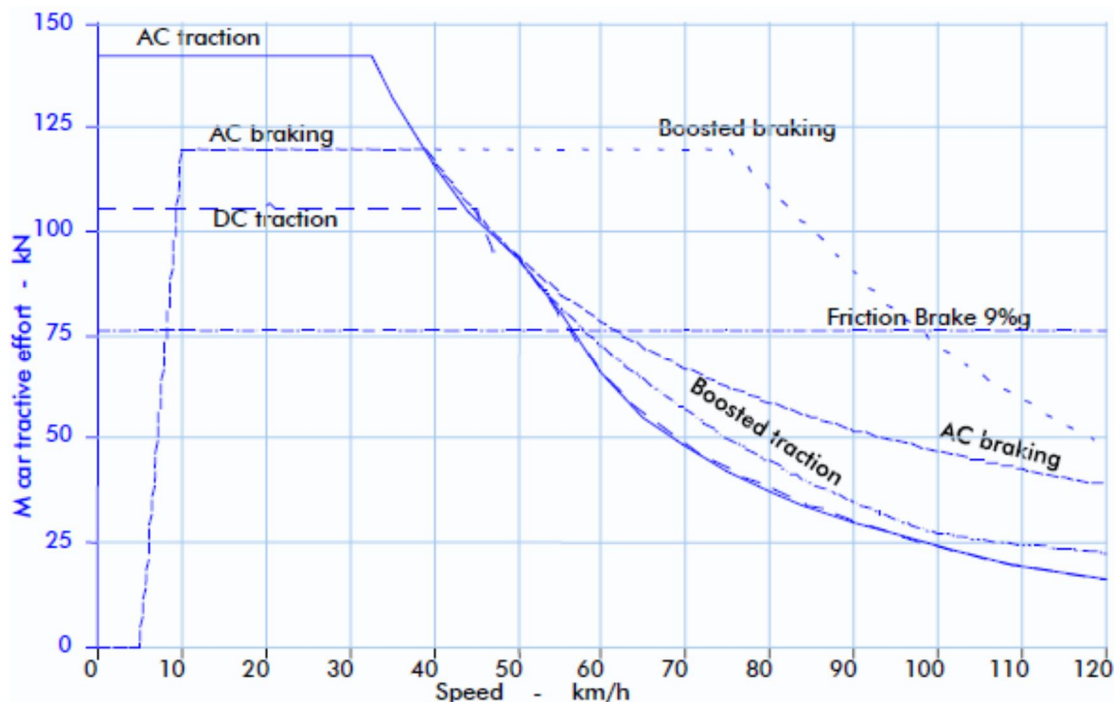


Figure 7 Tractive and braking effort curves for AC and DC traction systems and friction braking

Figure 8 below conveys the results of a simulation run of the DC and AC systems where overall energy used and brake wear are minimal in the case of AC traction systems with regenerative braking compared to its DC counterpart without regenerative braking.

ATO under full service loading 7 passengers per m ²			
	Existing DC	AC traction	AC traction with brake boost
Acceleration	0.5 m/s ²	0.7 m/s ²	0.7 m/s ²
Journey time	79 mins	78 mins	78 mins
Motoring energy	678 kWh	710 kWh	710 kWh
Regen Energy	0	283 kWh	365 kWh
Net Motoring energy	678 kWh	427 kWh	345 kWh
Traction energy	100 %	63 %	51 %
Overall energy reduction	0 %	30 %	40 %
Brake wear	100 %	70 %	10 %

Figure 8 Comparison of DC vs AC traction and braking systems under simulated conditions

12.4.5 Conclusions

The investigation into life extension of the Metro Cammell railcars concluded with the following findings:

- 1) Buying new trains to replace all of the existing fleet was not found to be financially attractive.
- 2) The carbody and bogie structure had the potential to be upgraded cost effectively to achieve a life extension for a total of 50 years in service (til 2035). This estimate accounted for the increased loading factor expected in future.

- 3) The DC traction motors if converted to AC traction motors could achieve good reliability and better train performances such as higher acceleration and less brake pad usage. Less maintenance and material wear costs from components such as brake pads could result in a payback period for the AC traction motors of circa 5 years. Considered "self-financing".
- 4) On-going optimisation of equipment refurbishment and fine-tuning of the maintenance work as part of the maintenance management routine were considered necessary to upkeep the performance and reliability of the train til 2035 economically.

However, in light of the Shatin to Central rail line upgrades, additional Government funding was made available for new 9 car trains starting in 2017 better suited to the upgraded rail lines. These are expected to replace the existing trains by circa 2020 when all new 9 car trains will be available and in service. Subsequently, it was considered no longer attractive for KCR to make significant upgrades to AC traction motors to the existing trains. The car body and bogie structure upgrade and on-going optimisation of equipment refurbishment and maintenance work were however implemented to allow the existing trains to remain in service until circa 2020 when they are expected to be replaced.

12.5 Philadelphia Rapid Transit Commuter EMU life extension project by PATCO.

12.5.1 Objective

The objective of this project was to upgrade the PATCO fleet to extend their design life to an optimal age before replacement.

12.5.2 Background

Companies Budd and Vickers built 120 stainless steel cars in the late 60's/early 70's comprising of single cars, married cars, and Budd English cars. The scope of the refurbishment was driven by obsolescence in equipment such as the braking logics, traction systems, EP braking system and also by the necessity to improve reliability, maintainability, and availability.

12.5.3 Relevance to PTA

There are many items of relevance to the PTA from the QR study conducted by AECOM. As with the PTA, KCR:

- Stainless steel car bodies
- Required investigation involving technical and economic considerations of complete replacement and extension of fleet life.
- Fleet trains are similar with common DC traction, 2 car door per side configuration per car, and 2 car-set units.

12.5.4 Work undertaken

- A cost-benefit analysis of the life extension options with consideration for Life Cycle Costs compared to improved reliability for modernisation and new replacement at end of life options.
- Analysis of compliance with relevant US standards
- Inspection of railcars which found:
 - Stainless steel car bodies in good condition with no corrosion despite extreme temperatures, high salinity levels due to gritting and road salt, and high moisture levels.
 - The carbody welding was not to design standards, some ring welding at brackets on side and centre sill show signs of crack propagation but not significant
 - Asbestos in ceiling insulation and on the underframe which required removal
 - NDT performed on bogies to confirm continued use
 - Complete upgrade of cars (approximately 90% new). Implementation of modernisation includes:
 - Upgrade from DC to DC IGBT chopper instead of AC. DC IGBT chopper was preferred over the AC system as a result of cost savings given similar functionality. Original system comprised of 1 traction system per car per, now converted to separate systems per bogie. Allows for easier replacement of bogies.
 - Single cars are being converted to married pairs -external end door closed off. These car bodies had high carbon content making cars susceptible to cracking when exposed to high temperatures i.e. welding. Required welding with suitable temperature and timeframe (refer to shot welding).
 - Some components were retained and overhauled, including the motors and gearboxes, coupler system, air compressor and compressor condenser.
 - PATCO overhauled the bogies and then free issued them to Alstom for installation.
 - Upgrade of ethernet, trucks and bolsters, undercar layout completely new with new looming, emergency door handles mechanically fastened, third rail DC pickup with 688 nominal DC required shoe gear refurbishment
 - The secondary structure had bridging plates inserted. Huckling/pop riveting was performed instead of welding to protect the carbody
 - Signalling block re-designed to allow for grade compensation

12.5.5 Conclusions

The life extension expectancy is 15-20 years, and any residual life thereafter is likely to be limited by bogie life.

The total cost of modernisation for each 2 car-set train was ~\$1.5M compared to new purchase of ~\$2-2.3M. Although the cost of modernisation was similar to a new purchase, the project was CAPEX governed resulting in modernisation being the preferred option. Contract value of 120 cars ~\$190M. Some costs of the new purchase include \$300k for car shell, \$150k for new bogies and motors

Eight pilot/prototype cars have been produced over the last 18months, with delivery rate commitment of 4 cars per month.

Using the DC chopper system is expected to improve motorisation providing performance benefits, reduced maintenance burden and extended maintenance periodicities. However, in regards to regenerative braking, it was identified later in the project that the infrastructure (substations and wayside) are highly unlikely to be adequate to support regenerative braking. Thus it is likely these trains will be commissioned without regenerative braking initially until system upgrades are in place.

Reduced dwell time benefits are expected as a result of having the option for 6 to 8 car operations and the improvements in signalling and door micro-processors (screw operation leading to increased speeds).

The data recording systems enhanced in upgrade are expected to result in improvements in trouble shooting and MDS information downloading off the system.

There is likely to be increased reliability and improved maintenance, however the benefits will be unmeasurable as historical data was not recorded

12.6 VIA Rail's RDC Fleet Rebuild Project

12.6.1 Objective

The objective of the RDC fleet overhaul project is to deliver improved accessibility, efficiency and reliable services with a focus on enhancing comfortable travel for passengers.

12.6.2 Background

In 2007, the Government of Canada initiated a \$516 million investment program to strengthen the passenger rail services. In 2009, another \$407 million was added to the program through Canada's Economic Action Plan, the Government's economic stimulus program. VIA Rail's capital investment is a total of \$923 million. The Rail Diesel Car (RDC) overhaul project is part of VIA Rail's capital investment project.

The RDCs operate as 2 three car units and they are constructed of stainless steel car-bodies. The RDCs were built in 1949 – 1962 by the Budd Company of Philadelphia, Pennsylvania. The fleet comprised of 3 car types, coach cars, baggage cars and coach/baggage cars.

The RDC have been operating for over 60 years since the early 1950s exceeding their intended original design life of 30 years. The rail cars are used in low density, short passenger/commuter areas such as the Victoria to Courtenay line on Vancouver Island and the Sudbury to White River line in Ontario.

Past refurbishments of the RDCs generally involved the overhaul of train systems and engines on an average 8 to 10 years interval. The RDC Fleet Rebuild Project is considered the first major overhaul project where the cars were stripped back to the car-bodies and structural assessments were performed.

12.6.3 Relevance to PTA

There are many items of relevance to the PTA, in particular:

- Business case investigation involving technical and economic considerations of complete replacement and extension of asset life.
- Similarities with stainless steel car-bodies and structures.
- The requirement for major system overhauls in order to support the continued operation and extension of asset life.

12.6.4 Work undertaken

The works undertaken have comprised of an exhaustive mechanical and electrical overhaul as well as a comprehensive aesthetic appearance improvement through interior and exterior refurbishments.

The works include but are not limited to the following:

Carbody

- Cars were stripped through the removal of equipment including interior and exterior mechanical systems and wiring.
- Structural evaluation of car-bodies to identify potential fatigue damage and performed Non-Destructive Test (NDT).
- Full visual inspection and condition assessment of railcars.
- Cracks of side sills were repaired by applying new stainless steel splices reinforced by huck bolts.
- Interior of casing was sprayed with water and sound proofed by ceramic coating.
- Wear and tear/damage assessment performed on the exterior doors and repair work was conducted as required.
- Installation of new windows and modified window frames.
- Fibreglass insulation installed in car-bodies.

Modifications and Upgrades

- Installation of new cable looming.
- Installation of new air brake system to the engine.

- Engine castings were stripped down, condition assessments were undertaken and repairs conducted as required.
- Installation of two wheel chair lifts in each car and enhanced washroom facilities to improve accessibility for passengers or reduced mobility.
- Installation of new passenger seats (new foam and new mocquette).
- Installation of 480 Volt generators to run the auxiliary equipment such as lighting, air compressor, heating, refreshment areas and washroom facilities.
- Installation of new HVAC systems and air compressors.
- Installation of new operator controls, LED lighting, CCTV system and batteries.

12.6.5 Conclusions

Structural evaluation revealed that the stainless steel car-bodies were considered in good condition for their age with no signs of corrosion despite Canada's harsh conditions of snow, rain and extreme temperature differences. Fatigue cracking to the side sill found was mainly caused by conducting poor weld repairs and lack of temperature control. It was noted that the structural members of the cars were constructed with stainless steel of 201 and 301 types. To prevent future propagation of cracks due to welding, stainless steel splices were reinforced by huck bolts.

The refurbishment of the RDCs also mitigated several obsolescence issues, in particular the electrical, controls and relay systems. Furthermore, the original wiring was perishing and beginning to crack, it was noted that there had been no systematic replacement over the years.

The scope of the refurbishment/life extension works was extensive, yet the business case existed.

The cost of the refurbishment and life extension works was estimated to be \$2M (+\$150k for bogie overhaul – separate contract) on a per car basis. The cost of car replacing the fleet was quoted at \$4.5M - \$5M (depending on the vendor) on a per car basis. Therefore the refurbishment works are approximately half the cost of new car replacements.

The design life of the cars following the refurbishment/life extension works is expected to be 40 – 50 years, compared to an estimated 40 year design life for the new replacement railcars.

As RDCs operate in low passenger commuter areas, lost time incidents are considered low priority and measured on the basis of delays >15 minutes.

Improved reliability, maintenance periodicity extensions are anticipated following the overhaul.

It is anticipated that the 480 horsepower engine will be more fuel efficient after the overhaul. Furthermore, the engine will be compliant with Transport Canada's exhaust emission standards (Euro II Emission standards). The RDCs were refurbished and built to VIA Rail's specification in terms of fire, electrical and material standards.

12.7 Queensland Rail (QR) EMU fleet assessment by AECOM.

12.7.1 Objective

AECOM were commissioned by QR to assess the viability of refurbishing and continuing to maintain the current fleet of EMUs for an extended period beyond the already exceeded design life expectation, or to retire the fleet in the near future. As part of the study, AECOM were tasked with conducting a cost-benefit analysis and analysis of the following items:

- Current maintenance/operational costs
- Forecast future maintenance/operational costs
- Operating reliability/availability
- Spare part supply chain integrity
- Design for efficient maintenance
- Environmental compliance
- Component obsolescence
- Structural integrity
- Rail safety
- DA compliance
- Train protection compatibility
- Compatibility with future rail car configuration
- Compatibility with infrastructure upgrades
- Detailed commercial and technical risk assessment
- Commercial benchmarking
- Optimal replacement timing
- Impacts on existing facilities and industrial arrangements
- Impacts on stock and contracts
- Regional impacts – other suppliers
- Customer requirements
- Option of retiring a portion of the fleet and using it as spare parts to extend the life of the remaining fleet
- Identify and discuss issues and process associated with retiring the fleet

12.7.2 Background

Queensland Rail was undertaking a project to significantly increase the size of its fleet in the Brisbane city network to meet forecasted increases in patronage growth. This involved determining a business case for the procurement of up to 200 three-car units to replace ageing rolling stock and to add to those to remain in the existing fleet. As part of determining a business case for these additional rolling stock, assessment of the current EMU fleet was required which subsequently led to the project being presented in this document.

The QR EMU Stock have been introduced onto the Queensland Rail passenger network over a number of years since 1979 and have an intended design life of 30 years. The fleet comprises of 87 units and represents approximately 40% of the total Queensland Rail suburban fleet. Having exceeded design life, there has been some deterioration in service and reliability of the fleet resulting in increased costs.

12.7.3 Relevance to PTA

There are many items of relevance to the PTA from the QR study conducted by AECOM. As with the PTA, QR:

- Aims to purchase a new rolling stock fleet to replace existing EMUs nearing, having reached and in some cases exceeded their operational life expectancy.

- Required investigation involving technical and economic considerations of complete replacement and extension of fleet life over a number of different durations.
- Fleet trains are similar with common stainless steel carbodies and structures, and similar operational activities.
- External factors such as environment and demographics are not dissimilar from that of Perth.

12.7.4 Work undertaken

Work undertaken included:

- Condition assessment of 2 EMU trains
- Inspection of EMU underframe for corrosion on 2 trains
- General inspection of train subsystems and component condition
- Review of other similar cases - London Underground and Melbourne fleets for benchmarking of reliability and cost
- Review of current maintenance activities, backlog and associated issues
- Review of current and historical performance issues
- Review of future network requirements, QR aspirations and relevant legislation
- Development of a cost estimate for continuing the operation of the EMUs beyond their 30 year design life which includes:
 - Incremental availability costs,
 - Incremental reliability costs,
 - Additional maintenance regime costs,
 - Incremental wheel rate maintenance costs, and
 - Establishment of EMU modification packages required to efficiently and safely extend the life of the EMUs.

12.7.5 Conclusions

The EMUs were assessed as being in a good state for their age. However, some technical issues were identified and deemed necessary to address. Reliability of the trains was below values achieved by similarly aged fleets. However, availability of trains and percentage of wheels undergoing maintenance per annum was seen to be consistent with the benchmark cases (London Underground and Melbourne Fleets) that were used.

The study calculated that if the EMUs continue in operation, the additional costs due to decreased availability and decreased reliability are likely to be as in Table 1 following:

Table 1 Additional costs for continued operation of fleet

Additional Costs	1 to 5 years	6 to 10 years	11 to 15 years	16 to 30 years
Decreased availability	\$12,746,000 pa	\$13,397,000 pa	\$13,884,000 pa	\$15,784,000 pa
Decreased reliability	\$2,585,000 pa	\$2,610,000 pa	\$2,417,000 pa	\$2,564,000 pa

Business cases for modification works for life extension of the rolling stock were considered feasible. Table 2 shows the four modernisation cases considered and associated costs of respective maintenance regimes and wheel wear rate costs:

Table 2 Four modernisation options developed

Years for Extension	Modification Works	Minimum package budget cost estimate (+/- 30%)	Increased maintenance regime	Increased wheel wear rate
5 years	Emergency door release, replacement of remaining resistor grids, replacement of the EP and main contactors, new exterior displays, new CCTV and new fixings for the items on the underframe	\$14,181,000	\$4,035,000 pa	1.7% pa
10 years	5 year package plus new Traction brake traction controller, new battery system and new interior	\$51,156,000	\$4,564,000 pa	1.9% pa
15 years	10 year package plus new cab electronics, new traction control system, new brake system, HVAC and a re-wire	\$324,597,000	\$2,402,000 pa	2.1% pa
30 years	15 year package plus new bogies, compressors and pipes and fittings on the air system	\$335,994,000	\$1,424,000 pa	3.5% pa

Based on the cost estimates above, total annual cost for each option is estimated as below in Table 3:

Table 3 Total annual cost estimate for options

	Annual cost
Do nothing option (over 30 years)	\$50,203,000 pa
5 year option	\$34,619,000 pa
10 year option	\$38,113,000 pa
15 year option	\$52,802,000 pa
30 year option	\$44,685,000 pa

The 15 year option was most costly as a result of significant capital expenditure and associated length for amortisation compared to the other options. However, whilst it appears the 5 year option is best other factors such as capital and operating costs and system benefits such as power consumption savings of the new Next Generation Rolling Stock fleet would need to be considered.

Recommendations were made in addition to the work packages for the purpose of supporting the management of the fleet and to improve its reliability and general performance. These were:

- 1) Perform non-destructive testing yearly on two bogie frames for early detection of crack propagation
- 2) Full metallurgical examination of a randomly selected gear wheel to identify any wear issues which may need to be taken into account for any extension of life program
- 3) A gearbox oil sampling process to gain a trend of the gearbox condition between overhauls
- 4) New gearbox seal to be identified and implemented (preferably in-situ) to correct seeping gearboxes
- 5) Immediate review of emergency release mechanisms, and then implement testing and monitoring regime
- 6) Revised maintenance regime for doors to be implemented and monitored
- 7) Source new door solenoid valves
- 8) Identify new traction brake traction controllers to be retrofitted across the fleet
- 9) Resistor grid change out and compressor change out programs to be incorporated into overhaul program
- 10) New mini circuit breaker and electro pneumatic contactors to be identified and retrofitted to the fleet
- 11) Contactor boxes to be fully cleaned of all copper residue
- 12) Commence investigations to identify replacement capacitors which carry charge for longer and do not leak
- 13) Revised track motor brush to be fitted with a wear mark linked to the new maintenance cycle and traction motor brushes to be replaced when the wear mark has worn away

- 14) Brake blocks to be changed when the wear mark has worn away or there is uneven wear. If uneven wear occurs, future block wear is to be monitored to establish if there is a problem with the brake cylinder or associated rigging
- 15) Full review of equipment fitted to the underside of the car body and a plan is established for secondary retention to be fitted to that equipment
- 16) EMU fleet not considered appropriate for the Cross River Rail tunnel due to potential engineering risks involving fire life safety, thermal loadings, and power ratings
- 17) If the 10 year work package is pursued, interior and associated facilities are to be fully compliant with the latest Disability Discrimination Act Regulations
- 18) Monthly train management reports to be generated to cover fleet safety, reliability and operational issues
- 19) A visualisation centre to be set up to generate a performance focussed team
- 20) Train failure data recorded is to include the unit associated with the fault and the central database is also adapted to include the root cause of each delay

Appendix D

Phase 2 Methodology

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Appendix D Phase 2 Methodology

Phase 2 Fatigue Life Assessment based on Track Testing (OPTIONAL)

Overview

The purpose of the Phase 2 study is to validate results obtained from Phase 1 by retrieving practical results from on board operational railcars. Practical results will be obtained through the implementation of measurement and recording instrumentation on or in the trains. Recordings will include; vehicle accelerations, strain-time histories and speed measurements amongst others. This data will be generated for trains in both tare (empty) and loaded conditions so that a comprehensive validation process can be completed. Practical data recording of strain and acceleration will be conducted concurrently for two reasons, which enables correlation between results for any given time and it should minimise the time which the units are instrumented for.

Once the practical data has been recorded it can be used to check and compare against the results generated from Phase 1. Based on a rain-flow analysis of the strain time histories and the acceleration time histories conducted by the test house responsible for conducting the track testing, an assessment of vehicle life based on manual calculation will be conducted. Rainflow stress cycles counting is the most common and practical form of stress cycle counting. Rainflow counting is used to measure the likely impact of the most damaging stress cycles.

Testing Specification

The recordings of primary interest to be obtained during Phase 2 are the strains imparted on the carbody and the accelerations.

A description of the recording instrumentation and the methodology for instrumentation set up and testing is provided below:

Strain Gauge Testing

For the strain gauge testing there will be an initial preliminary study conducted to identify the peak stress locations from the Phase 1 analysis so that the practical testing can focus on positioning the gauges so that strain time histories can be generated during normal vehicle operation for some areas of peak loading. It is also important that a series of more 'typical' strains and strain locations are tested to provide a thorough validation of the results generated in Phase 1.

It is proposed that there is a single reference channel system is used and that the test team rove the channels inside the train (keeping a fixed reference location) while the train moves. By taking this approach it can be determined exactly how the key points of interest are behaving, as this system setup will enable a magnitude and phase relative to the reference channel. This would provide a very cost effective solution and AECOM can provide in-house DAQ and accelerometers.

AECOM has come to the following conclusions:

- 1) It is believed that the best solution would be to use external, isolated strain amplifiers (datasheet can be provided) whose output can be fed into AECOM's standard Data Acquisition System (DAQ, AECOM's standard DAQ is laptop based). This requires:
 - a) Attended measurements (i.e. a graduate sitting in the train with the laptop on his lap). Connecting leads would have to be run through the carbody panelling.
 - b) Since there are no power-points in the train, the test engineer would have a 60 or 120 Ahr battery at their feet to power the laptop (note, AECOM has conducted similar tests for RailCorp, though the trains did have power points which were used).
 - c) Measurement periods were originally scoped for two full days testing, however this will need further clarification given the results obtained during Phase 1.

- 2) Strain gauging a car and collecting data for longer periods of one week or more is not possible for following reasons:
 - a) It would require a laptop and large hard drive to store all data.
 - b) The use of a laptop for unattended logging would be discouraged because of:
 - i) The large power consumptions; and,
 - ii) The risk that the laptop crashes and all data is lost following the crash.

It should be noted that AECOM has assumed that the train maintainer (Bombardier Transportation, Downer EDI Rail Group) would undertake the installation of the strain gauging equipment. Due to the intrusive nature of the installation stemming from the requirement to attach strain gauges to the car body shell AECOM considers the maintainer best equipped to undertake this task. AECOM would observe the works as they are undertaken to ensure the instrumentation is installed in the correct locations. As this work is to be undertaken by a third party, it should be noted that PTA may incur additional charges as a result of the train maintainer undertaking this task. An estimate of the fees cannot be provided at this time.

Acceleration Testing

Acceleration testing would be required for trains operating in tare and loaded conditions and it would be advantageous for recordings to be conducted over a period of time where peak and off peak service patronage is experienced as well as weekday and weekend testing.

AECOM considered three potential alternatives for measuring and monitoring accelerations incurred by the train before identifying a preferred method of conducting the acceleration monitoring. The recommended method is described below:

- 1) Accelerometers will be secured to large heavy plates which will, due to their mass and friction, will restrict their movement and avoid the necessity for implementing any permanent fixtures to the floor of the car body. Ideally AECOM would situate the plates and accelerometers inside the vehicles above the secondary suspension at a position to be confirmed with and agreed by PTA. The areas would be cordoned off from the public using barriers. The monitoring would be supervised at all times by AECOM personnel. This method is considered to be advantageous for the following reasons:
 - a) The safety of public and operators is maintained.
 - b) Inconvenience to public and operations staff is minimal; instrumentation can be barriered off causing minimal disruption to commuters.
 - c) The ideal locations for accelerometer placement should be achievable, optimising the validity of results obtained.
 - d) Equipment is supervised throughout and data recording can be checked in progress, any issues can be resolved on the spot.
 - e) No permanent modifications to the vehicle are required and there is not likely to be any intrusive work undertaken.

AECOM considers this methodology most preferable as it optimises safety of the vehicle and passengers, incurs minimal disruption to its services, minimise requirement for modification to the unit and/or propensity for damage. Consideration was given to two further alternatives, which are listed below for PTA's information along with the advantages and disadvantages of each.

- 2) Mounting the accelerometers the exterior of the vehicle body on the underframe using permanent or semi-permanent fixtures. The advantages and disadvantages are described below:

Advantages

- a) Does not impede passenger ingress/egress and patrons should be wholly unaffected by instrumentation.
- b) No interference with interior fittings or fixtures and will not damage the unit floor.

Disadvantages

- c) Locations for accelerometer placement may not be ideal due to space limitations between bogie and underframe.
 - d) Mounting the equipment to the unit's underframe would likely require holes to be drilled in order to provide sufficient retention for fixing the accelerometers in place, adhesives have been considered but surfaces are not expected to be optimal.
 - e) Complexities of establishing safe surfaces and retention devices would be timely.
- 3) PTA provides a dedicated unit for sole purpose of Phase 2 testing.

Advantages

- a) No physical disruption to patrons on board a train.
- b) Instrumentation could be placed in ideal locations

Disadvantages

- c) Would require possession of a train for a period of approximately a week, minimum of one day for installing load, minimum of two days testing, one day for removing load, minimum of one days further testing in tare condition.
- d) Propensity to damage floor through load installation and removal.
- e) Propensity for service disruption through commandeering a 'test train'.

A number of the team AECOM proposes for this task have prior experience of undertaking acceleration tests on ballasted test units. Based on the experiences of AECOM's team, Approach 3, described above is least recommended due to the time and difficulty associated with the ballasting (addition of sandbags or water tanks) units to obtain the loaded condition of a unit.

It should be noted that our proposal has not considered the costs associated with methodologies 2 or 3 and in the event PTA would prefer one of these two alternatives AECOM would need to adjust the costings for the scope of Phase 2.

For measuring the accelerations experienced by the vehicle, the monitoring of the inputs to the carbody from the bogies are key, ideally accelerometers should be located directly above each of the secondary spring positions. The distribution of accelerometers in this manner will enable the measurement of roll, pitch, yaw, bounce and twist.

In addition it would be useful to place an accelerometer on the centre of the passenger floor, centrally between bogie pivots. This will allow determination of the body bending natural frequency mode for comparison with the FEA model.

AECOM is able to source accelerometers capable of measuring from 0 to 3g, and tri-axial.

Reporting

Upon completion of testing AECOM will assimilate the results in to the Final Report which was submitted on completion of the Phase 1 scope of works.

A draft report will be submitted which will include an additional section incorporating the results identified during Phase 2 as well as amendments to any other sections of the original report affected by the Phase 2 results. Once PTA has provided commentary on the draft report, a final report will be issued.

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Appendix E

Options Cost Analysis

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A-Series EMU Railcar Review



A-Series EMU Railcar Review

Prepared for
Public Transport Authority

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Glossary

Abbreviation	Definition
AC	Alternating Current
ATO	Automatic Train Operation
ATP	Automatic Train Protection
BCU	Brake Control Unit
BS	British Standard
CoG	Centre of Gravity
DC	Direct Current
DCU	Door Control Unit
DDA	Disability Discrimination Act
DMA	Driver Motor A
DMB	Driver Motor B
EMU	Electrical multiple unit
EN	EuroNorm
FEA	Finite element analysis
GO	General overhaul or F service
GPS	Global positioning system
GWRC	Greater Wellington Regional Council
HVAC	Heating ventilation air conditioner
LED	Light emitting Diode
LTI	Lost time incident
MCB	Main circuit breaker
MDP5MD	Mean distance per 5 minute delay
NDT	Non-destructive testing
OHL	Overhead Line
OEM	Original equipment manufacturer
PIS	Passenger information system
PTA	Public Transport Authority (Perth)
QR	Queensland Rail
RCM	Reliability Centred Maintenance
TCU	Traction Control Unit
TS	Tube stock (London Underground)
TC	Train cancellation
UGL	United Group Rail
WSP	Wheel slip/slide protection

Executive Summary

Introduction

The Public Transport Authority of Western Australia has commissioned AECOM to conduct a residual life study of the A-series rolling stock fleet. The A-series railcars were first introduced in 1991 with an intended design life of 30 years.

The Public Transport Authority's intention is to determine the most appropriate outcome for the long-term future of the A-series railcars. The recommendation made as a result of the investigation will be used as input into the asset management and capital replacement plans of the A series railcar fleet.

The study focuses on the necessary work packages required for each of the following options:

- Straight replacement at end of service life
- Life with existing technology and or minor enhancements of the railcar.
- Re-engineering life

The study considers the remaining lifespan of the A series fleet as well as the operating expenditures associated with its continued operation and potentially degrading performance. Due consideration is given to the intermediate options of minor and major functional enhancements which would enable reliability and maintainability improvements to be realised.

In order to identify the residual lifespan of the railcars a detailed fatigue life and structural assessment of the A-series railcars is undertaken.

Methodology

To enable better granularity in the study the alternatives for continued operation of the A-series fleet are further represented by the Options as defined in Table 1.

Table 1 Options definition

Option Number	Ref	Title	Duration of extension (years)	Operating life	Year extended to
Option 1	1	Design life expiry	N/A	30	2021
Option 2	2a	Life extension (Minor mods)	5	35	2026
	2b	Life extension (Minor mods)	10	40	2031
Option 3	3a	Life extension (Re-engineering life – DC traction)	20	50	2041
	3b	Life extension (Re-engineering life – AC traction)			

Work packages appropriate to the scope of each Option were derived during the course of the study. In order to identify the suitable scope for each Option it was necessary to conduct a comprehensive review of the operating paradigm of the A-series.

Results

The A-series can be considered in a good state of repair given their age. However there are a series of technical issues that were identified during the course of this study that should be attended to. Reliability has been maintained at a level lower than that normally expected of a similar aged fleet. Availability of trains in terms of on-time running performance is below target but the contribution of rolling stock incidents to the network performance is relatively small by comparison to other factors such as 'weather'.

A comprehensive FEA model has been generated for fatigue life prediction. However, the results of the fatigue life study of the carbody suggest that the A-series railcars are experiencing concentrated high stresses at eight

locations. The stresses being generated through the modelling are of sufficient magnitude to lead to a very short fatigue life. It is implied that the carbodies should have experienced some cracking already in the asset life.

Asset inspections have been undertaken in the localised high stress areas, it has been observed that the welded joints between door pillars and sole bar are of an improved classification than the drawings prescribe. Sensitivity analysis has been undertaken and it is evident that small changes to the vehicle stresses imparted by a number of assumed loads have a significant impact on the damage incurred and fatigue life of the carbody. Further refinement of the load inputs is necessary to improve the accuracy of the model outputs.

From a financial perspective, values associated with the packages range from AU\$141 million to AU\$645 million and typically the period of life extension drives the level of investment (refer to Table 2). However, these values should be taken into consideration given the depth of analysis and the scope of work.

Table 2 Cost estimates for each Option package

Option1	Option 2a	Option 2b	Option 3a	Option 3b
\$141,344,000	\$247,948,500	\$372,547,000	\$592,172,000	\$644,400,400

These cost projections would need to be weighed against CAPEX & OPEX costs of replacement vehicles if the existing fleet were to be decommissioned at the dates determined for each package.

The cost of re-engineering associated with Option 3b, which included re-motorisation to AC traction was comparable to that of the new Matangi stainless steel rolling stock delivered to Greater Wellington Regional Council.

A strategic risk assessment was undertaken during the course of the study. It is apparent that the strategic risk exposure to PTA also increases with the term of life extension.

The main areas of concern for extended operation of the A-series include, failure to realise the benefits of upgrades involved in the re-engineering, lack of system compatibility and versatility of the A-series for continued operation, continued operation of A-series will reduce buying power for new rolling stock, reliability and safety features of A-series are not succinct with new rolling stock technology.

Options 1 and 2a present opportunities for decommissioning the A-series fleet in alignment with break periods in existing maintenance agreements, and potential order points for new rolling stock. Options 1 and 2a require the lowest investment by PTA and a good improvement to rolling stock reliability is believed achievable through the employment of reliability centred maintenance processes coupled with maintenance exam balancing and maintenance task blocking.

Recommendations

The following recommendations are made:

- Asset inspections are recommended to check for the presence of cracks and verify the consistency of welds with the carbody design;
- Further refinement of the FEA load inputs are necessary to improve the accuracy of the model outputs and validation of the fatigue life prediction should be undertaken before deciding on a preferred Option;
- The recommendations for work packages in each of the Options should be employed;
- Improvements to 'Weather', 'Passenger complaints', 'Electrical' and 'Driver' lost time incident reports should feature as part of an initiative to improve on-time running performance; and,
- PTA should give due consideration of the suitability of the A-series to the future business and system needs.

1.0 Introduction

The Public Transport Authority of Western Australia (PTA) has commissioned AECOM to conduct a review of the alternative options pertaining to the continued operation and the remaining life of the A-series railcar fleet.

PTA is responsible for operating Perth's urban passenger rail system which includes the operation of two Electrical Multiple Unit (EMU) rolling stock fleets, the A-series and the B-series which serve five lines which achieved 41 million passenger journeys during 2012.

The A-series railcars were manufactured in a joint venture between ABB (now Bombardier Transportation) and Walkers Limited (now Downer Group) in Maryborough, Queensland and were purchased with a planned economic life of 30 years. The A-series fleet was delivered in two batches, 43 off between 1991 and 1993 and a further 5 off in late 1998 to early 1999.

Since the majority of the fleet has now surpassed 20 years of service of an intended design life of 30 years, it is now entering the final third of the intended service life. PTA has engaged AECOM to consider the various engineering options regarding the fleet's residual or potentially extended life.

For the benefit of the reader this report has been split into two distinct components. A comprehensive analysis of the A-series' operation has been conducted and part one of this report explains the historic nature of the fleet, its operation and service patterns and discusses those elements of the operating paradigm which are both important and relevant to the scope of this study.

The second part of this report focuses on a number of 'Options' available to PTA for the future operation of the A-series fleet.

2.0 Scope

The majority of the A-series fleet is entering the final third of its intended design life and as such PTA is evaluating the future of the A-series railcar fleet. PTA has engaged AECOM to undertake a study of the A-series EMU railcar fleet, to a number of options which could be pursued regarding the fleet and to recommend the most appropriate option for the fleet in the future.

The study considers the remaining lifespan of the A series fleet as well as the operating expenditures associated with its continued operation and potentially degrading performance. Due consideration is given to the intermediate options of minor and major functional enhancements which would enable reliability and maintainability improvements to be realised.

In order to identify the residual lifespan of the railcars a detailed fatigue life and structural assessment of the A-series railcars has been undertaken.

2.1 Purpose

The Public Transport Authority's intention is to determine the most appropriate outcome for the long-term future of the A-series railcars. The recommendation made as a result of the investigation will be used as an input into the asset management and capital replacement plans of the A series railcar fleet.

2.2 Scope

The deliverable required is a comprehensive report of the Public Transport Authority's A-series fleet, which encompasses the following;

- An assessment of the condition and performance of the A series fleet including a structural assessment, FEA and fatigue modelling followed by an inspection of a railcar,
- A consideration of the options:
 - Straight replacement at end of service life;
 - Life with existing technology and or minor enhancements of the railcar; and,
 - Re-engineering life (including time taken to re-engineer, transportation to/from facility and number of railcars out of service at one time during the re-engineering and prototype options). Consideration to be given to where the re-engineering could occur.
- Budget estimate of costs of all options considered (with advantages and disadvantages),
- Performance targets suitable for each option, and how these performance targets support the achievement of Public Transport Authority's on time running target of 95% of scheduled services being within 4 minutes of timetable,
- A summary of the risks associated with each of the options, based upon those identified via strategic risk assessment,
- Experience from other rail systems, Europe/America/Australasia, and,
- A recommendation from an engineering perspective as to which option is preferred and why this option has been selected.

3.0 Methodology

This section of the report describes the methodology that was applied in order to establish the present condition of the A-series fleet.

From the commencement of the project AECOM conducted reviews of the fleet maintenance data, material usage, asset inspections, and interviews with maintenance personnel amongst other processes to establish a general appreciation of the current asset condition of the A-series fleet.

A selection of the evaluation activities are summarised below in Table 3 for information.

Table 3 Methodology

Evaluation Area	AECOM Methodology
Fatigue life assessment	FEA modelling is conducted to assess the residual fatigue life of the assets through a structural analysis of the carbody.
Condition assessment of sample EMUs	Mechanical and electrical anecdotal evidence inspected to form appreciation of current asset health through a tacit assessment. Asset inspections are also undertaken to identify the presence of corrosion for the readily visible areas of the carbody.
Current maintenance / operational costs	Review of current maintenance tasks undertaken and an analysis of the current costs of these activities is undertaken. Interviews with maintainers and fleet engineers are undertaken.
Operating reliability / availability	Review performance data and statistics, plot trends, look at variances in performance and costs analyse the trends.
Commercial benchmarking	Review against current commercial expectations of on-time running and whether these can be met with the A-series in the future in the light of the above reviews and assessments.
Spare part supply chain integrity	Perform an "at risk" parts analysis (obsolescence etc.) and compare this with the life expectancy and chart future supply chain. Study repair and overhaul statistics and compile lists of parts used and inventory requirements.
Environmental review	Review latest requirements against the present A-series design. Identify any systems requiring action in the immediate future.
Impacts on existing facilities and industrial arrangements	Review of the steps needed to increase the life of the A-series fleet and assess how this affects the existing facilities.
Impacts on stock and contracts	Review of the steps needed to increase life of the A-series fleet and assess how this affects the existing stock inventory and the current maintenance contracts that are in place.
Market analysis	Conduct a review of the operating systems around the world that have incorporated re-engineering of life in order to continue the operation of ageing rolling stock assets.
Forecast future maintenance / operational; costs	Using the data provided by the client of the existing costs, establish a predicted cost of maintenance for several fleet maintenance plan concepts.
Optimal replacement timing	Assessment of life cycle costs and evaluate when this will become least cost efficient against the cost of new rolling stock.
Strategic risk assessment	Conduct a risk assessment of the strategic risks associated with each of the options in the study.

4.0 Cost Analysis

4.1 Methodology

This section explains the methodology and the process that were applied to generate the cost estimations which were consolidated during the course of this study.

For the majority of cases, existing data has been provided by PTA or the maintenance service provider. Typical costs retrieved from PTA and the maintenance service provider included, but was not limited to:

- Maintenance contract value
- Material costs, retrieved from inventory system
- Maintenance fitter labour rates
- Overhaul costs

Where cost information was required but not available from PTA or the maintenance services provider, quotations were sought from established suppliers of equipment or works. Those suppliers with existing familiarity of the A-series railcars were considered most suitable to quote for works. Scope was developed during conversations with PTA and the maintenance service provider as well as the suppliers in order to qualify an appropriate content was estimated.

A selection of the suppliers approached during this process is listed below, though this list is not exhaustive:

- Faiveley
- Knorr Bremse
- Alstom Transport
- ART Engineering

The suppliers were approached because of their existing or historic association and familiarity with the A-series. However, quotations were retrieved within the timescales of the project and as such the values retrieved are reflective of high level scope definition, limited exposure to A-series railcars, and short periods for development of estimates.

4.2 Qualifications and Assumptions

The following qualifications and assumptions apply to the costs presented in this study:

- Estimates provided in the report are in accordance with the requirements of a Class iv estimate as designated by procedure CPPR006;
- Pricing information provided by PTA and the maintenance service provider are accurate and form the basis of the estimates in this report;
- Cost escalation has not been applied to estimates;
- Costs and quotations which were retrieved from historic data are indexed by 5% per year to generate 2012 representative prices, unless stated elsewhere;
- Currency exchange adjustments are not made and have not been accounted of in the cost estimations, with the exception of costs in Table 11;
- Referring to Table 11 currency exchange rate adjustments have been made based on the rates appropriate at the time of expenditure. Currency exchange rates were retrieved from www.x-rates.com and then validated against alternative rates providers for the specified periods;
- Maintenance contract prices are taken from the A-series Maintenance Agreement 21JUL11 Contract No. 2010051 and assumed to be accurate regarding the present scope delivery;
- No escalation of the maintenance contract values has been made for adjustment of rates in the future;

- Forecasting of maintenance contract prices allows for escalation only due to degrading asset condition (associated with Option 2b, 3a, and 3b specifically) and is representative of extra maintenance that may be required;
- Cost analysis for the power consumption of the A-series was calculated from data provided by PTA for 2012 rates;
- Estimates are exclusive of owners indirect costs, such as the cost to PTA of administering a contract, changes to contracts or employing and managing contracts or works;
- The Option estimates do not account for costs associated with future endemic failures, unforeseen events and failure events which AECOM has not been notified of;
- Costs associated with decommissioning the A-series fleet are not included in the package valuations;
- Residual values of assets are not calculated;
- New rolling stock prices provided in Section 5.5 were sourced from Railway Gazette or Railway Technology;
- The cost of continuing to maintain the fleets during decommissioning is not included in the Option package estimates;
- Individual quotes supplied by OEM vendors which were retrieved during the course of this report are subject to the terms, conditions, assumptions and exclusions of the vendors. Vendor quotes and associated terms and conditions are included in the Appendix G for reference. AECOM does not accept liability for the accuracy or reliability of such quotations;
- A contingency of 5% has been applied to the Maintenance Contract;
- A contingency of 15% has been applied to all other values estimated or quoted in this report;

Option specific qualifications

Option 1

- The existing maintenance contract continues to be employed for the period of operation until the railcars are decommissioned. This is an extension to the current maintenance contract of 1.5 years. It is assumed that the price will remain constant for the extended period;

Options 2a

- Indicative estimations are made for alternative maintenance contract arrangements. It has been assumed that a the introduction of a new maintainer may lead to a price escalation over the existing rates possibly resulting from forming a more pessimistic opinion of the asset condition and, or PTA negotiating less favourable terms than those which exist in respect of the current maintenance contract;

Option 2b

- The maintenance contract value extending beyond the duration of the existing agreement has been escalated by 20% to compensate for the age of the fleet and further wear and tear which will be incurred as a result. The escalation of 20% is indicative based on the experience of AECOM, it is recommended that PTA reviews this value and recommends to AECOM appropriate adjustment if necessary;

Option 3a

- Future energy consumption predictions and associated costs are based on 2012 rates, future energy price escalation is excluded from the estimates;
- A fleet wide DC traction motor rewind programme is excluded from the suppliers quotation for traction modernisation works (Option 3a) an adjustment is made in the report for inclusion of the associated motor re-wind costs;
- The DC traction motor upgrade quotation provided by the vendors excluded the provision of a facility to undertake the works. Two provisionally suitable facilities were identified. However, neither facility owner would provide a lease only quotation. A quotation was retrieved for the provision of a facility through an escalated labour rate which included a value for 'overheads' in addition to the typical hourly rates for the

provider's personnel. The traction modernisation quotations were adjusted to factor in the value of the local labour provision by the facility owners;

Options 3b

- Future energy consumption predictions and associated costs are based on 2012 rates, future energy price escalation is excluded from the estimates;
- During the first 15 years of operation, maintenance of new rolling stock is expected to cost 50% of the value of the current A-series maintenance value. This is based on information provided on the New Zealand rolling stock fleets; Matangi and Ganz Mavag. This is provided for high level conceptual comparisons of new versus old rolling stock maintenance costs.

5.0 Part One – Understanding the operating paradigm of the A-series

This section of the report introduces the operating paradigm of the A-series, by reviewing the fleet's service life. A comprehensive analysis has been undertaken of the data that exists from the fleet's introduction from 1991 to present day. The following sections summarise the notable events and proceedings that have occurred during this period and discusses the effects the A-series had on the Perth metropolitan railway and the impacts that the A-series vehicles were exposed to.

In order to assess the requirement for any potential undertakings forming part of the 'Options Analysis' as required by the Scope, it was necessary to interpret the operational data available for the A-series fleet.

This section catalogues the findings of the following studies:

- Service operation duty cycle
- Maintenance regime
- Reliability
- Obsolescence
- Availability

It has been necessary to understand the historic operation of the A-series fleet, and the patterns of its service life in order to identify the areas in most need of attention and to better contemplate the effects of modifications or lack thereof, to continuing the A-series service life for each option being evaluated.

The findings in the following sections are based on the following analyses and activities:

- Fault data – reported from EMU asset management system
- Asset inspections of railcars 236, 246 during GO/F exam (railcars 201,247 undergoing A or B Services)
- LTI data and train cancellation data
- Materials expenditure
- Smart rider data
- OEM maintenance manuals
- PTA adopted maintenance manuals

Interviews with a series of key stakeholders were undertaken during the study, see Table 4:

Table 4 Interviewed stakeholder parties

Name	Title	Organisation
Garry Taylor	Rolling stock Manager	PTA
Rodney Raymond	Prospector Engineering Manager	PTA
Geoffrey Hingston	Electrical Engineer	PTA
Les Robinson	Mechanical Engineer	PTA
Maurice Cox	Assistant Mechanical Engineer	PTA
Carl Delaney	Operations Manager	Bombardier Downer
Paul Dubyniak	Maintenance Manager	Bombardier Downer
Ian Bertram	DMU Shed maintenance lead	Bombardier Downer
Kenny Currin	EMU Shed maintenance lead	Bombardier Downer

5.1 A-series Overview

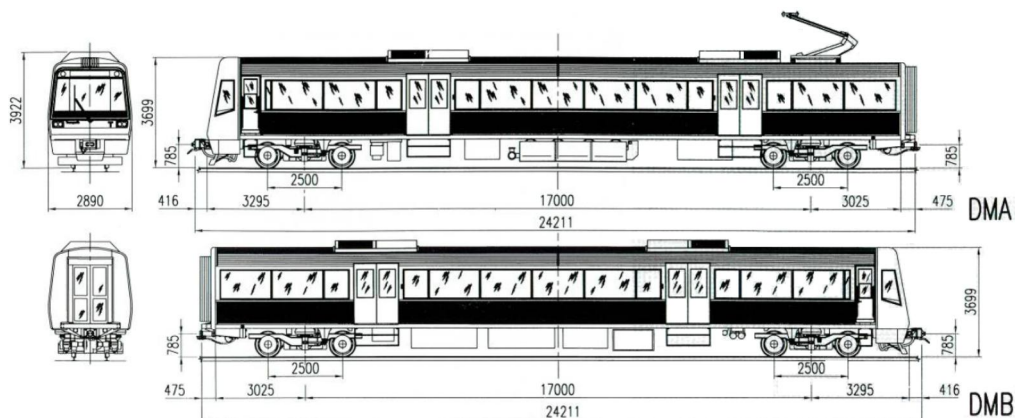
The A-series railcars were manufactured in a joint venture between ABB (now Bombardier Transportation) and Walkers Limited (now Downer Group) in Maryborough, Queensland.

The A series fleet was supplied to the Public Transport Authority in two separate lots:

- Supply of 43 railcars – Delivery 1991 to 1993
- Supply of 5 railcars – Delivery December 1998 to March 1999

The A-series vehicles are permanently configured as two-car units. A basic schematic is provided in Figure 1.

Figure 1 A-series railcar schematic



There are some minor differences between the two deliveries nominated above, resulting mainly from the passage of time between the two procurement phases and technology developments in the interim period. However all A-series railcars are both electrically and mechanically compatible.

A-series railcars are capable of speeds up to 110 km/h. The two cars of each unit are permanently coupled with semi-permanent drawbar style couplers, whereas coupling of multiple units is undertaken via a Scharfenberg automatic coupler. System power is provided by a 25kV AC overhead line

There has been little work undertaken to update or to renew the main train systems, including train management, braking and propulsion systems. However, communication systems have been updated to a modern system utilising automated message announcement system which utilises GPS to play route messages at set locations.

High level technical data is provided in Table 5.

Table 5 A-series railcar technical summary

Item	Technical Description
Train Configuration	2-car units, DMA and DMB cars
Gauge	1067mm
Railcar length (over coupler faces)	48,422mm
Car length (over coupler faces)	24,211mm
Tare mass	90,000kg (48,000kg DMA and 42,000kg DMB)
Power supply	Overhead line 25 kV AC, 50Hz
Seating arrangement	Longitudinal bench seating (63 seats)
Standing capacity at crush	153
Seated capacity at laden	63
Maximum acceleration rate	0.8m/s ²
Maximum deceleration rate	1.12m/s ²
Maximum service speed	110 km/h
Propulsion system	Six separately excited DC traction motors

5.2 Summary of Fleet Operations

5.2.1 A-series

The A-series' operate predominantly on the East to West heritage lines of PTA's network, namely:

- Armadale Line – travelling in a south-east direction from Perth to Armadale, there is also a spur line serving Thornlie, a station which opened in August 2005.
- Fremantle Line – travelling in a westerly direction from Perth towards Fremantle.
- Midland Line – travelling east from Perth to Midland.

A network diagram is illustrated in Figure 2

Figure 2 PTA route network diagram



An image of A-series railcar 212 at Perth station is presented in Figure 3.

Figure 3 A-series railcar 212



Since September 2009 the requirement has been to operate 45 railcars during the peak service from the fleet of 48 railcars. This availability scheme enables one railcar to be stopped for a rolling 12-week general overhaul (F service) and one railcar to be stopped for either a rolling modification program or for major repairs.

The off-peak service requirement is for 36 railcars between the morning and afternoon peak periods as well as the evening service. Weekend services are served by 20-21 railcars.

The average annual mileage in 2012 was 144,360 km per two-car unit. This value is attributed on the basis that the total of the whole of fleet mileage in 2012 was 6,784,826 km during a 52-week year and the sum of the total mileage is distributed evenly between the 47 railcars. Railcar 246 was out of commission for the entirety of 2012 and therefore is assumed to have not contributed to the fleet mileage.

Key performance parameters derived by PTA for operating the network services are;

- A reliability target of 30,000 kilometres (as required by the railcar maintenance contract) per Lost Time Incident (LTI) where an LTI is defined as any delay greater than or equal to four minutes that is caused by a railcar fault.
- The reliability target of 30,000 kilometres per LTI is to be achieved after an initial ramp up over two years following the commencement of the maintenance contract.
- A reliability target of 200,000 kilometres per Cancellation where a Cancellation is defined as a train being withdrawn from service because it was not capable of completing the timetabled journey.
- The PTA strives to achieve a 95% target for on-time running of scheduled services.

Prior to the current maintenance contract for the A-series being commissioned, PTA identified a reliability target of 30,000km per LTI as adequate to enable the on-time running target of 95% to be achieved.

It is worth noting that PTA imposes stricter Key Performance Indicators (KPI) on itself than those used throughout the country by other public transit authorities/rail operators. This is reflected by PTA monitoring its performance on the occurrence of LTIs where the metric is a delay of four minutes or more, whereas it is known that other rail operators across Australia record LTIs upon the occurrence of a delay of five minutes or more.

5.2.2 B-series

The PTA also operates a more modern EMU fleet on the urban network, the B-series.

The B-series (EMU) fleet comprises of 46 three-car units, procured and delivered in multiple lots

- Phase 1 – 31 railcars delivered from 2004
- Phase 2 – 15 railcars delivered from 2008
- Phase 3 – 22 railcars (original order of 15 railcars extended to 22 railcars) to be delivered from 2013

The B-series' predominantly provide services on the North to South lines of the PTA's network (refer to Figure 2), namely:

- Joondalup Line – travelling from Perth and the underground station northbound Joondalup. A large proportion of the alignment is integrated with the centre of the Mitchell Freeway reserve.
- Mandurah Line – travelling in a southward direction, from Perth's underground station south to Mandurah. Part of the alignment is integrated in to the centre of the Kwinana Freeway reserve.

The maximum operating line speed is 130km/h – a speed which is unachievable by the A series railcars.

Figure 4 shows an image of a B-series EMU.

Figure 4 B-series railcar 487



The B-series railcars comprise of three cars permanently coupled with semi-permanent drawbars. B-series railcars operate as singles or pairs forming a six-car train.

The B-series features Bombardier MITRAC Traction system with IGBT inverters powering 8 AC traction motors distributed amongst the three vehicles providing a 66% motorised unit.

It is understood that the B-series railcars were designed for priority of operation on the Mandurah to Clarkson lines and not specifically to provide services currently undertaken by the A-series on the East-West heritage lines for extended durations. It is understood that without modification the B-series may not be able to sustain operation on the heritage lines. Furthermore the B-series design lacks consistency with modern industry standards for rolling stock.

On this basis the B-series is not considered a suitable long-term replacement for the A-series without modification works being undertaken to the train interior and motorisation. Therefore, future capacity expansion on the East-West heritage lines is assumed to require new rolling stock.

5.3 Maintenance Summary

The content of this section is intended to provide the audience with an appraisal of the maintenance history of the A-series fleet so that the future performance projections as discussed in Section 7 for each of the Options can be better estimated.

A-series trains are maintained at Claisebrook depot, located in East Perth and linked to the Armadale and Midland lines.

The depot facilities at Claisebrook enable light and heavy maintenance requirements of the A-series to be managed. Component and system overhauls are typically conducted off-site.

A maintenance and cleaning contract was commissioned with Downer Group and Bombardier Transportation (Maintenance Pty Ltd) as a joint venture which commenced on 1 January 2012 for a period of 7.5 years, with an optional extension for a further 7.5 years at PTA's discretion.

5.3.1 Gap analysis of the OEM and PTA planned preventative maintenance services

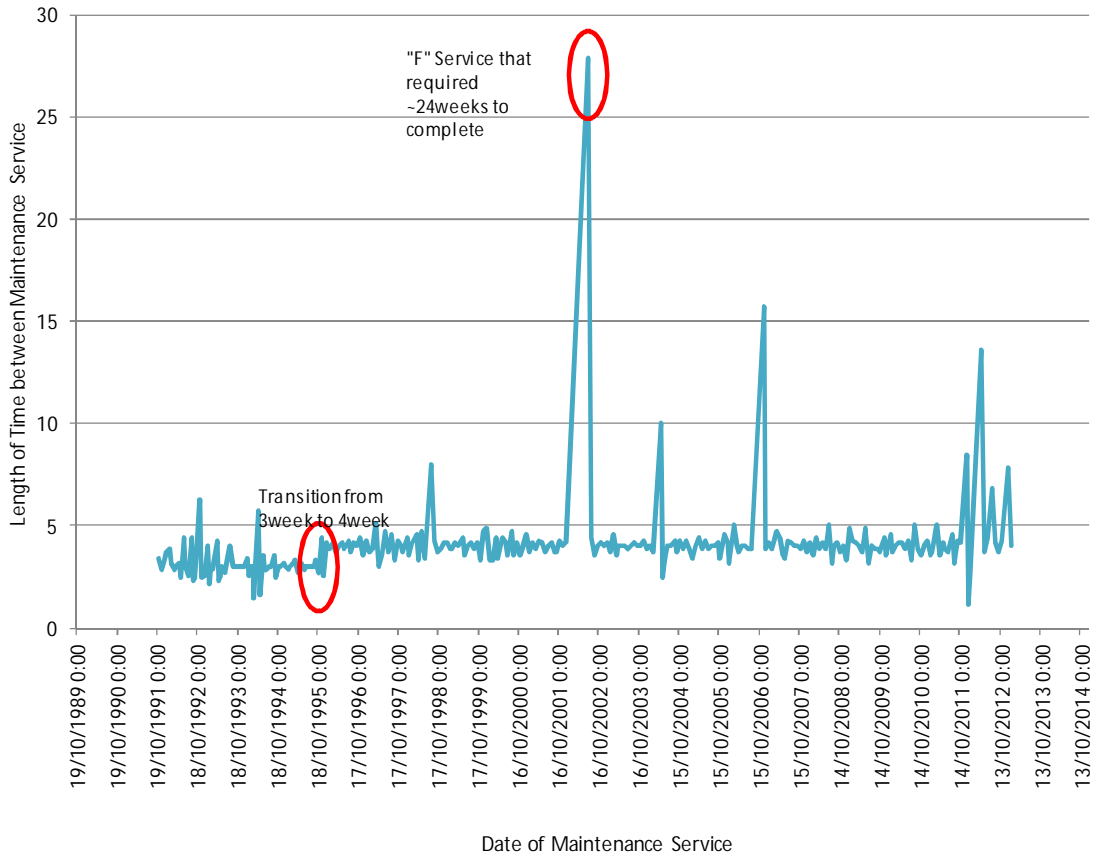
The current planned preventative maintenance regime consists of the activities described in Table 6:

Table 6 Current planned preventative maintenance regime

Service	Description
A service (4 weekly)	General inspection of the railcar, testing and checking of control systems and switches, and inspection and adjustment where necessary to some equipment including air conditioners, traction motors, and main compressor.
B service (12 weekly)	In addition to the content of the A service examination, perform testing, checking, and inspection of other components such as the high voltage equipment, condenser fins and motors of air conditioner, air reservoirs and bogie equipment.
C service (36 weekly)	In addition to the content of the B service examination, detailed further checking and adjustment of components of equipment such as couplers, auxiliary compressors, and traction motors.
D service (72 weekly)	In addition to the content of the C service, significant use of consumables such as lubricants on equipment, cleaning and inspection of more components, and replacing of oil in the main compressor.
E service (144 weekly)	In addition to the content of the D service, replacement of micromesh oil filters and intrusive inspection of pantograph cylinder for corrosion.
F service (general overhaul)	In addition to the content of the E service, refurbishment, intrusive maintenance, and re-calibration of equipment.

A gap analysis of the differences between the current regime and the original OEM recommended regime identified that the current maintenance regime outlined above, was first implemented in 1995. Prior to this, the Original Equipment Manufacturer's (OEM) recommended regime was employed. The transition period from the OEM's maintenance regime to the current regime can be seen in Figure 5 whereby the periodicity of the A service was extended from three weeks to four weeks.

Figure 5 Maintenance Intervals of railcar 1



The graph in Figure 5 presents the length of time between maintenance services for railcar 201 during the period 1991 to the present day. Each of the spikes represents a service. The smaller spikes represent the A and B services, whereas the larger spikes represent larger maintenance undertakings such as C, D, E and F services as marked on the graph.

Comparison of the OEM and PTA maintenance regimes is identified below:

- Extension of A service from 3 weekly to 4 weekly
- Extension of B service from 9 weekly to 12 weekly

Gap analysis of the maintenance regime was undertaken to a maintenance task level and further differences between the OEM recommendations and PTA schedules were observed. It was identified that some task content was extracted from the services and individual task periodicities were extended. The detailed maintenance regime gap analysis is presented in Appendix A. A high level summary of the main differences between the OEM and PTA maintenance regime exam content is summarised in Table 7. The table also identifies those failure modes that may have eventuated from, could be detected or are associated with the activities listed.

Table 7 Extension of task periodicities

Activity	OEM Periodicity (weeks)	PTA Periodicity (weeks)	Potential faults which could occur or be detected during maintenance activity
Inspection of primary and secondary suspensions	3	12	Splitting of airbags and vibration issues
Inspection and replacement of earth brushes on bogie	9	36	Earthing faults
Cleaning, checking, and lubricating of auxiliary converter components	36	72	Leaking capacitors, converter disc faults, circuit breaker trips
Checking the traction motor over-current relays for correct calibration	36	144	Overheating of traction motor contactors and underperformance of motor speed
Removing the pantograph dust boot and inspecting the cylinder for corrosion	72	144	Wear and tear of rams and seals
Main circuit breaker operation testing, changing the interrupter and cleaning the air filter	72	Not identified in manuals but could be listed separately	Tripping of main circuit breaker often with no fault found
Hydraulic dampers removed and tested for correct function throughout a complete stroke	72	Tested at bogie overhaul which is to be every 8 years*	Dampers leaking and seizing
Replacement of sprung finger contacts in auxiliary converter	72	Condition based (currently being replaced)	Overcurrent leading to burnout of thyristors
Removal of end covers and old grease of axle box bearings and clean and regrease before re-fitting end cover	144	Limited to grease injection every 72 weeks	Overheating of axle box and damage to axles
Statutory replacement of sprung finger contacts in thyristor converter	288	Condition based replacements	Overcurrent leading to burnout of thyristors
Inspection of pantograph system and replacement of components	288	Pantograph overhaul is conducted as part of a separate programme	Corrosion to the copper contactor, cracks to the mounting points, and centre bands fatigued
Overhaul of gearbox	288	Condition monitoring of oil in gearbox	Leaking, low amount of oil may cause motor burn
Overhaul of hydraulic dampers	288	Replaced on condition	Dampers leaking and may seize

*Bogie overhaul periodicity is reported to be 8 years. Neither the OEM or PTA manuals refer to a specific maintenance periodicity for overhaul of bogies. It is reported by PTA that of the fleet of 48 railcars, only five to nine railcars have received bogie overhauls (20 – 36 bogies of 184) during the period of operation.

The OEM recommended maintenance regime for the A-series was deviated from three to four years after service introduction. Typically, during the first few years following fleet introduction there are often 'teething problems' experienced, resulting from compatibility and integration issues occurring. It is often necessary to undertake series' of modification programmes to achieve steady state fleet performance during this period. In order for a maintainer to make valid enhancements to an asset's maintenance regime the asset should be in a stable state of performance over a sustained period enabling the maintainer to develop a more comprehensive understanding of the assets interaction with the system.

It is possible that implementing changes to the maintenance programme of the A-series so shortly after its service introduction, was sub-optimal for preserving long term asset performance.

Although follow up reviews are understood to have taken place of the appropriateness of the maintenance regime changes, no documented evidence was provided during the course of the study which assessed the effectiveness of the significant changes implemented in 1995 or those iteratively after 1995.

Without review of the findings it is difficult to determine the resultant effect on the A-series other than consideration of the present fleet reliability as discussed in Section 5.4.

Conducting a Reliability Centred Maintenance (RCM) study would identify the appropriate periodicities for the maintenance tasks to be undertaken and is recommended as a means of improving rolling stock reliability.

5.3.2 Schedule of planned preventative maintenance services

Analysis of the maintenance services for railcars 201, 210, 220, 230 and 247 was performed. The current planned preventative maintenance regime is considered cumulative rather than balanced, whereby the content of each maintenance service (A through to F) is conducted on the same occasion.

Assessment of the annual kilometres travelled has identified the average weekly kilometres accrued for the A-series fleet over the period of 1999 – current, have increased from approximately 2650 km travelled per week to 2900 km per week, an increase of 13,000 km per railcar per year on average or approximately 10% of the annual service duty during this period.

Concurrently, maintenance periodicities have remained largely unchanged at four-week intervals between A and subsequent services. The annual service duty on the vehicles has increased by approximately 10% over the past 14 years and a large proportion of the fleet is over 20 years old.

It is considered worthwhile to perform a review of the periodicities of maintenance services to ensure the fleet can achieve the required reliability in light of possible increases in future mileage and aging of the fleet.

It is understood that the railcars have been maintained in accordance with a time based maintenance schedule, although maintenance scheduling is also tracked on a kilometre basis.

Analysis of the kilometres travelled and time periodicity between maintenance for services A-E for railcars 201, 210, 220, 230, and 247 from 1999 to current times has identified that there were very few occasions where planned maintenance work was deferred. Only 2-4% of train maintenance activities were conducted outside the planned preventative schedule by a margin of 10% or greater, thus exceeding the maintenance interval by over 30 days and exceeding 3300 km (the four-weekly maintenance interval of 3000 km and a tolerance of 10% as used by operators in Europe to track on time maintenance delivery) between maintenance interventions.

It is observed that PTA is conducting routine planned preventative maintenance on-time consistently and the fleet will have benefitted in terms of reliability from this performance. It is recommended that the historic performance of on-time maintenance is continued (by the maintenance service provider) and instances of deferred work are avoided.

5.3.3 Heavy maintenance

A separate workshop (DMU workshop) is used to perform the F service and general overhaul activities, whereas running maintenance (scheduled services A-E) is conducted in the EMU shed. Conducting maintenance in this arrangement means that the occupancy of roads for heavy maintenance during F services does not impact the availability of the running maintenance facility.

The illustration in Figure 5 shows that the first F service undertaken on railcar 201 required 27 weeks offline for the work to be completed, well beyond the expected duration of four weeks. Since then, completion times for F services have improved gradually and more recently F services require eight to twelve weeks for completion.

It has been observed on other projects that extended maintenance durations serve to compound delays and lead to inefficiencies in works undertaken which can compromise both reliability and availability. For example, a railcar that is taken out of service for an extended period of time will experience many maintainer shift changeovers, many lunch breaks and other interruptions. Each of these disruptive occurrences will lead to extension of downtime, increased risk of omitted maintenance activities, inconsistency in inspections and workmanship.

The two main issues which result are that the facilities and the railcar are not available for a long period of time impacting on availability and that inconsistencies in maintenance will arise ultimately leading to more frequent failures and therefore lower reliability.

It is understood that the content of the maintenance services (prior to the maintenance contract being initiated) is blocked in such a way that parts of maintenance services are completed in the periods of off-peak operation.

It is possible that balancing and optimisation of the maintenance regime could further reduce the 'shop time' for servicing railcars and should reduce inconsistencies in undertakings.

5.3.4 Major overhaul of A-series fleet

The A-series fleet are currently undergoing a major overhaul (F-service) at Claisebrook depot. The following tasks are being performed:

- Replacement of window frames
- Overhaul or replacement of seat frames
- Replacement of cab equipment and electronics on a condition basis
- Replacement of door leafs and bodyside saloon door actuators on a condition basis
- Repairs to underframe componentry and casings on a condition basis

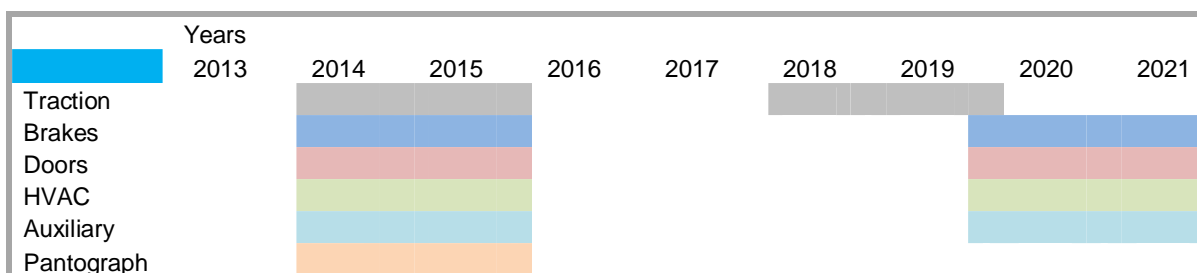
Prior to the rolling stock maintenance contract being implemented on the 1st of January 2012, major overhaul had been performed on railcars 201-233. Railcars 234, 235 and 246 (following an incident where underframe equipment damage was incurred) were completed during 2012. The remaining cars will be completed through the maintenance contract

In addition to the content of the F-service/general overhaul the following work is proposed by the maintenance contractor to be undertaken:

- Overhaul of main compressors
- Installation of new air dryers
- Replacement/overhaul of the pantograph
- Overhaul of HAVC
- Overhaul of brakes
- Overhaul of traction system including rewind of the traction motor (on condition basis, approximately four out of six motors per railcar are rewound) and component replacements on the traction control unit
- Overhaul of bogies

The overhaul scope, terms and conditions and suppliers are still being finalised. The programme for overhaul concentrates the scope on a per unit basis such that the main systems are removed from a unit overhauled and replaced. This programme is expected to commence at a rate of one railcar completed every month, but the maintenance contractor hopes to accelerate this rate during the programme and improved availability of rotatable spares would also improve the schedule rate. It is expected that if the first 10 off railcars are completed at a rate of one railcar every four weeks, the availability of spares and improved efficiencies in programmes might see a reduction in the programme length of a railcar to two weeks. This should enable a scheduled completion of the fleet in a little over two years as per the programme in Figure 6.

Figure 6 Projected overhaul programme to be conducted by maintenance contractor



It was identified during the course of this study that many of the periodicities for component overhauls had been extended from the original OEM recommendations, but furthermore the overhauls have not been conducted at the adjusted periodicities. The bogie overhaul is used as an example, it is understood from information provided that the OEM maintenance interval for bogie overhauls was intended to be every eight years, and this period was extended to nominally 10 years by PTA. However, reports indicate that a maximum of 18 railcars have received bogie overhauls, though the true value might be as low as five railcars. This information suggests that at least 30 railcars have not received bogie overhauls since fleet introduction. Results presented in Appendix B suggest that endemic failures leading to LTIs have not materialised or have not been detected as a direct result.

5.3.5 Maintenance labour and material costs

The maintenance services contractor has provided high level information to enable a financial value to be attributed to each of the maintenance services.

The current labour resource requirements for each of the services and an associated estimate of the labour cost are presented in Table 8:

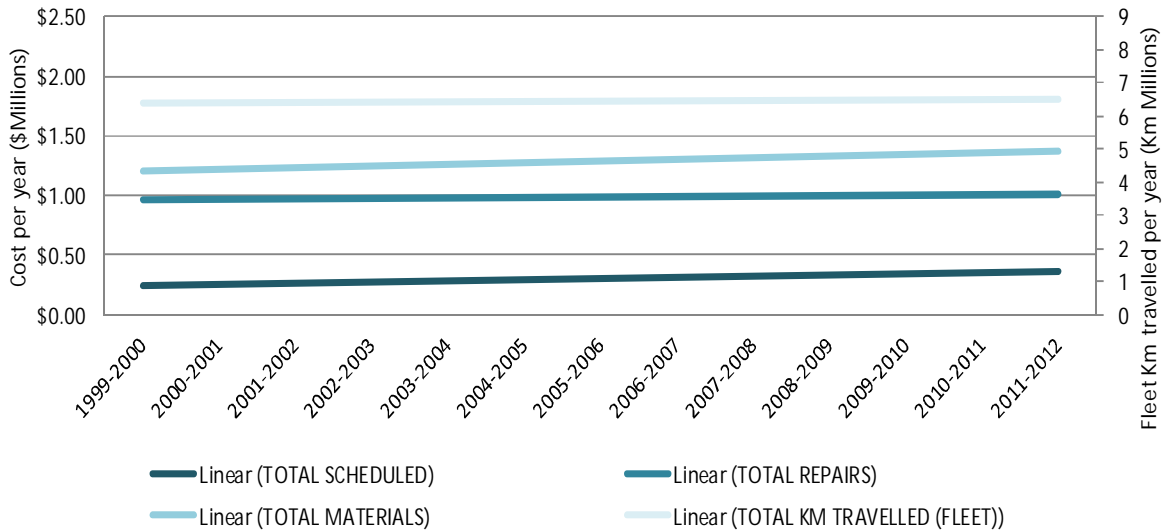
Table 8 Maintenance Labour Requirements

Service Type	Total Linear Hours	Duration (days)	No. and Type of Employees	Total Cost (excl. overheads)
A	5	1	1 Mechanical Fitter ,1 Electrical fitter, 1 T/A Mate	\$480
B	8.5	2	1 Mechanical Fitter ,1 Electrical fitter, 1 T/A Mate	\$816
C	14	2	1 Mechanical Fitter ,1 Electrical fitter, 1 T/A Mate	\$1,344
D	16	3	1 Mechanical Fitter ,1 Electrical fitter, 1 T/A Mate	\$1,536
E	18	3	1 Mechanical Fitter ,1 Electrical fitter, 1 T/A Mate	\$1,728
F	Unknown	~3.5 months	5 staff	Unknown

It is understood that whilst the durations specified in the third column of Table 8 represent the number of total shop days a railcar spends in the maintenance facility, maintenance is blocked in such a way that railcars are returned for peak service operation. It is thought that there is an opportunity for further refinement of the maintenance regime through balancing and blocking of tasks which may improve shop time of the railcars.

With reference to Figure 7, the general trend of year on year material costs shows a gradual increase both the scheduled and unscheduled material costs. This also correlates with a periodic increase in the kilometres travelled. It is noticeable that materials spend is increasing at a faster rate than the kilometres travelled. Whilst the relationship between the two is not expected to be linear, it is expected that the greater rate of materials spend increase is also partly attributable to the increasing age of the fleet and general mechanical wear on componentry. It is worth noting that the impacts of inflation and supply chain issues (obsolescence) are not factored in and would affect the materials spend. It is expected that as the fleet continues to age, the material spend increases will accelerate.

Figure 7 Year on Year Material Costs versus Fleet Kilometres Travelled

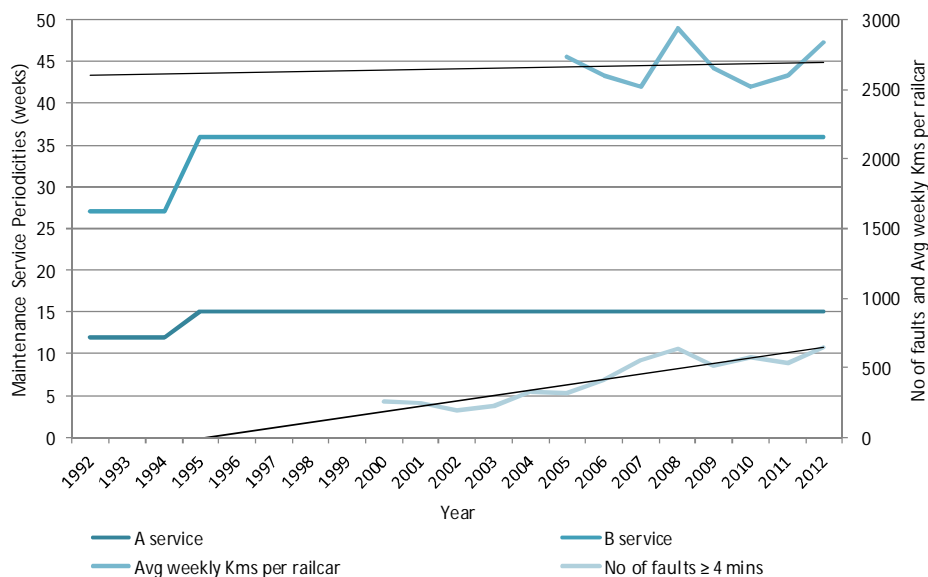


5.3.6 Section summary

The A-series fleet is now in the order of 20 years old (with the exception of railcars 244-248). The maintenance regime was changed after a period of 3 years in operational service, whereby maintenance intervals were generally extended and service content was reduced. Since this intervention the maintenance regime has changed little. Concurrently, the service duty cycle shows an increasing cost trend where the distance travelled has increased by approximately 10% during the past decade (patronage figures during this period were not made available for analysis). Additionally materials expenditure has increased over time and component overhauls are deferred from their intended periodicities.

The deviations from the OEM’s recommended preventative maintenance activities may have impacted the reliability of the fleet and consequently the availability of train services. Whilst it is recognised that OEM maintenance instructions often leave room for refinement, attributes such as the aging of the fleet and increasing service duty (kilometres travelled) are likely to have contributed to the growing number of faults over time and the maintenance schedule has not evolved to counteract the effect of these changes. The number of faults over time versus distance travelled and maintenance periodicities for A and B services are shown in Figure 8.

Figure 8 Maintenance, Mileage, and Faults



It is expected that improvements can be made to the current maintenance regime in order to achieve greater reliability and availability as well as potentially reducing the labour resource requirement and material spend. Whilst the existing maintenance contract is in place, labour and material expenditure remains largely the responsibility of the maintainer, however the residual effect of not implementing improvements could be borne by PTA in the longer term.

It is recommended that an RCM study be conducted in alignment with maintenance optimisation initiatives such as moving to a distance based maintenance schedule, balancing the maintenance schedule and not deferring component overhauls.

The following points are concluded from studying the maintenance regime of the A-series:

- The OEM maintenance regime is no longer followed and may be having a detrimental effect on the reliability.
- PTA modified the OEM maintenance schedule within four years of fleet introduction;
- The modifications to the OEM maintenance regime deployed by PTA comprise of periodicity extensions to A and B services as well as sub task elements of the larger services and maintenance activities;
- Maintenance is blocked such that parts of services are conducted between peak times;
- The service duty cycle in terms of kilometres travelled by the fleet has increased approximately 10% over the past 10 years;
- The maintenance schedule is based on a time based periodicity;
- Regular maintenance service periodicities are well adhered to, with only 2-4% being deferred;
- Component overhauls periodicities are not adhered to and work is deferred or not undertaken; and,
- Materials expenditure has increased over time.

In light of the observations made regarding the current maintenance regime it is expected that the following recommendations may achieve greater reliability and availability as well as potentially reduce the labour resource requirement and material spend:

- Conduct a RCM study to identify low reliability systems and key maintenance improvements;
- Deploy a revised maintenance schedule with appropriate periodicities;
- Track maintenance and conduct maintenance planning using distance rather than time;
- Fragment large services and exam and balance the maintenance regime to even out workload and increase train availability;
- Introduce maintenance blocking to optimise maintenance undertakings and consistency; and
- Avoid deferring component overhauls.

5.4 Present Reliability and Performance

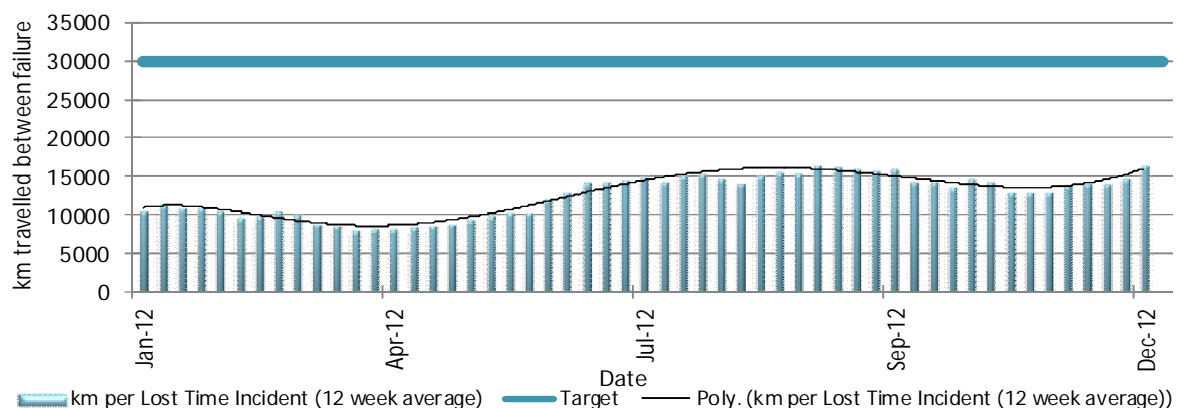
An analysis of the fleet reliability and availability was undertaken during the course of this study. Reliability has been considered in terms of total failures occurring, lost time incidents and train cancellations. Similarly so performance has been reviewed and measured considering a 95% target for on-time running.

5.4.1 Reliability

The assessment of the current reliability of the A-series fleet is based on data provided for the year 2012. On 1 January 2012 a maintenance contract was awarded to joint venture group Bombardier Transportation and Downer Group. The 2012 period provides the most current and meaningful data able to reflect present reliability of the fleet in terms of the kilometres travelled between lost time incidences (LTIs) and train cancellations (TCs).

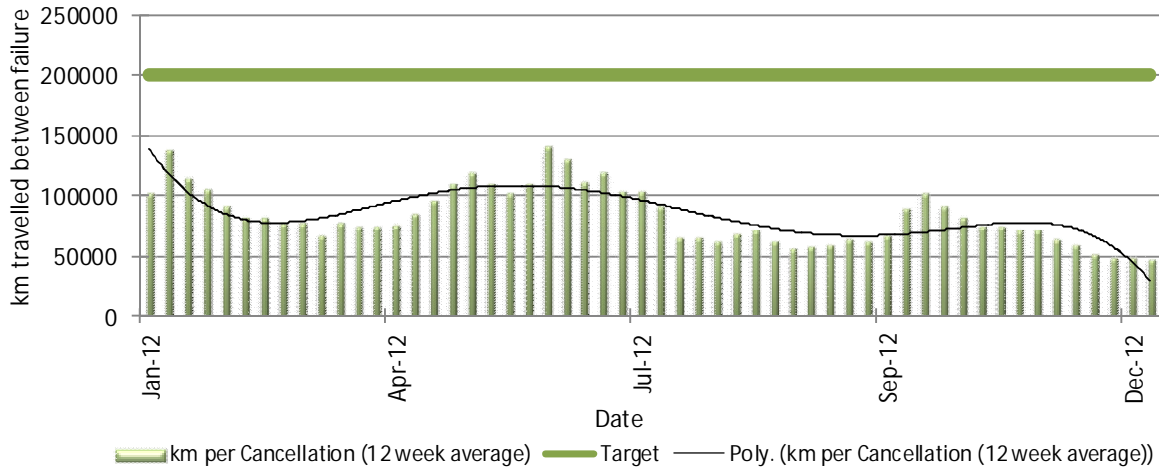
The PTA defines a lost time incident as an event where a train is delayed for a period greater than or equal to four minutes. This is a more stringent metric than the national industry standard of greater than or equal to a five minute delays. Figure 9 below conveys the LTI performance during the 2012 period. The graph shows a slight decrease in reliability from 10,750km per LTI at the outset of the maintenance contract to its lowest level for the year of 8,150km per LTI during the beginning of the second quarter. It is evident that the trough in reliability experienced during the second quarter is endured for a short period before reliability increases again and stabilises at approximately 15,000 km per LTI from the end of quarter 2 onwards for the remainder of the year achieving an annual average of 12,750km per LTI.

Figure 9 A-Series kilometres per Lost Time Incident \geq 4 minutes (2012)



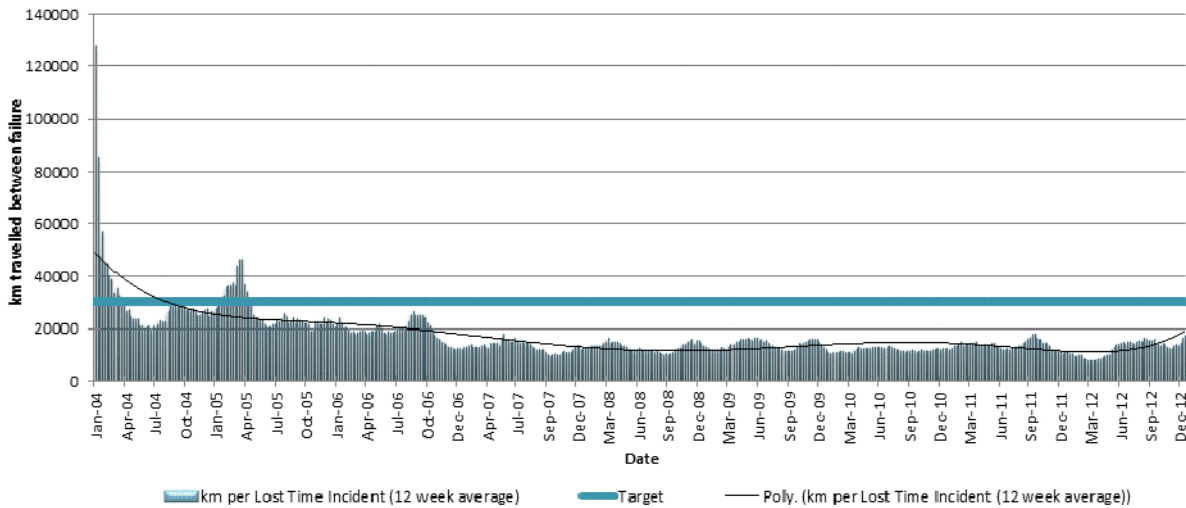
The PTA reports a target reliability of 30,000 km is required in order to achieve a system performance of 95% on time running. The maintenance contract requires the maintenance services provider to achieve a reliability of 30,000km per LTI after a ramp-up period of two years following contract initiation.

Figure 10 A-series kilometres per Train Cancellation Incident (2012)



It is apparent from Figure 10 that there has been a decrease in the distance travelled per train cancellation. Large fluctuations in performance are evident throughout the year, but the trend is for a declining performance. This data is consistent with reports from the PTA regarding an increase in the LTIs for delays of equal to or greater than 15 minutes (data not available). It can be inferred that the occurrence and resolution of smaller impact failures is improving during the 2012 period whereas the responsiveness to more significant rolling stock failures and events is worsening. It is reported that the maintenance contractor is not currently achieving the levels of reliability agreed to in the terms of the contract.

Figure 11 A-series kilometres per Lost Time Incident ≥ 4 minutes (2004-2012)



Historic reliability data is presented for the period January 2004 to present. It is evident from the data plots in Figure 11 that there are three phases of reliability. For a period of approximately three quarters of a year from July 2004 to April 2005 a reliability of 30,000km or greater was achieved. Between April 2005 and October 2006 a reliability of approximately 20,000km per LTI was maintained. From October 2006 to December 2012 a reliability of 15,000km per LTI was maintained (some fluctuations where reliability periodically lifted or lowered are observed in this period). It is apparent that a reliability of 30,000km per LTI has not been achieved since April 2005, however reliability has not continually decreased over this period as might be expected with an expiring asset. However, given the good state of asset health and opportunities to improve upon the maintenance regime it is considered feasible that reliability of 30,000 km per LTI and beyond is achievable.

It is noted that comparisons between the reliability performance of the A-series prior to, and after the maintenance contract award are difficult if there are differences in the way the faults and incidents are recorded.

A-series LTI and TC data was categorised on a train system basis for further analysis. System allocation of the LTIs and TCs incurred during 2012 are displayed in Figure 12. Excluding "Miscellaneous" items which were activities unidentified or not categorised, it can be seen the majority of LTIs are related to faults in the saloon and cab, Automatic Train Protection (ATP) system, electrical control, air and brakes. Traction, communications and electrical control all feature highly in terms of fault attribute proportions.

Figure 12 LEFT: Pie Chart of LTIs ≥ 4 minutes in 2012

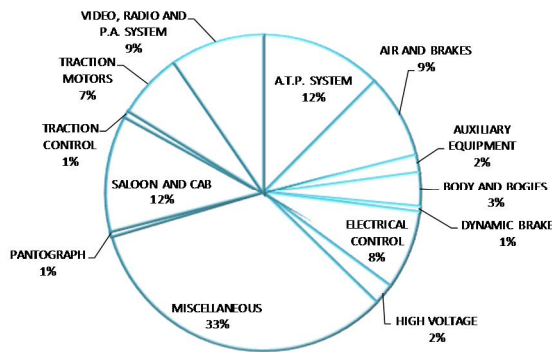
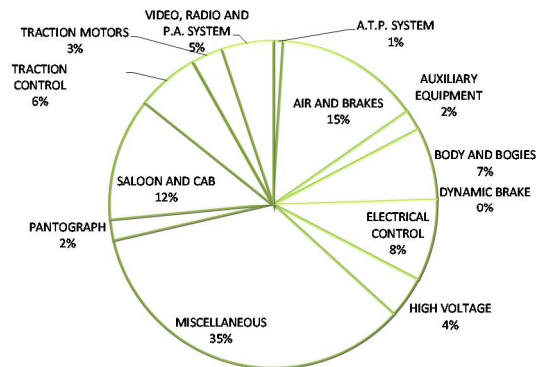


Figure 12 RIGHT: Pie Chart of Train Cancellations in 2012



It is apparent from Figure 12 that there is some commonality between the systems leading to the greatest number of LTIs and those leading to the highest frequency of train cancellations with the exception of ATP. The graph on the right also shows the inclusion of 'body and bogies' as a major contributor to train cancellations attributable to rolling stock.

It is recommended that due to the significant proportion of 'miscellaneous' faults that PTA considers a further breakdown of categorisation for the faults attributed to this segment.

5.4.2 Performance

AECOM has assessed the factors contributing to the on-time running performance and identified that the proportion of events leading to LTIs resulting from rolling stock related issues was only 13%.

Figure 13 shows the breakdown of events leading to lost time incidents on the PTA network during 2012.

Figure 13 LEFT: Actual Operational Delay distributions at 12,758km/LTI (Jan'12 – Dec'12)

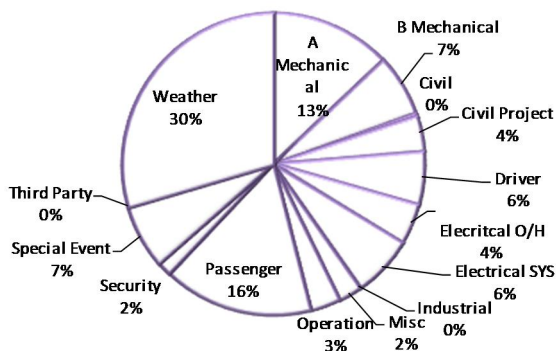
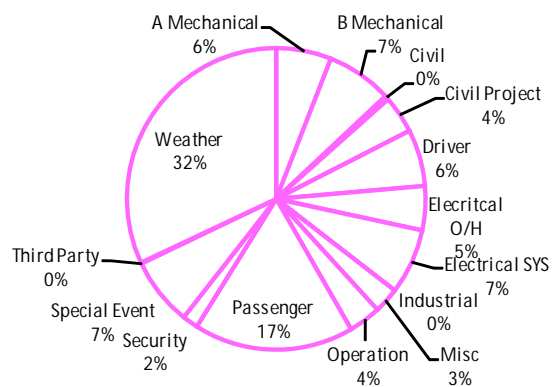


Figure 13 RIGHT: Hypothetical Operational Delay distributions at 30,000km/LTI



The current performance of the A-series trains in terms of achieving on-time running services given LTIs ≥ 4 minutes and LTIs ≥ 5minutes is at 93.52% and 95.88% respectively (Figure 14 and

Figure 15). Given PTA's internal target of ≥ 4 minutes for LTIs, the data analysis conducted as part of this report suggests that the target of 95% on-time running is not presently being met.

It can be seen in Figure 14 that if the reliability of the rolling stock is hypothetically improved from the current 15,000 km per LTI to 30,000 km per LTI and all other systems on the network which impact on-time running remain constant, the overall on-time running performance benefits from only an additional 0.48% (greater than or equal to 4 minutes) increasing on-time running from 93.6% to 94.0%. The effect of this improvement still falls short of achieving the overall operational performance target of 95%. Due to the nature of the relationship (exponential) between rolling stock failures, mean distance per LTI and on-time running it is not possible for rolling stock reliability alone to be improved to an extent where a 95% target for on-time running is achieved, if all other contributors remain unchanged.

Figure 14 Actual versus Hypothetical Operational Performance in 2012 for percentage of trains on time ≤ 4 mins

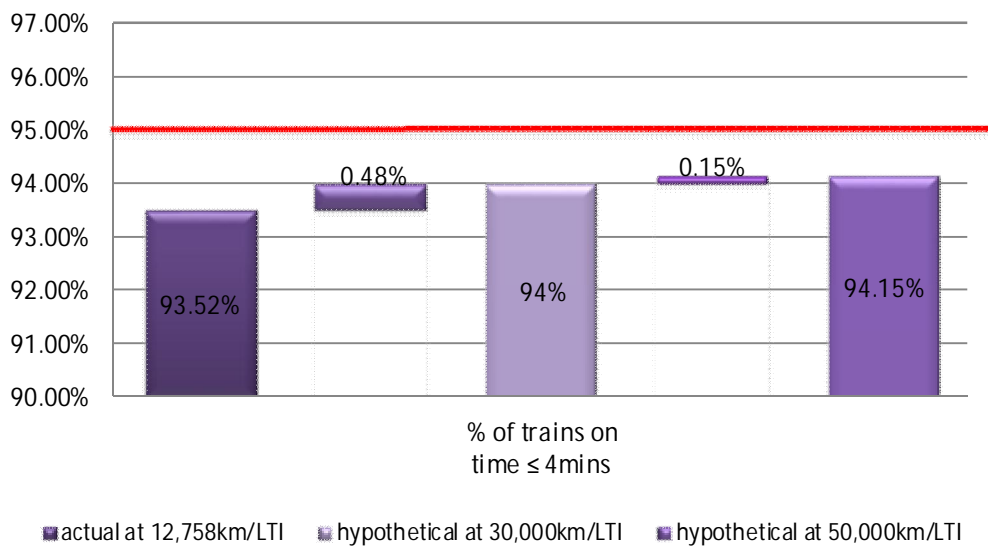
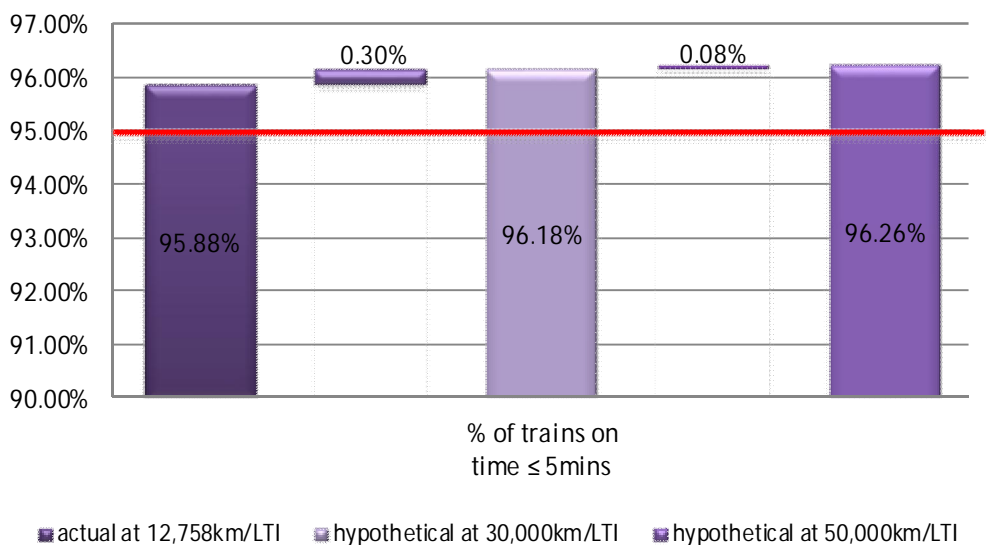


Figure 15 Actual versus Hypothetical Operational Performance in 2012 for percentage of trains on time ≤ 5 mins



It is interesting to note that a similar study was conducted during the development of the performance targets as prescribed in the maintenance contract. The analysis conducted using 2008/2009 data is presented in Figure 16. The graph shows that there is a greater impact of increasing the rolling stock distance per LTI on on-time running for the 2008/9 period than the 2012 period (0.78% versus 0.60%). This is explained by observing the proportional

distribution of system faults in Figure 17. Figure 17 shows the total rolling stock faults have decreased in absolute numbers from 3,145 to 2,786 but also proportionally to from 22% to 13% between 2008 and 2012. This suggests that the A-series rolling stock faults have slightly reduced over the period but the system has performed poorly by comparison and the rest of the system faults have increased by a large amount. By far the greatest contributor in 2012 to the total system faults is 'Weather'. It is also noticeable that this element has increased by the greatest percentage since 2008/9 also.

Figure 16 Actual versus Hypothetical Operation Performance in 2008/2009

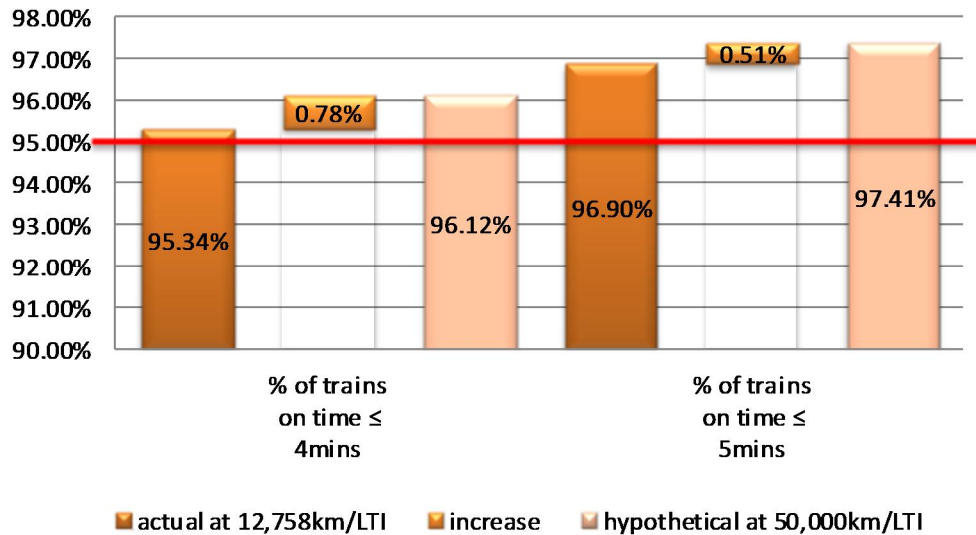


Figure 17 LEFT: Actual Distribution of Operational Delays (2008/2009)

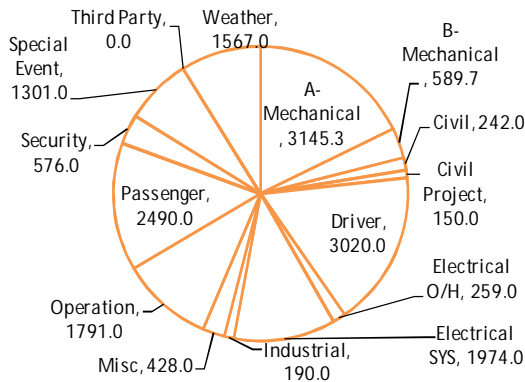
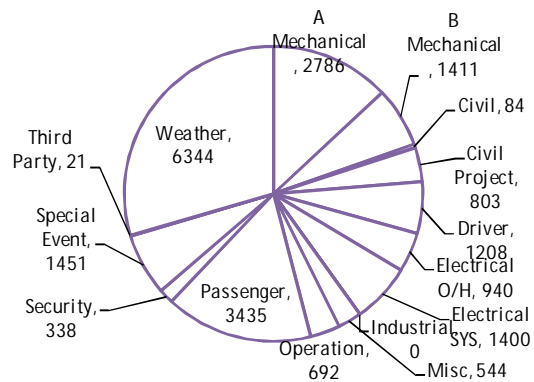


Figure 17 RIGHT: Actual Distribution of Operational Delays (2012)



5.4.3 Benchmarking

In order to put the present reliability performance of the A-series in context, the reliability of similar fleets has been assessed. Fleets of a similar age, design or utilising common technology types were considered relevant in this comparison. Key items of comparison are presented in Table 9.

Table 9 Similar aged fleets reliability comparison

Tube Stock	Year of introduction	Cars per train	Data range from	Reliability	Reliability Metric	Distance per annum
				km/fault	Km/LTI	
A-series	1991	2	2012	12,500	≥4 mins	140,000
QR EMU	1981	3 and 4	2012	8,000	≥5 mins	110,000
Central Line 92 TS	1992	8	2010	9,375	≥1 mins	909375

Tube Stock	Year of introduction	Cars per train	Data range from	Reliability	Reliability Metric	Distance per annum
				km/fault	Km/LTI	Km
Class 321	1998-91	4	2009	22,000	≥5 mins	Unknown

QR fleet

AECOM has recently conducted an Asset Assessment of the Queensland Rail EMUs and identified that the fleet is averaging marginally above 8,000km per LTI (where a LTI is understood to be defined as a delay of 5 minutes or more).

There are 87 railcars in the QR EMU fleet, configured into three-car units with a maximum operating speed of 100 km/h. The railcars are motorised in two batches; 67 x 8-motor and 20x 6-motor three car sets. The railcars feature axle mounted 135 kW DC traction motors service mileage per railcar per annum is approximately 110,000 km on a network system which is not dissimilar to the East/West Heritage lines served by the A-series.

The availability performance target for the Queensland Rail fleet in terms of on-time running is 96% (where the metric for on time running is preventing LTIs of equal to or greater than 5 minutes) it has been identified that the system achieves in the order of 89% on-time running, though the proportion of this target apportioned to rolling stock is unknown.

Based on the data presented above the A-series fleet and PTA network is out performing that of QR.

Central Line 1992 London Underground tube stock

The Central Line 1992 Tube Stock (92TS) provides a reasonable basis for comparison with the A-series. The 92TS was constructed in a similar era as the A-series. 92TS features DC traction motors fed from a 630V DC third rail system. The railcars feature a full ATO and ATP operating system with fully blended dynamic regenerative rheostatic and E.P. brake with slip/slide protection. Automatic controlled spring applied, air-released parking brakes. The traction equipment is Brush Traction/ABB G.T.O. thyristor, dc chopper control with all axles motor by Brush Electrical Machines type LT130, frame-mounted traction motors.

The railcars achieved 9,375 km per fault (where a fault is attributed to any event incurring a delay of one minute or more). This value whilst lower than the typical distance per LTI of the A-series is a far more onerous target and is achieved when undertaking a mileage duty cycle in the order of six times greater than that of the A-series.

Notably there are fairly significant differences between the A-series and 92TS fleets both in terms and design and operation. The 92TS uses a DC power supply for the DC traction equipment, meaning there is no rectification equipment for converting an AC supply for DC traction as in the A-series. The duty cycle of London Underground tubestock is far more onerous in terms of the acceleration and deceleration profiles, the Central Line is no different, it is understood to have been operating for a long period way beyond the expected duty cycle as defined in the fleet's Basis of Design both in terms of patronage and distance travelled. Additionally it is evident from Table 9 that the railcars are covering nearly seven times the annual distance of the A-series.

British Rail Class 321 EMU

Class 321 railcars received the worst reliability for any ex-British Rail EMU fleet in the UK for 2007/2008 – the reliability of the fleet was recorded at 22,000 km per LTI (in this period an LTI was measured as mean distance per 5 minute delay, this metric was later made more onerous and reduced to mean distance per 3 minute delay). Class 321 railcars feature DC traction, fed by a 25 kV overhead lines and were manufactured in 1988 and therefore make a reasonable basis for comparison to the A-series. The railcars are currently the focus of a detailed traction modernisation study.

5.4.4 Section summary

PTA strives for a 95% on-time running target to be met. At present and according to the data which has been provided that target is not being achieved. The largest contributing element to the LTIs on the network is due to 'Weather'. Rolling stock contributes 13% of all LTIs and in order for the on-time running target of 95% to be met a rolling stock reliability of approximately two million kilometres per LTI would have to be achieved.

5.5 Technical Summary

A technical summary of the A-series fleet is provided in this section. It includes an evaluation of the A-series fleet's current condition and likely future maintenance requirements. This evaluation is based on findings from the inspection of railcars 236 and 246 which were undergoing F service at the time of the study and railcars 201, 247 and 234 during A and B services. Discussions were held with a series of personnel from PTA and Bombardier Transport/Downer EDI organisations. Additional technical information on the fleet, including asset health assessments is detailed in Appendix B.

5.5.1 Carbody

The A-series carbody structure is stainless steel housed underneath a stainless steel exterior skin.

Railcars 236 and 246 were presented to AECOM for inspection during the period of this study. Neither railcar displayed any signs of corrosion to the carbody structure in the areas visible during the depot visits. Window frames in the saloon and door apertures were visible. Residual evidence of corrosion was detectable from the removal of the aluminium window frames but it was apparent that corrosion had not ingress into the carbody skin or sub-structure. Very minor corrosion was witnessed on the roof of railcar 247 whilst in the EMU shed for an A service. The very mild surface corrosion was localised to a series of rivet heads which were reportedly heavily cleaned with wire brushes and gauze.

Overall, the carbodies are in very good condition and do not contribute to more than 1% of the total LTIs and TCs reported for the fleet. Some carbody roofs show signs of corrugation which is understood to be a result from heat expansion and contraction of materials. QR EMUs have also shown corrugation in a consistent or worsened state than that observed on some A-series though it is not understood to have adversely affected the fleet operation or the structural integrity of the carbody in anyway. One railcar of the A-series fleet is reported to have incurred physical damage to the roof in the pantograph well leading to a large crack propagating in this area in the order of 500mm long and incurring water ingress. However, the damage is understood to have been generated by physical damage through impact and not through general fatigue. It has since been repaired and is not of immediate concern to the maintenance personnel.

A FEA study was performed on the carbody structure as part of this works, refer to Section 6 for carbody FEA results and discussion.

The underframe appears to be in a good state of health showing little signs of corrosion. Railcar 246 had suffered an incident where the underframe boxes were impacted and lost. AECOM was able to inspect the underframe cut-outs showing very clean stainless steel sheeting and excellently conditioned looming which had previously been routed in protective trays.

Fixings for underframe boxes are generally sound though a valid observation is that they do not feature secondary retention. The exteriors of the underframe equipment cases are suffering badly with corrosion and repairs are ongoing.

Of concern is the identification of cracks in some mountings of the transformers. It is understood the cracks originate from welding issues which occurred during manufacture and the fatigued brackets are being tested and re-welded. It is not known whether this will become an endemic defect and it is recommended that frequent inspection of the transformer mountings is conducted with the use of NDT and ultrasonic techniques.

A general point of note is that the A-series railcars do not feature anti-climber devices to reduce over-riding events or modern Crash Energy Management (CEM) structures and systems for energy absorption in collisions. These features are fundamental requirements of modern international crash worthiness standards such as BS:EN 15227:2010. Any extended operation of the A-series should incorporate a comprehensive review of carbody modification to incorporate such technology in the train design.

5.5.2 Cab

Cracking was evident on several of the GRP frontages inspected during this study. The cracks were forming longitudinally in line with the carbody from the joint between Cab GRP and the stainless carbody. The cracks are not substantial but are great in number and should be monitored frequently going forwards. It is notable that the A-series frontage has a distinctly older look in comparison to the newer B-series and has discoloured over time probably resulting from UV exposure. It is understood that the GRP frontage does not house any major substructure for the vehicle and could be easily regenerated with little intrusion to the carbody design or equipment contained in the cab area.

Fatigue of cab glass surrounds is evident and sealings have perished on numerous vehicles. Fracturing and corrosion of cab door hinges has also occurred. It is understood that these issues should be rectified through planned overhauls in the near future. Inadequate cab dashboard backlighting is reportedly an issue of discomfort to drivers.

The current system uses filament bulbs for back lighting displays, gauges and push buttons with the exception of a LED backlight for the speedometer. It was noted that a complete upgrade program for the dashboard backlight is readily available if required.

The traction brake controller poses a concern whereby drivers are finding them 'notchy' and lacking consistency in the range of motion as a result of an overhaul that was conducted by the OEM in 2009/2010. Whilst not directly affecting reliability, the maintainer and the OEM Faiveley are currently investigating this issue.

5.5.3 Saloon interior

General condition of the interior is good. Saloon interiors feature fluorescent lighting tubes overhead (reliability analysis shows they are a frequent failure item) although the only recordable train cancellation or LTI events result from lighting blackouts. LED saloon lighting could replace the existing fluorescent tube lighting to maintain consistent brightness with improved reliability and reduced energy consumption.

The power supply of incandescent headlights is currently being modified to be separated from the main train power supply system. This will prevent power surges, caused by failing inverters tripping the main circuit breakers. To date 26 railcars out of 43 have been completed. The last five railcars (railcars 244-248) were commissioned with a separate power supply for the headlights.

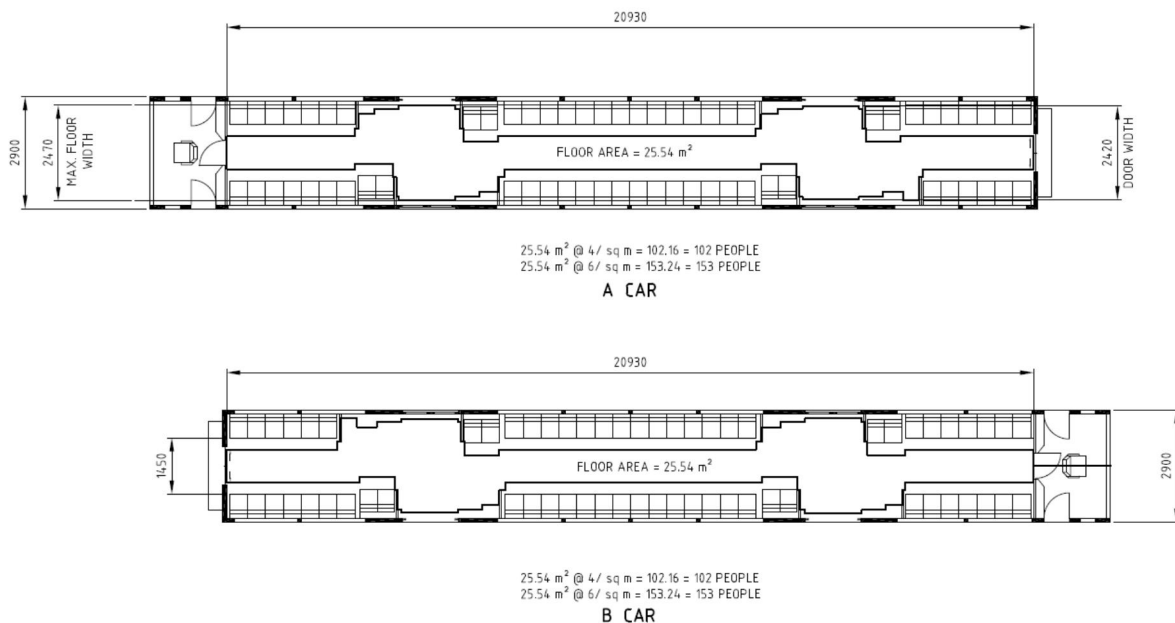
Carpets were replaced fleet-wide from 2002 to 2007 and those observed are in a good state of repair. Grab poles are removed and renewed, a mixture of grab pole conditions has been witnessed in service operation, with poles heavily scratched and showing large areas of bare metal as well as very clean and new poles. Notably this is an aesthetic issue rather than one concerning reliability of the vehicles, but nevertheless has a strong customer facing implication.

Originally, the A-series trains featured two inward-facing rows of bench seats either side of the car forward of the front set of doors and to the back of the rear set of doors, with transverse two plus two seating between the doors

However, the A-series have been reconfigured with two inward-facing bench rows running the entire length of the car. This reduces the number of seats available but increases standing room capacity. The present seating layout is illustrated in Figure 18.

Each car also has four wheelchair spaces available.

Figure 18 Longitudinal bench seating layout of A-series railcars



5.5.4 Wiring and electrical cables

Wiring was inspected in the following cab areas, below and in the cab desk housing, in cab back wall equipment cupboards as well as exterior underframe equipment boxes and in cable trays routing the underframe looms (where removed on railcar 246 whilst undergoing repair work). The physical condition of the looms is considered exceptional for a railcar of this age. Cables remain neatly packaged and well bunched, looms are restrained frequently and diligently to avoid rubbing, erosion and damage. Cables were found in a very good order, showing no signs of strain, over-extension or tight bends heat stresses. Electrical insulation properties are unknown and it is understood flash-testing has not been conducted recently. However, earthing issues are typically localised to a limited number of train sub-systems, and electrical faults associated with power of signal transmission resulting from cable wear are not of substantial proportion in the reliability data provided, other than the faults reported for the ATO system.

It is recommended that the wiring specifications are checked against modern standards in terms of, but not limited to; fire retardant properties and toxicity.

5.5.5 Traction

The traction system is showing signs of its age and degrading condition as a result of general wear of the motors. Further there are early signs of potential obsolescence of components in this system.

The motors are original and currently undergoing a condition based overhaul maintenance program whereby 60 to 70 percent are likely to receive a re-wind of coils and the remainder are planned to undergo basic overhaul. It is reported that presently traction motor overhauls are taking approximately three months per motor through a single supplier, however it is understood that there have been multiple suppliers available previously and overhaul durations were in the order of three weeks per motor. However, the shaft and frame will remain from the existing motor which raises concern as a result of the unknown life expectancy associated with the pinion and drive.

It is understood that the traction motor overhaul is undertaken at five year intervals approximately with a commutator grind performed in situ every two and half years.

There are some reports of overheating occurring with gearboxes and axle bearing boxes. Gearboxes are currently being overhauled every five years. . Axle bearings have injections of grease every 72 weeks and are monitored for bearing wear. They are replaced with expired wheelsets. The re-greasing methodology differs from the procedure recommended by the OEM manuals which prescribes a bearing clean and regrease by detaching of the axle end cover. A further difference is noted in the periodicities for maintenance of gearboxes and axle boxes whereby they are overhauled every 288 and 144 weeks respectively. The traction control system is a 20 year old system and experiencing a range of faults including leaking capacitors, semi-conductor failures through overheating, pitting in the doors, and micro arcing and earthing faults are experienced due to aged and worn insulation of the thyristor converter. Condition based overhaul of thyristor converters are planned to commence in the near future. Traction control circuit boards have been identified as requiring a custom built replacement and likely to be more feasible than re-soldering the current boards if they were upgraded. No plans at this point in time have been expressed to commence this process.

It is recommended that motor armatures and pinion shafts are tested for integrity on a routine basis during overhaul. Traction motors should receive a fleet wide overhaul programme which includes re-winding the motor coils if an extended lifespan is expected.

It should be noted that A-series railcars had previously operated on the Joondalup to Mandurah line (On opening of the Perth to Mandurah line in 2007, A-series ran services between Cockburn Central to Whitfords, Prior to the B series coming on line in 2004, the A-series ran the Currambine to Perth services) during commissioning and early operation of the B-series fleet. It is reported that during periods of sustained operation of the A-series on the North to South lines there have been increased occurrences of traction motor flash overs due to sustaining high operating line speeds.

5.5.6 Bogies

Bogie frames on inspection showed no signs of cracks and appear to be in good state of health. Bogie equipment functionality is representative of the age of the system. Whilst little heavy maintenance work has been undertaken on the bogies historically, data suggests that the condition of the bogies has not yet been adversely affected and less than one percent of the total faults attributable to rolling stock are related to bogies. According to the 'EMU' railcar data base, 24 railcars received bogie overhauls between 2002 and 2011, of which four were completed prior to 2005. However it has also been reported that the Paradigm system records 18 railcar sets in total having

received bogie overhauls, and further reports indicate that 5 railcars have received bogie overhauls. Thus there appears to be conflicting reports and possibly issues with maintenance traceability in regards to this activity.

It is reported by the maintenance contractor that bogie overhauls will be performed again over the upcoming years and then routinely in a programme of eight-year intervals. Major issues identified include cracking of rubber casing on primary suspension springs and axle boxes and gearboxes reportedly overheating. Though these items are relatively infrequent the resultant impact could be as severe as derailment. In addition to the current 72 weekly axle box grease injections and monitoring of gearbox oil, it is recommended the upcoming overhauls include additional maintenance of gearboxes and axle boxes, which would as a minimum, include the scope of the OEM manuals. Gearbox oil sample monitoring should be undertaken at frequent intervals.

It is also recommended that a non-destructive test (NDT) and ultrasonic examination programme is undertaken to validate the structural integrity of the frames and welds. It would also be prudent to conduct an FEA study of the bogie to predict a residual fatigue life. Verifying bogie frame structural integrity is a key element in determining the feasibility of life extension as replacement of the bogies is of significant cost and would make life extension of the fleet less attractive.

5.5.7 Passenger doors

Passenger door leafs are currently being overhauled or replaced with new leafs (new doors were designed from reverse engineering the existing leafs and are being replaced on a 'like for like basis) on a condition basis during the F service. Door leafs are aluminium honeycombed with stainless sheeting panels on the exterior, the honeycombing has poorly deteriorated though the leafs have proven to last 20 years. Some manufacturing issues are being experienced with new doors and as a result are causing some issues in operation which aren't detectable prior to fitment, however it is reported that issues are being addressed with the supplier.

Door overhead equipment including door tracks and actuators are experiencing warping, fatigue and, oil contamination from the main compressor. Door actuators and door tracks are being replaced fleet-wide on F-services. It is recommended all door overhead equipment be replaced to improve reliability of the fleet. Faults with door tracks and leafs as well as door control units have contributed to 8% of the rolling stock delays and train cancellations over the past 12 years. Issues experienced with door control units (DCUs) are delays in detection and location of incorrect door status. An installation programme for DCUs on railcars 201-243 commenced in the early 2000's and was completed in 2011. During this period it is believed that some of the replacement components have become obsolete during this period. It is recommended that the DCUs should be considered for replacement to mitigate further risk of obsolescence and potentially degrading reliability. A significant proportion of DCU faults have resulted from platform detection system introduction and integration issues from 2011 which have since been resolved. A programme of overhaul of the main compressors is commencing and it is likely to improve the future performance and reliability of the existing pneumatic door system which currently experiences oil contamination issues.

5.5.8 Brakes and air

The brake and air system contributes 15 percent to the total of the fleet's operational delays and train cancellations attributable to rolling stock. Contributing factors are largely due to failure of obsolete active electrical components and tripping of wheel slip protection. It is recommended to replace the brake control unit and consider replacement or upgrade of the WSP system for improved sensitivity against trips and to de-risk obsolescence.

Failing mechanical components including fatigued callipers, and corroded brake ratchets and manifolds are currently being replaced on a condition basis. Fleet wide replacement of worn polymer bearings is to commence soon. Degraded and worn mechanical and pneumatic components are also causing noise issues noticeable and reported by passengers.

According to reliability data provided, tripping of the main compressor motor is an increasing attribute of brake failures. From the discussion held trips occur more in the summer time due to overheating of the compressor motor. Between 12 and 18 main compressors were last overhauled from 2002 to 2011 on a condition basis.. Some main compressors also experience oil and water condensation mixing. However, most main compressors have been modified to a six pole motor to enable sufficient heat to prevent condensation. It is recommended that installation of a new compressor should occur in the event of life extension. However, the maintenance contractor reports a programme of overhaul will commence soon, which should be considered before deciding on replacement. It is understood the OEM for the brake system is reluctant to commit to an overhaul programme of the callipers due to inconsistencies in the modification status and mechanical wear to the bogie mounted brake

equipment between railcars. The OEM has recommended that the bogie mounted brake equipment, in particular brake callipers, should be replaced on all railcars.

5.5.9 Heating ventilation air conditioning (HVAC)

The HVAC system contributes to one percent of all rolling stock failures. However, there are a series of issues reported by maintainers which may begin to impact the failure frequency in the near future and lead to reduced reliability of the system. Of most concern is the HVAC compressor. This is experiencing mechanical component fatigue and electrical component failure resulting in short circuiting of the motor and earth faults that cannot be traced. Oil carry over occurs from the compressor to other components such as valves and evaporator and condenser coils affecting their performance. The HVAC system also has refrigerant leaks and the system piping is showing signs of age. Although maintainers are commencing an overhaul of the compressors with new air dryers which will reduce oil carry over, it is recommended a system upgrade be performed if life extension is considered.

There are a large number of complaints reported from drivers as documented in the reliability data provided, particularly on hot days during summer. Currently, cooling in the cab is provided by a recirculation of the saloon air by a blower fan forcing air through into the cab. A valid consideration for continued operation would be the installation of a cab HVAC unit for improved driving comfort.

5.5.10 Automatic train protection

The ATP system contributes to a large proportion of train delays and cancellations attributable to rolling stock. The majority of ATP failures result from transmission faults whereby the transmission rack is experiencing communication issues with the antenna. An increasing number of ATP faults are attributable to the damaged buttons on the driver's cab panel triggering the ATP system. This is currently being addressed through ATP panel button upgrades across the fleet.

ATP components such as the transmitter, receiver, and recorder cards have been replaced and cables are replaced on a condition basis since they were first installed from 1990 to 1994. ATP system changes should be considered on a holistic basis. The network system needs should be evaluated before committing investment to on-board or line side modification or improvement programmes.

5.5.11 Communication system

The nature of this system is highly prone to technical obsolescence. With upgrades to the communication system completed on all trains during the past year it is already recognised that elements of the systems are facing obsolescence risk. Reported issues which have since been largely resolved include incorrect information displayed on PIS displays and passenger intercom announcements as well as lack of door 'gongs' when trains are stationed at platforms, and system crashes requiring resetting for rectification. There have also been intermittent failures with the train radio control, corrosion of the aluminium roof mounted antennas, these issues are not yet affecting reliability however may pose future risk.

RAPID (Recording and Passenger Information Dissemination) software crashes contribute to the greatest quantity of communications system failures. PTA is working with the maintenance contractor for a solution.

5.5.12 Auxiliaries

The main issues observed with the Auxiliaries are leakage of capacitors in the converter, tripping of the circuit breakers and early failure of batteries (resulting from faulty battery chargers). It is known that capacitors have been recently replaced. These should be replaced with more reliable batteries. Note active components such as the semi-conductors and capacitors are being replaced with component stocks built up during historic purchasing programmes by PTA, where the components are now obsolete. Subsequently, replacement models will need to be sourced over the forthcoming years to allow for additional lead times.

5.5.13 Couplers

The electrical coupler heads have failed to perform due to worn flexible components and seals or damaged electrical contacts. This is a common occurrence with auto-couplers being frequently engaged and disengaged through normal service operation. The male and female connections become bent, damaged and dirty through constant use and interim repairs, such as pin replacement become more frequent with time. Some corrosion is evident on the couplers and headstock and should be monitored over time.

5.6 Market Analysis

A comprehensive review of market conditions pertaining to the content of this study has been conducted.

The following reviews were conducted:

- Case studies of life extension studies and projects nationally and internationally, such as:
 - Philadelphia Area Transit Company - PATCO (stainless steel carbodies, DC traction)
 - VIA Rail (stainless steel carbodies)
 - Hong Kong MTR (reconfiguration, traction modernisation)
 - QR (Stainless steel carbodies, DC traction, commonality in the design)
 - Ganz Mavag New Zealand (business case of modernisation versus replacement)
- Reliability and performance benchmarks (use of case studies above and 92 Central Line TS)
- New rolling stock prices (Australian build and International EMU builds)

The results of the case study analyses are presented in the Appendix C in detail. Information of specific interest and relevance to the Options considered in this study is referenced where applicable throughout this section. Though a few key points are summarised below:

- Operators of stainless steel carbody structured fleets have observed very long fatigue life of railcars with minor structural modifications required for sustained life for periods of 50 years or greater.
- Typically major modernisation schemes, refurbishments and regeneration projects are valued between 50 and 75 percent of the cost of replacement rolling stock in each instance.
- Often scope of refurbishments or modernisation schemes are expanded from initial estimates due to unforeseen issues when rolling stock is more intrusively inspected and disassembled.
- More frequently it is observed that original DC traction systems are replaced by AC traction, however, DC modernisation schemes are also observed and successful business were proven (in the case of PATCO) AC traction system replacements for original modernisation.
- Operating costs for existing stock post deployment of modernisation schemes are projected to be greater than those of new rolling stock, in the order of 50% for the Ganz Mavag versus Matangi case.

Benchmarking of reliability and availability performance was undertaken and discussed throughout the course of the report. Rolling stock of similar age, technology or operation has been used for benchmarking and comparisons the results of the analysis are presented in Table 10.

Table 10 Reliability performance comparison for similar rolling stock fleets

Tube Stock	Year of introduction	Cars per train	Data range from	Reliability	Reliability Metric	Distance per annum
				km/fault	Km/LTI	Km
A-series	1991	2	2012	12,500	≥4 mins	140,000
QR EMU	1981	3 and 4	2012	8,000	≥5 mins	110,000
Central Line 92 TS	1992	8	2010	9,375	≥1 mins	909375
Class 321	1998-91	4	2009	22,000	≥5 mins	Unknown

In order to consider what the potential replacement options for the A-series and the associated costs are likely to be, a review of national and international tenders was undertaken to identify new rolling stock prices. Table 11 summarises a few key values below. Contract values were published by Railway Gazette.

Table 11 New rolling stock market analysis

Class	Country for delivery	Manufacturer	Country of origin	For	Contract size	Total contract value AUD	Price base	Unit price per car
X'trapolis	Aus	Alstom	Italy/ Australia	DOT Victoria	38x6 car	\$564	2008	\$2.48M
Matangi	NZ	Hyundai Rotem	South Korea	GWRC	48x2 car	\$145M	2008	\$1.51M*
Matangi	NZ	Hyundai Rotem	South Korea	GWRC	35x2 car	\$115M	2012	\$1.63M* *
B-Series	Aus	Bombardier	Australia	PTA	22x3 car	\$243M	2012	\$3.7M
A-Train	Aus	Bombardier	Australia	Transport S.A	22x3 car	\$269M	2011	\$4.08M
378	UK	Bombardier	UK	NLR	23x4 car	\$525M	2007	\$4.00M* **
379	UK	Bombardier	UK	Eversholt	30x4car	\$264M	2010	2.20M** **

*The contract value was priced in NZD; the exchange rate applied was 0.7069, provided by x-ratesexchangerates.com

**The contract value was priced in NZD, the exchange rate applied was 0.8165 provided by x-ratesexchangerates.com

***The contract and car price includes a 12 year maintenance contract an adjustment of -30% has been applied, and is affected by a weak AUD, contract was valued in GBP the exchange rate applied was 0.4645 GBP to AUD, provided by ratesexchangerates.com at average 2007 value.

****The contract and car price includes a 36 month maintenance regime an adjustment of -10% has been applied, contract was valued in GBP the exchange rate applied was 0.58 GBP to AUD, provided by ratesexchangerates.com at average 2010 value.

Figure 19 A-Train impression courtesy provided by AdelaideNow



It is suggested that the Adelaide A-train is the next generation evolution of the (Bombardier/Downer) B-series, as illustrated in Figure 19. The contract value presented in Table 11 is consistent, albeit slightly inflated, with that of the recent B-series order commissioned by PTA. The Unit cost for the B-series and A-train are in the order of AU\$4 million per car.

The railcars are a favourable three-car configuration manufactured with stainless steel carbody shell, featuring AC traction and MITRAC control software. A notable feature is that the railcars are designed with two doors per saloon bodyside.

Figure 20 Greater Wellington FP Class Matangi manufactured by Hyundai Rotem



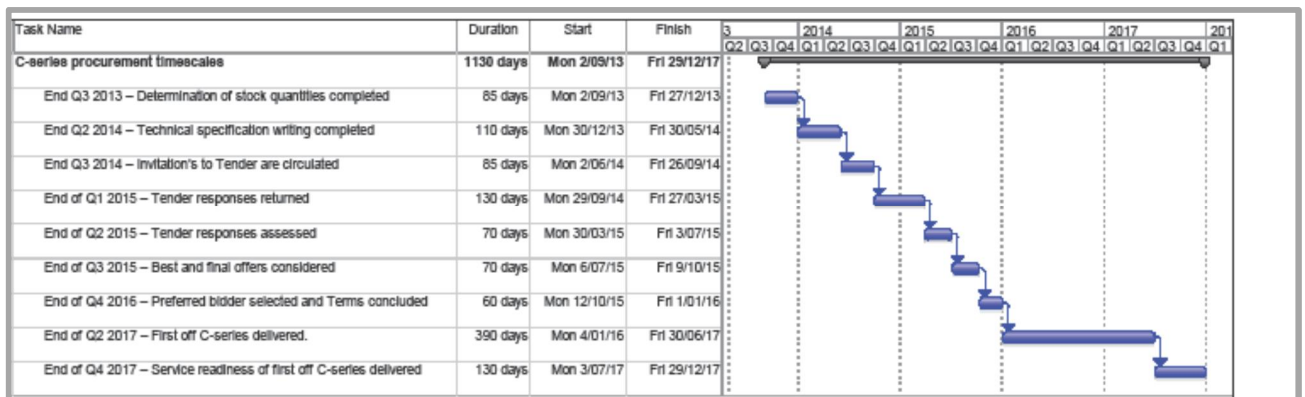
Figure 20 shows Unit FP4103 Greater Wellington Regional Council (GWRC) FP Class Matangi at a station platform. Railcars are two-car configuration featuring two saloon doors per side and 8 AC traction motors drawing power from a 1500v DC overhead catenary system. Stainless steel is used for carbody construction and capacity (seated and standing) is 277 distributed between the two cars. The FP class Matangi's, manufactured in South Korea, are valued at approximately AU\$1.6 million per car, approximately a third of the price of rolling stock manufactured in Australia.

Purely for the purposes of comparison, the costs for two recent Bombardier Transportation Electrostar orders (Class 378 and 379) are presented in the Table 11. The Electrostar's are the most widespread EMU class operating in the UK at present and new rolling stock prices are in the order of GB£1.2 million per vehicle, or AU\$1.8 million. Note, that the Electrostar fleets feature aluminium carbodies.

The requirement for increasing rolling stock capacity is unclear at present both in terms of schedule and quantity. However, it is understood there is an increasing demand for capacity expansion. For the purpose of this report it is assumed that new rolling stock will be required from 2018 or 2025 for deployment on the East-West heritage lines in order to either supplement or replace the A-series fleet.

A high level schedule has been provided in Figure 21 to illustrate the associated timescales with a new fleet procurement cycle which has been used in the Options analysis.

Figure 21 Indicative schedule of new rolling stock procurement



It is a reasonable assumption that a large rolling stock order should return a more favourable unit price due to the economies of scale benefitting the 'one-off' costs (such as; engineering design, process engineering,

manufacturing flow development, jig development etc.) through distribution over larger order volumes. On this basis it would be beneficial if capacity occurs in consolidated parcels. However, for a number of reasons (political, funding, schedule) it may not be feasible to consolidate rolling stock orders this way and alternative programmes of procurement may be administered similar to that of the B-series.

5.6.1 Section summary

The purpose of the analysis conducted in this section was to provide an overview of the lessons learned in life extension projects which have relevance to the future operation of the A-series fleet. The feedback from those involved in rolling stock life extension projects is that the costs of major re-engineering works are generally in the order of 50-75% of new rolling costs though the operating costs of continued operation of existing assets can be up to 50% greater than that of new rolling stock.

New rolling stock prices were acquired in order to provide a benchmark against which re-engineering costs associated with Option 3 can be later compared. It is evident that stainless steel rolling stock of simple system design can be procured from the international market for as little as AU\$1.6 million per car, whereas Australian manufactured rolling stock carries a heavy price premium of AU\$4 million per car. If stainless steel and 'buy-Australia' legislation are not critical requirements of a new procurement scheme there are EMU fleets available from Europe and elsewhere with advanced systems and technology achieving high reliabilities (in the order of 100,00km/LT \geq 3 minute delays) available for approximately AU\$2 million per car (though exchange rates are currently favourable to Australia they are subject to change).

5.7 Disability Discrimination Act (DDA) 1992 Compliance

5.7.1 Review documentation

PTA is currently in the process of producing a document detailing compliance of the A-series railcars with the DDA requirements. The section presents a high level investigation into A-series DDA compliances based on conversations with PTA personnel and a review of the following documentation in order to assess the implications on the PTA A-series railcars. It excludes review of the DDA requirements applicable to associated rail infrastructure:

- Disability Standards for Accessible Public Transport 2002, Australian Government, May 2011
- Australian Standard AS1428.1 (2009), Standards Australia, 2009
- Australian Standard AS1428.2 (1992), Standards Australia, 1992

5.7.2 Evaluation

The PTA has performed appropriate modifications on all of the A-series railcar vehicles to comply with a majority of the DDA requirements. Those that have not been complied with have been presented to the DDA with the following rationales:

- Hearing Augmentation (using hearing aid loops) – installation is costly as it would require stripping of the fibreglass panelling along the length of the train. The PTA has consulted hearing impaired stakeholders with this matter and they are satisfied with the current ridership conditions. Australian Standard AS1428.2-1992 Clause 21.1 requires the system to cover at least 10 percent of the total area of a railcar.
- Exterior door opening buttons are above the Australian Standard AS1428.1-2009 Clause 13.5.3(b) compliance levels of 1200mm above the plane of the train floor – to relocate these is costly and disruptive to services as it would require modification of the stainless steel body exterior necessitating long down times for the vehicles. The PTA has had very few ridership complaints pertaining to this non-compliance. However to deal with any potential boarding issues, there are Customer Service Assistants at selected stations to assist people with disabilities as they enter and exit to and from the trains.
- The Emergency Door Release button is located at the top of the door entrance. Whilst this item is not specifically outlined in the DDA, it may potentially present a form of door control, which would then be considered non-compliant with the DDA. Re-locating the passenger emergency door release button to a more suitable area for people with disabilities would require interior modification.

PTA is in the process of conducting an internal compliance review, the results of which are not yet available. It is recommended that due consideration is given to pending changes with the standards and how the existing design may or may not meet the standards. Similarly due consideration should be given to the compatibility of planned or potential future train modifications and enhancements to meeting DDA standards.

Transport Standards state that compliance must be achieved over a 30-year period from 2002 for passenger rolling stock, within the following interim progress requirements:

- 25% by the end of 2007
- 55% by the end of 2012
- 90% by the end of 2017
- 100% by the end of 2032 (For trains only – other rail infrastructure must achieve 100% by 2022)

Since it is not yet apparent what specific DDA compliance will be required for legacy fleets, it has not been considered further in this report. Other than to note, there is an increased risk of modifications being required for greater life extension periods.

6.0 Structural Analysis and Residual Fatigue Life Calculation

6.1 Methodology

Package 1 – Finite Element Analysis and Structural assessment of the Carbody

The residual fatigue life and structural analysis has been undertaken by Design and Analysis Ltd of the UK by conducting a Finite Element Analysis (FEA) study of the carbody.

After careful consideration during the tender phase it was decided that the fatigue analysis and structural study should be split into two distinct phases. The Phase 1 component of the FEA work included a fatigue analysis of the carbody using standard load cases described in BS EN 12663 as well as utilising a series of input data from previous projects completed by Design and Analysis and those available for the A-series and the PTA urban network. The Phase 2 element of the FEA study encompassed a validation of the analysis of the carbody based on track test data in order to verify the initial load cases.

The results of the Phase 1 study are included in this report, whereas the work associated with Phase 2 is not.

The methodology implemented to carry out the scope of work for FEA fatigue and structural analyses to generic rail load cases, was as follows:

1) Generation of Load Case Document

A fatigue load case document has been generated that summarises all the applicable load cases defined in BS EN 12663 and GM/RT2100, as well as the input loads available for the PTA urban network and technical data for the A-series trains. The document specifically describes how the force values are derived for this vehicle and how they are applied to the FEA model.

2) Generation of Finite Element Analysis Model

An FEA model has been generated of the DMA car. The DMB car is passed by comparison with the DMA car. This is based on the following; the DMA car as a significantly higher mass than the DMB car, the DMA car has the pantograph well which is considered a weaker structure than the continuous roof of the DMB car and the DMA car has additional underframe mounted equipment and support bracketry.

The model has translated the 2D detail drawings into a 3D FEA model. The FEA model is mainly constructed from thin shell elements to represent the stainless steel sections used in the carbody construction. The FEA software used will be the Altair Hyperworks suite of software, with the model solution conducted in Optistruct and NX Nastran.

3) Model Solution

Load cases were applied and then the model was 'debugged' to achieve a successful solution for each load case. Validation of the model was undertaken via interrogation of reaction loads with respect to applied loads.

4) Post Processing

Interrogation of the model results was conducted to determine the maximum and minimum principal stress levels for each fatigue classification presented within the design. Finally, manual fatigue calculations were carried-out based on either BS7608 or Eurocode 3 to predict vehicle life.

Practical verification was recommended (Phase 2) of the results presented following Phase 1 of the study and the work associated with Phase 2 requires intrusive work to be undertaken on an A-series railcar requiring the installation of accelerometers and strain gauges. The optimum installation of which would be inside the passenger area of an operational railcar. It was proposed that the Phase 2 element would be postponed until the results of the Phase 1 FEA study were available in order to cause minimal disruption to PTA's services. The detailed methodology AECOM prepared for Phase 2 is provided in Appendix D.

6.2 Assumptions

Table 12 identifies the list of assumptions regarding the fatigue model input loads. The table identifies the source of the input, an explanation for its inclusion, and comments on a means to improve accuracy. Detailed input assumptions are prescribed in the Fatigue Load Cases Document for the A-series Railcar (Report Number C3263-001 Issue D).

Table 12 FEA fatigue model input sources and explanatory notes

Input description	Basis of assumption	Further comments
Train build reflective of drawings	Drawings	On inspection railcar 236 found to have what appeared to be a 15mm toe dressed weld instead of 3mm fillet on door pillar to sole bar joint
Car tare masses	Specification	Weighed masses should be used
Car mass centre of gravity	Only vertical CoG provided, lateral and longitudinal CoGs estimated	CoGs based on weighed masses should be used
Underframe component mass	4 of 30 masses retrieved from drawings or during inspection.	Other underframe component masses estimated using Class 465 data
Underframe component mass centre of gravity	Estimated as centre of volume from drawings	Could be measured through accurate weighing
Passenger loadings/passenger mass conditions	Estimated from Smartrider data	Adjusted to use data from Smart Rider
Passenger loading/unloading cycles	LU standard 2-01202-025	Adjusted to use data from Smart Rider
Passenger loading/unloading number	Estimated from Smartrider data	Previously LU standard 2-01202-025
Vertical inertia	BS:EN12663	BS:EN12663 might reflect high cycle frequency compared to A-series network (previously LU standard 2-01202-025)

6.3 Inputs

6.3.1 FEA model and fatigue calculation data

The FEA model is constructed from 2D shell elements with a global mesh size of 25mm, although in high stress areas the mesh size has been refined to 7.5mm to increase accuracy. The FEA model has been generated from drawings and is an accurate representation of the data supplied. The FEA model has been checked and applied load reactions also checked. All loads represent the loading outlined in the load case document.

Load cases analysed: LNG 1-4, LAT 1-4, VRT 1-4, PAS & TWS, (see C3263-001-Issue C for details)

Stress extraction: Eurocode 3 requires the nominal stress to be used; this has been taken one element away from stress concentration.

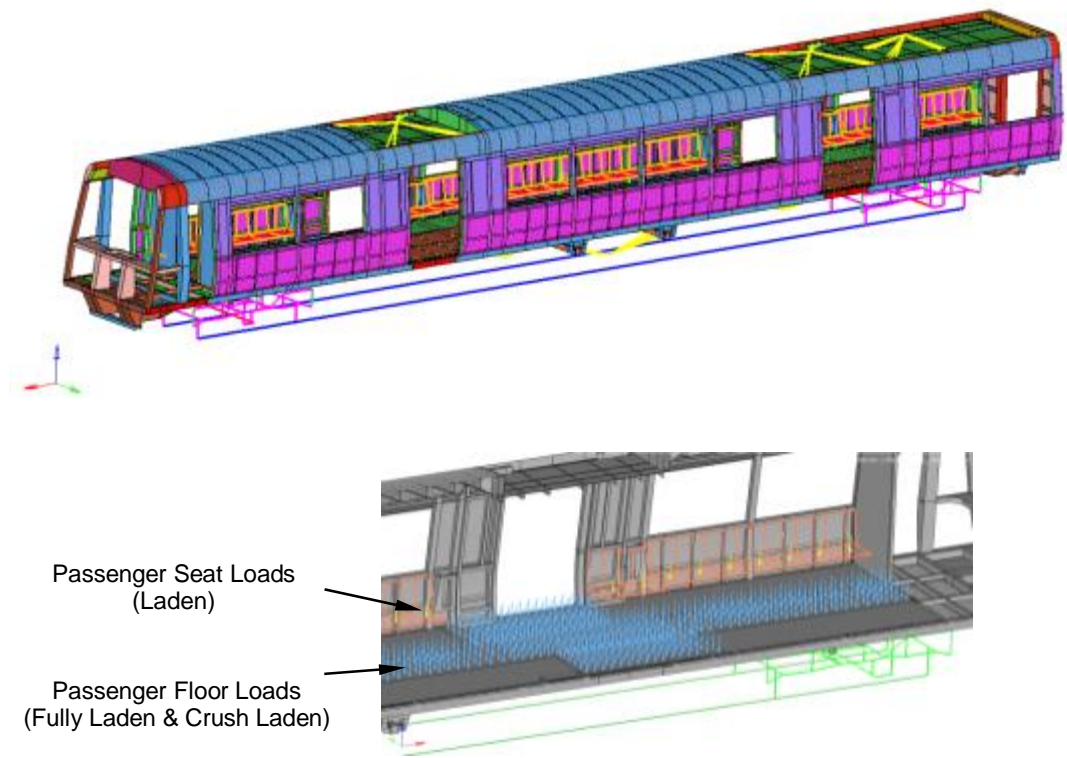
Cumulative Damage calculated for Eurocode 3 Fatigue Detail Categories:

- Category 36: Root cracking of fillet welds
- Category 80: Toe cracking of full penetration welds
 - Stress levels have been factored by $\sqrt{2}$ at the Category 36 features to account for throat thickness.

The vertical load case was assessed against a reduced total cycle number of 10×10^6 cycles as opposed to the 110×10^6 cycles stated in the load case document C3263-001-issue B. The 10×10^6 cycles now used is a value specified in BS EN 12663. Imagery of the FEA model is presented in

Figure 22.

Figure 22 FEA model carbody complete and cutaway section of carbody



6.4 Results

A total of 14 load cases have been analysed:

- | | |
|-----------------------------------|----------------------------------|
| Longitudinal Tare (LNG 1) | Longitudinal Laden (LNG 2) |
| Longitudinal Fully Laden (LNG 3) | Longitudinal Crush Laden (LNG 4) |
| Lateral Tare (LAT 1) | Lateral Laden (LAT 2) |
| Lateral Fully Laden (LAT 3) | Lateral Crush Laden (LAT 4) |
| Vertical Tare (VRT 1) | Vertical Laden (VRT 2) |
| Vertical Fully Laden (VRT 3) | Vertical Crush Laden (VRT 4) |
| Passenger Loading/Unloading (PAS) | Track Twist (TWS) |

Typical stress plots with exaggerated deflections are shown in the Appendix H.

6.4.1 Structural steel framework and surface panelling

From the results it can be seen that the majority of the carbody is lowly stressed. However, there are six areas of the carbody that have been identified as not achieving a fatigue life of 30 years. Of these six areas Table 13 identifies the lowest life found in each area.

Table 13 Summary of fatigue life results for framework and panelling

Location	Location	Weld Class	Worst Load Case	Cumulative Damage	Life (Years)
1	Door Corner Bottom	36	VRT 2	27.02	1.1
2	Cab Back Wall Bottom	36	LAT 2	17.60	1.7
3	Wastrail	36	VRT 2	12.43	2.4
4	Window Stiffener	36	VRT 2	9.72	3.1
5	Door Corner Top	80	VRT 2	9.66	3.1
6	Body Side Column	36	VRT 2	8.60	3.5

6.4.2 Spot welds

The vehicle external skins are spot welded to the supporting structural steel framework using thousands of 6mm spot welds. In total the FEA model contains 12,979 spot welds. The forces in each of the spot welds were returned from the FEA for all 14 load cases.

In total 10 spot welds were found to have a life of less than the 30 year design life requirement. These spot welds were centred on two areas of the vehicle. Of these two areas Table 14 identifies the lowest life found in each area.

Table 14 Summary of fatigue life results for spot welds

Location	Weld Class	Worst Load Case	Cumulative Damage	Life (Years)
Door Corner Top	125	VRT 2	4.86	6.2
Roof Stiffener	36	VRT 2	1.98	15.2

6.4.3 Bolted joints

Two bolted joints have been assessed as structurally critical to the safe operation of the vehicle and therefore requiring fatigue assessment. The critical bolted joints which were considered structurally critical to the vehicle are:

- Centre pin bracket to bolster joint
- Coupler mounting joint

A fatigue analysis of the critical bolted joints has been undertaken. The results suggest that all bolted joints meet the 30 year life requirement.

6.5 Discussion

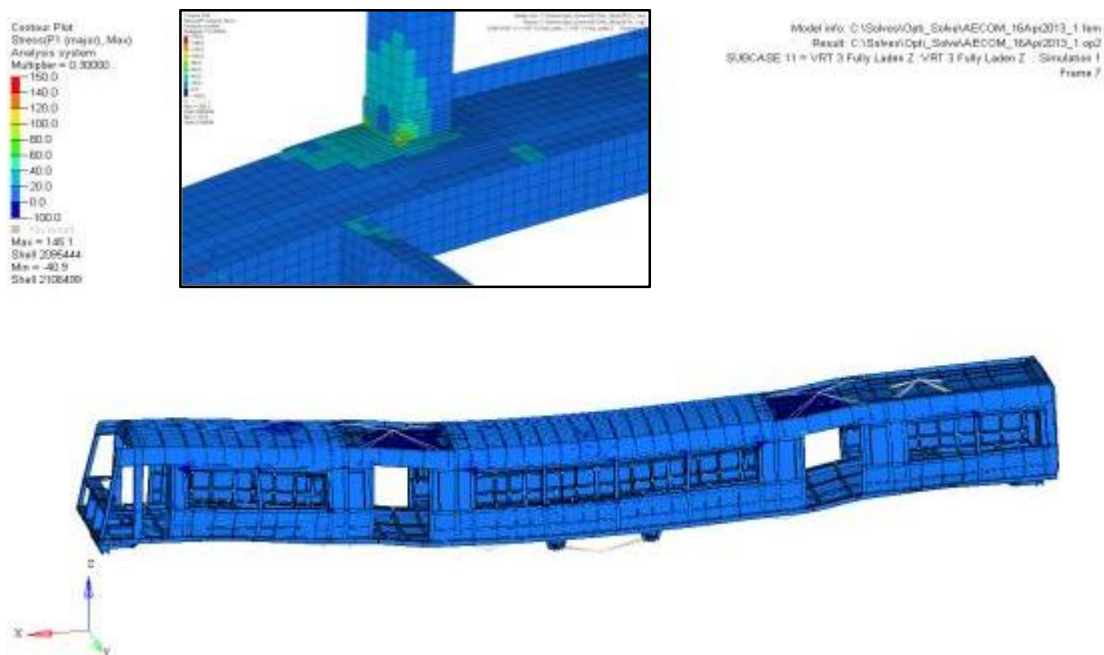
The high stresses identified in the analysis are in locations that are typical of this type of design of carbody. The A Series carbody design suffers from having welds exactly where the geometrical stress concentrations are likely to be. A number of these critical locations are where fillet welds have been used. These welds fall into the lowest weld classification designated by Eurocode 3 of Class 36 for a failure from the throat of the weld.

This design is representative of other carbody designs of the same era. This stress concentration, combined with factors necessary when assessing welds, results in very low life predictions. These vehicles were designed prior to the widespread use of Finite Element Analysis as an engineering tool and today these design features would be avoided.

AECOM has conducted a preliminary inspection to the weld between the base of the door pillar to the solebar (Location 1 see Figure 23). It was observed that there appeared to be a toe dressed weld of approximately 15mm

throat width instead of a 3mm fillet. If the weld throat size becomes significantly larger than the plate thickness then failure through the weld throat becomes unlikely and failure from the weld toe becomes more likely. Based on the geometry we have in this rail vehicle, failure from the weld toe falls into a higher category of Class 80. Changing the classification of the welds from a design specified Class 36 to be re-categorised as Class 80 welds (if confirmed) will return a significantly higher fatigue life.

Figure 23 FEA results Location 1



For this vehicle, the predicted life is very low in the locations identified. Why then, given that the vehicles have already served a 22 year life, have the predicted cracks not appeared, or the train failed catastrophically? There are five possible explanations:

- 1) The train manufacturing does not reflect the design;
- 2) The FEA model does not represent the actual vehicle;
- 3) The loading is too severe, meaning the actual A Series carbody does not see the loadings applied;
- 4) There are cracks present in the vehicle structure but they have not been noticed; or
- 5) The fatigue analysis methodology is too conservative.

6.5.1 The train manufacturing does not reflect the design

It has been observed during an asset inspection that the fillets welds at Location 1 (only 2 welds observed for railcar 236) are not to drawing and are in reality larger than a 3mm fillet, see Figure 24.

Figure 24 Railcar 236 welded joint between door pillar and solebar



It has yet to be confirmed whether the weld is consistent with design, however, if it were the case then this would increase the weld classification to a class 80 for a likely failure through the weld toe instead of the weld root. The weld throat was crudely measured at approximately 15mm at the throat rather than 3mm as prescribed in the design if this were the case this weld would no longer be of concern. Closer inspection of the welds suggests they are toe-dressed and are of a substantially higher strength than identified in the design. It is not yet possible to inspect the welds of Location 2 due to panelling and covers in the door aperture. Figure 25 illustrates the difference which an amendment to weld classification can make to the result.

Figure 25 Effect of weld classification on fatigue life

Fatigue Eurocode 3		Stress [Mpa]			Damage	Damage
		Max	Min	Worst	Class	Class
		Prtn	Prtn		36	80
LNG 1	Longitudinal Tare	0.1	-6.5	6.5	0.00	0.00
LNG 2	Longitudinal Laden	0.1	-6.9	6.9	0.00	0.00
LNG 3	Longitudinal Fully Laden	0.3	-6.9	6.9	0.00	0.00
LNG 4	Longitudinal Crush Laden	0.3	-6.9	6.9	0.00	0.00
LAT 1	Lateral Tare	34.36	-0.6	34.4	0.22	0.00
LAT 2	Lateral Laden	34.4	-0.7	34.4	3.74	0.00
LAT 3	Lateral Fully Laden	32.0	-0.7	32.0	0.28	0.00
LAT 4	Lateral Crush Laden	30.8	-0.7	30.8	0.03	0.00
VRT 1	Vertical Tare	47.2	-1.6	47.2	0.56	0.01
VRT 2	Vertical Laden	54.6	-1.7	54.6	14.97	0.21
VRT 3	Vertical Fully Laden	74.7	-2.3	74.7	3.57	0.09
VRT 4	Vertical Crush Laden	84.6	-2.4	84.6	0.65	0.02
PAS	Passenger Loading/Unloading	124.4	-2.8	124.4	1.57	0.00
TWS	Track Twist	0.4	-54.2	54.2	1.43	0.02
BLD	Lateral Damper	0.1	0.0	0.1	0.00	0.00
Cumulative damage					27.02	0.35
Years					1.1	86.2

6.5.2 The FEA model does not represent the actual vehicle.

The FEA model has been checked and is believed to be a true representation of the drawings/information supplied, with a mass distribution in accordance with the mass data supplied. It would be evident in the photo imagery that exists if there is significant additional structure on the vehicles that is not represented in the drawings and there appears to be no such evidence

6.5.3 The loading is too severe, meaning the actual A-series carbody does not see the loadings applied

It is possible that the track condition is sufficiently good and is maintained to such levels throughout the vehicle life, such that the inertia loads experienced in reality are much lower than that stated in the European standard

It is also possible that the vehicle does not experience the patronage levels which were input to the modelling simulation. AECOM has been able to consider the effects of differing the passenger loadings and passenger mass distribution on fatigue life.

It is understood that any reduction in stress to the carbody will have a cubic effect on the damage incurred. Therefore accuracy of inputs is critically important.

Figure 26 Adjustment to passenger mass and passenger loading

Previous				New Data				
Load Case	Mass Condition	Acceleration	Number of cycles	Load Case	Mass Condition	Acceleration	Number of cycles	
1	Tare	±0.15g	3.1 x 10 ⁶	1	Tare	±0.15g	0.5 x 10⁶	
2	Laden	±0.15g	3.0 x 10 ⁶	2	Laden	±0.15g	8.6 x 10⁶	
3	Fully Laden	±0.15g	3.0 x 10 ⁶	3	Fully Laden	±0.15g	0.8 x 10⁶	
4	Crush Laden	±0.15g	0.9 x 10 ⁶	4	Crush Laden	±0.15g	0.1 x 10⁶	
			Total Cycles				Total Cycles	10 x 10 ⁶

Previous				New Data				
Load Case	Mass Condition	Vertical Acceleration (Z-Axis)	Number of cycles	Load Case	Mass Condition	Vertical Acceleration (Z-Axis)	Number of cycles	
PAS 1.1	0.33 x Crush	- 1g	1 x 10 ⁶	PAS 1.1	0.33 x Crush	- 1g	1.98 x 10⁶	
PAS 1.2	0.50 x Crush	- 1g	0.5 x 10 ⁶	PAS 1.2	0.50 x Crush	- 1g	6.80 x 10³	
PAS 1.3	0.66 x Crush	- 1g	0.3 x 10 ⁶	PAS 1.3	0.66 x Crush	- 1g	5.40 x 10³	
PAS 1.4	0.83 x Crush	- 1g	0.12 x 10 ⁶	PAS 1.4	0.83 x Crush	- 1g	2.20 x 10³	
PAS 1.5	1.00 x Crush	- 1g	0.08 x 10 ⁶	PAS 1.5	1.00 x Crush	- 1g	1.00 x 10³	
			Total Cycles				Total Cycles	2 x 10 ⁶

The results of the adjustments presented in Figure 26 show a marginal improvement in fatigue life:

- Location 1 – Life increase to 1.1 years from 0.7 years.
- Location 2 – Life increase to 3.3 years from 2.6 years.

The reduction has arisen due to the reduction in the higher passenger density values; however, there has not been a significant reduction as the total number of cycles has not reduced.

The following inputs are likely to impact the result of the fatigue life study:

- Unit mass and distribution;
- Underframe component mass and location;
- Vertical inertia accelerations; and,
- Number of cycles.

6.5.4 There are cracks present in the vehicle structure which have not been noticed

It is possible that cracks are present and have not been noticed. The cracks may have relieved the concentrated initial stresses and propagation has not been as excessive since. It should be noted that, it is possible for cracks to have developed in the door corners without propagating to a significant extent once the initial stress concentration has been relieved. These cracks may not noticeably affect the overall structural performance of the vehicle.

The Central Line 92TS experienced greater than expected loading during the first years of operation. It incurred fatigue cracking to the door aperture corners and saloon window surrounds. Cracks appeared during the first 5 years of operation and the fleet was put on a frequent monitoring programme although it continued in operation. The 92 TS is still in operation today and carries far greater load than its design had ever intended. London Underground is considered to be a particularly cautious and conservative operator and have not seen evidence of crack propagation to the extent that railcars should be removed from service. It is believed that the initial cracking which occurred relieved the concentrated stresses without catastrophic failure.

It is understood that the Locations 1 and 2 as identified in this results section have not been closely inspected for cracks and many railcars may never have had the panelling around the doors removed as it is not required for any of the planned maintenance or overhaul interventions.

6.5.5 Fatigue analysis methodology is too conservative

SN curves contained in Eurocode 3, [Ref. 2], have an inherent amount of conservatism built in to ensure safe design. Part of the SN curve conservatism stems from the fact the standard needs to cover all types of steel. In this case stainless steel is modelled which has a high ultimate tensile strength to yield ratio and may therefore be more resistant to crack initiation and propagation.

6.5.6 Further actions

Actions to identify the correct explanation or combination of explanations are:

- 1) Identify those highly stressed areas which are life limiting for each of the study Option life spans.
- 2) The proposed work outlined as Phase 2 in the project plan is embodied. This will allow the high stress areas of the carbody identified during this analysis to be strain gauged so that more accurate life predictions based on actual vehicle loadings can be made. The findings of this work will also allow adjustment of the FEA based load cases if the on track loadings are significantly different to those estimated.
- 3) The areas of the vehicle where this report has identified a life lower than the 30 year design life should be subject to inspections and non-destructive testing for the presence of cracking. This includes the spot welds.
- 4) It is recommended that a thorough dimensional investigation using a weld gauge is carried out for the critical welds identified in this report. This may allow the Class 36 welds to be re-categorised as Class 80 welds, which will return a significantly higher fatigue life in these areas.
- 5) Review the input assumptions and seek to better the accuracy through improved measurement or calculation techniques.

6.6 Market Analysis

During the course of the study feedback was sought regarding the asset life potential of stainless steel rolling stock fleets. Discussions were held with the operators, engineers (present and former) and other persons knowledgeable in fleet operation. Research suggests that rolling stock employing stainless steel carbodies are observed generally to exceed the intended design life.

QR EMU

A sample corrosion assessment report of the QR EMU fleet has been reviewed and it is reported that the results show that the structural areas of the undercarriage of the car and metallic integrity is excellent. Test results show that none of the side sills, head stocks, bolsters show signs of corrosion. The floor did show signs of corrosion particularly in the area of the headstock and backing bar, however these areas are not reported to be of structural importance to the railcars. The QR EMUs are in the order of 34 years old and since a new rolling stock order has not yet been placed, the railcars are likely to remain in operation until they are in the order of 40 years old. Recommended treatments are patch repairs to the corroded carbon steel areas of floor and headstock, as well as installation of secondary retention systems to the underframe equipment boxes.

It is known that the A-series design uses a greater proportion of stainless steel in the exterior panelling and for the underframe too. Whilst the QR EMUs are reported to be in a good state of health for the age, corrosion of the underframe is evident (see Appendix I). Corrosion of the underframe is not expected to pose a similar risk to the A-series railcars due to the incorporation of stainless steel throughout the underframe and an argument could be made that the railcars would achieve a better service life by comparison as a result of this and the less precipitous conditions in Perth by comparison to Brisbane.

Philadelphia Area Transit Company (PATCO)

Companies Budd and Vickers built 120 stainless steel cars in the late 60's/early 70's comprising of single cars, married cars, and Budd English cars. A refurbishment was recently undertaken where the scope was largely driven by obsolescence in equipment such as the braking logics, traction systems, EP braking system and also by the necessity to improve reliability, maintainability, and availability.

The inspection of railcars found:

- The stainless steel carbodies in good condition with no corrosion despite extreme temperatures, high salinity levels due to gritting and road salt and high moisture levels.
- The carbody welding was not to design standards, some ring welding at brackets on side and centre sill show signs of crack propagation but not significant
- NDT performed on bogies to confirm continued use
- The secondary structure had bridging plates inserted. Huckling/pop riveting was performed instead of welding to protect the carbody

The life extension expectancy is a further 15-20 years of operation post refurbishment.

It should be noted that railcars manufactured by Budd in the United States are known to be heavily built units of unreserved strength and mass.

VIA Rail Diesel Cars

The Rail Diesel Car (RDC) overhaul project formed part of a US\$907 million VIA Rail capital investment project.

The RDCs operate as 2 three car units and they are constructed of stainless steel carbodies. The RDCs were built in 1949 – 1962 by the Budd Company of Philadelphia, Pennsylvania and have been operating far beyond their intended design life of 30 years. The railcars are used in low density, short passenger/commuter areas. The RDC Fleet Rebuild Project is considered the first major overhaul project where the cars were stripped back to the carbodies and structural assessments were performed. Major system enhancements were also undertaken.

Structural evaluation revealed that the stainless steel carbodies were considered in good condition for their age with no signs of corrosion despite Canada's harsh conditions of snow, rain and extreme temperature differences. Fatigue cracking to the side sill was found and it was determined this had been mainly caused by conducting poor weld repairs and lack of temperature control. It was noted that the structural members of the cars were constructed with stainless steel of 201 and 301 types. To prevent future propagation of cracks due to welding, stainless steel splices were reinforced by huck bolts at critical locations.

The design life of the cars following the refurbishment/life extension works is expected to be 40 – 50 years, compared to an estimated 40 year design life for carbon steel or aluminium replacement railcars.

6.7 Conclusions

The following conclusions are made in light of the FEA fatigue modelling which has been undertaken:

- The fatigue life of the A-series trains has been predicted to be extremely short at just over one year for the worst case location;
- The present life of the A-series railcars far exceeds the predicted fatigue life from the FEA analysis;
- The carbody design concentrates stresses in the jointed areas;
- The majority of the carbody is lowly stressed; and,
- The following explanations are given for the distinctly short fatigue life result generated by the fatigue life modelling:
 - Manufacturing processes have differed from design;
 - Inaccuracy in the FEA model;
 - Inaccuracy in the model inputs;
 - The A-series railcars have already experienced fatigue cracking; and,
 - The fatigue analysis methodology is too conservative.

6.8 Recommendations

These recommendations are made on the basis of the results retrieved:

- Inspect the carbody for cracks in the locations identified;
- Validate the accuracy of the input loads by the following courses:
 - Train mass and CoG – accurate weighing of railcars;
 - Component underframe masses – accurate weighing of masses;
 - Vertical inertia – acceleration testing as described in Phase 2;
 - Experienced stresses and strains – strain gauge testing; and,
 - Measurement of the weld sizes in high stress locations.
- Non-destructive testing of high stress areas such as dye pen and ultrasonics for surface and sub-surface cracks

7.0 Part Two - Options Analysis and Discussion

The following sub-sections of the report discuss the alternative options available for the A-series fleet. A concise comparison of each of the Options with one another is provided in Section 9 which considers cost, strategic risk and schedules as well as other factors.

The items discussed and opinions expressed in this section of the report are based on the analysis conducted and findings outlined throughout Part One of the report.

The Options being considered are as follows:

- Straight replacement at end of service life;
- Life with existing technology and or minor enhancements of the railcar; and,
- Re-engineering life.

The implications of these Options on the design life of the railcars are provided in Table 15, below:

Table 15 Options definition

Option Number	Ref	Title	Duration of extension (years)	Operating life	Year extended to
Option 1	1	Design life expiry	N/A	30	2021
Option 2	2a	Life extension (Minor mods)	5	35	2026
	2b	Life extension (Minor mods)	10	40	2031
Option 3	3a	Life extension (Re-engineering life)	20	50	2041
	3b	Life extension (Re-engineering life)			

All costs obtained during the course of this study should be considered as 'budget estimates' accurate to $\pm 30\%$. A comprehensive list of the assumptions which apply to the costs presented in this report in Section 3.

Each of the options is discussed in the following areas:

Assumptions – those specific to the Option and which costs or schedules are based;

Asset health – those recommendations which are pertinent to maintaining a consistent level of asset health at the same level as currently found on the fleet;

Market analysis – those findings from research and case studies which are relevant to the Option;

Reliability, availability and target meeting – how the Option is expected to perform in future;

New rolling stock introduction – the impact of new rolling stock introduction on the Option; and,

Cost analysis – an appraisal of the cost of the Option.

It is assumed where there are works which are expected to be included in the existing scope of works for the maintenance contractor they are presented as nil cost to PTA in the following sections. Where ultimate contractual responsibility is unclear for any of the Options (PTA or maintenance contractor), the values for those scope activities have been applied to the PTA cost model to maintain a reasonable level of conservatism.

7.1 Option 1 – Straight Replacement at End of Service Life

The first 43 railcars of the A-series fleet were delivered from 1991 and are over twenty years in to their intended design life. If there is no extension to the operation of the A-series, a planned replacement at the end of the intended design life is likely to take place in a further 8-10 years.

Since the results of the Phase 1 FEA study suggest that the carbody has already exceeded its fatigue life, continued operation of the A-series should be undertaken with due diligence. The recommendations presented in Section 6 should be carried out in order to validate the desk top fatigue life analysis and determine the level of risk inherent with continued operation of the A-series.

7.1.1 Assumptions

The following assumptions are made in the context of replacing the A-series at the end of its design life:

- Rolling stock capacity expansion (New rolling stock) will be required from 2018. Replacement railcars are phased in with replacement rolling stock – New rolling stock;
- New rolling stock will require new maintenance facilities;
- Both the first and second batch of the A-series railcars will be decommissioned in the same programme;
- The A-series will be life expired from 2021, decommissioning is necessary before this date.

7.1.2 Asset health

During the completion of this study AECOM has conducted a series of asset inspections, and completed discussions with reliability, fleet engineers and maintainers from PTA and the Maintenance Service provider. Further reliability analysis has been undertaken in order to understand the present state of health of the A series and the likely future performance.

It was deemed an objective to identify the initiatives and practices which would most likely maintain the existing reliability with low financial investment to complete the period of operation associated with Option 1.

AECOM understands that the overhaul activities, as listed in Table 16 are likely to be undertaken during the remaining term of the maintenance contract:

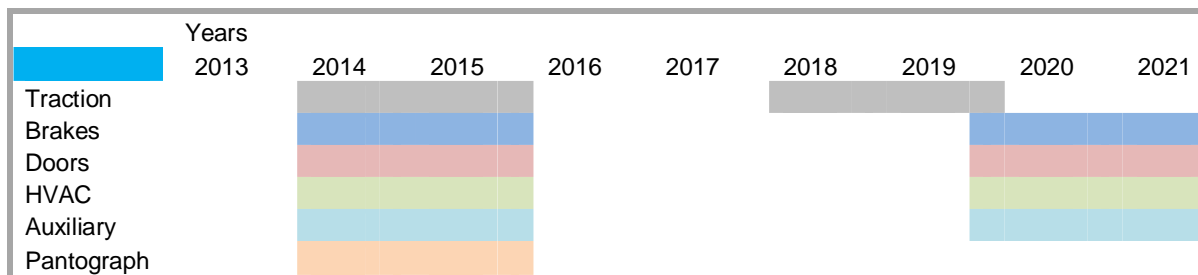
Table 16 Overhaul activities in current contract

Overhaul Activity	
Main circuit breaker	Dampers
Pantograph	Brake disc, motor & trailer
Gearbox	Bogie, motor & trailer
HVAC	Air compressor
Power/Brake controller	Air boxes
Driver's console	Air dryer
Traction control system	Brake calliper
External passenger doors – heavy (door leaf not included)	EBC5 brake rack
Gangway doors – heavy (bellow not included)	Brake system - valves, cocks, general
Cab doors (door leaf not included)	Auxiliary converter
Driver's seat	Automatic coupler
Main transformer	Semi-permanent coupler
Thyristor converter	Auxiliary transformer / reactor
Contact box (does not include overhaul of internal components)	PFC unit
Auxiliary relay box (does not include overhaul of internal components)	Wheelsets
Brake resistor	Traction motor – rewound on condition basis

Based on the information provided to AECOM during the course of this study, it is believed the total material and labour cost for the activities described in Table 16 over the contract life is in the order of AU\$36 million which is believed to be absorbed by the maintenance contractor under the terms of the existing maintenance contract.

An overhaul programme projection is presented in Figure 27. It can be observed that the overhauls conducted during the 2014 to 2015 period will alleviate the planned requirement for heavy maintenance until 2018/2019 in the case of the traction motors and later still for the other train systems.

Figure 27 Projected overhaul programme to be conducted by maintenance contractor



From the analysis conducted AECOM is able to propose that the following programmes be considered in the event that the railcars are to be decommissioned at the end of the design:

Recommendations

- Avoid deferring maintenance, specifically component overhauls;
- Conduct a RCM programme in order to identify appropriate maintenance periodicities;
- Initiate a periodic fleet check (including ultrasonics) for bogie cracking;
- Initiate a periodic fleet check of underframe equipment case integrity ;
- Initiate a periodic fleet check (including NDT and ultrasonics) of Transformer and Auxiliary case brackets and fixings ;
- Rectify manufacturing quality/design issues with door leaf design;
- Gearbox oil sample testing on a routine basis;
- Conduct sample checks of electrical insulation;
- Conduct structural analysis through NDT and strain testing of a sample carbody;
- Inspect motor pinion shaft for pitting, score marks and damage as part of the gearbox overhaul;
- Undertake sample NDT testing and ultrasonic analysis of bogie structure; and,
- Improve traction motor overhaul programme time through sourcing from an expanding supplier network.

Detailed findings of the asset health assessment are described in Section 5.7 Technical Summary and Appendix B.

7.1.3 Market analysis

The QR EMU fleet is nominally 10 years older than the A-series and there is commonality in some system design, technology and performance. The QR EMU is considered to act as a reasonable projection of potential future issues which could be experienced by the A-series. A full case study of the QR EMU life extension was provided as part of this study for review and consideration. A few key points which should be reviewed in the context of the A-series railcar study are summarised below, and these should be considered by PTA when developing programmes for continuing operation of the A-series:

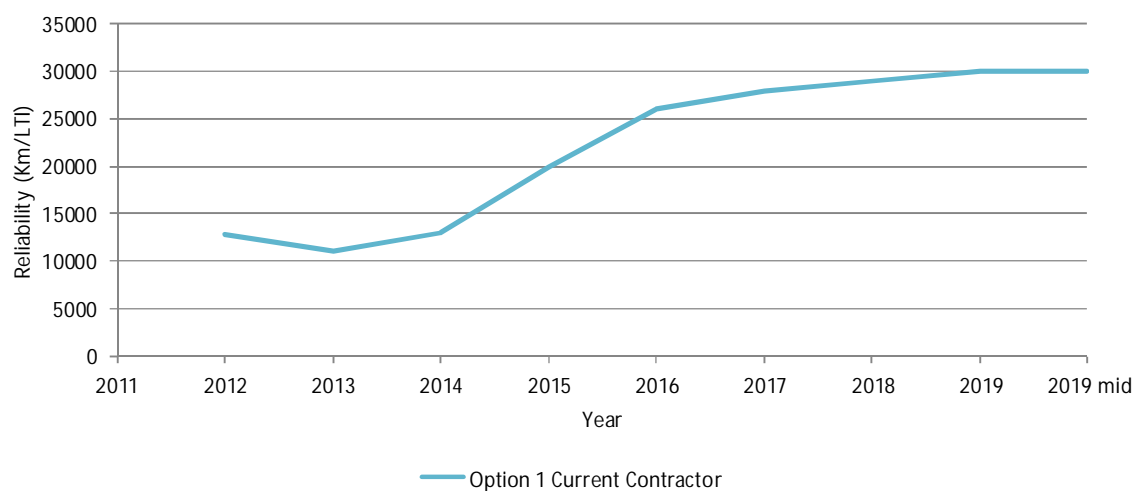
- There is commonality in the carbody structure and service duty, QR EMUs show no evidence of fatigue in the carbody structure which would typically be evidenced by cracking;
- Bogie frames differ between the fleets, however QR reports no fatigue issues;

- Gear box leakages confined to only one railcar;
- Door issues are consistent with age and those experienced on the A-series (see Appendix B);
- Traction motors are clean and in good condition, modifications have been made to brush springs to improve reliability;
- Large quantity of capacitors leaking and/or melting;
- Traction control relays and electronic control equipment are now obsolete, investigations for replacements are being undertaken;
- Some problems experienced with battery charger (experienced also with A-series);
- New compressors are being installed;
- Minor corrosion evident on roof, extensive surface corrosion to underframe (notably the QR EMUs feature carbon steel underframes);
- Underframe fixings experiencing extensive wear and bending; and,
- Corrosion present inside HVAC ducting.

7.1.4 Reliability and availability target achievement

Predictions for future reliability are difficult to make based on historic performance data. The maintenance contract has been in place for a 12 month period and reliability targets are not yet being achieved. It is understood that the maintenance service provider is undertaking a series of reliability improvement plans and initiating a component overhaul programme to rejuvenate system performance. It is predicted reliability will steadily increase over the next five years until targets are achieved and then experience steady state til the end of the current maintenance contract in mid-2019. This prediction is illustrated with the predicted reliability curves in Figure 28 for the A-series.

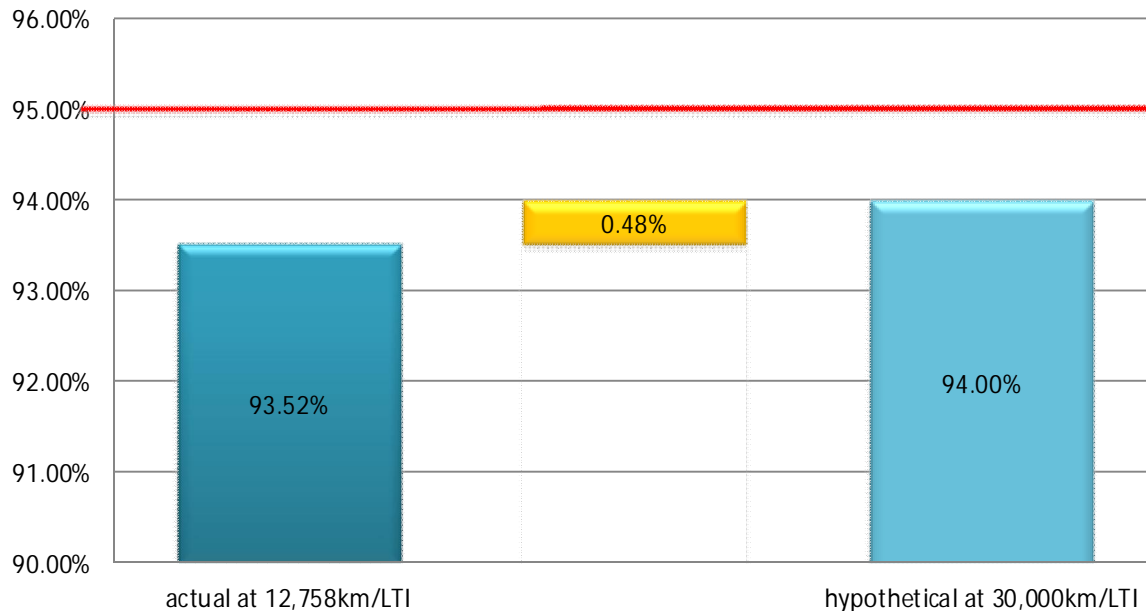
Figure 28 Option 1 (Replacement mid-2019) Expected Reliability under Current Maintenance Contract



An indicative reliability curve has been projected for the A-series in Figure 28 during the remaining period of the assets design life. The curve tracks what is expected to be the likely achievable reliability growth of the A-series based on the works being undertaken and forecasted for the assets (as discussed in Section 5.4).

The subsequent effect of achieving the current and the forecasted 30,000 km per LTI is displayed in Figure 29 for ≥ 4 mins.

Figure 29 Effect of Reliability Improvements on Operational Performance (LTIs measured as ≥ 4 mins)



It is evident that achieving a reliability of 30,000 km for the A-series rolling stock is not sufficient for a target of on-time running of 95% to be accomplished.

7.1.5 Maintenance contract

In order to adhere to the intended design life of the assets, the A-series fleet would commence decommissioning from 2021. The existing maintenance regime includes a contractual break option period in June 2019, whereby the contract can be terminated by PTA or continued for another 7.5 years (PTA is required to provide the maintainer with its intentions six months prior to the maintenance contract break point). Comparing the timescales for the maintenance contract and design life of the A-series it is apparent that the two do not align. There are two reasonable alternatives for fleet decommissioning listed below:

Alternative 1 Decommission the fleet at 30 years of service; and,

Alternative 2 Decommission the fleet prior to 30 years of service.

Alternative 1 leads to a period of 1.5 years or greater whereby the A-series maintenance will need to be supported by a contract or party different than that which is presently employed. Contractual complexity, availability of maintainers, training and other issues may discourage this tactic.

Alternative 2 means that the full design life of the asset is not achieved, however the risks associated with continued maintenance support of the railcars are avoided if the A-series is phased out during the existing maintenance contract.

7.1.6 New rolling stock introduction

It is understood that the B-series is not a suitable replacement for the A-series without modification. It is therefore expected that the phase out of the A-series will be synchronised with the phasing-in of a new rolling stock fleet, designed for operation on the heritage lines.

PTA has reported that a new rolling stock fleet will be required to serve the growing service demand in the future.

The introduction of new rolling stock could provide a reasonable opportunity for PTA to decommission the A-series. There are likely to be two significant capital investments associated with new rolling stock introduction:

- Procurement of the rolling stock; and,

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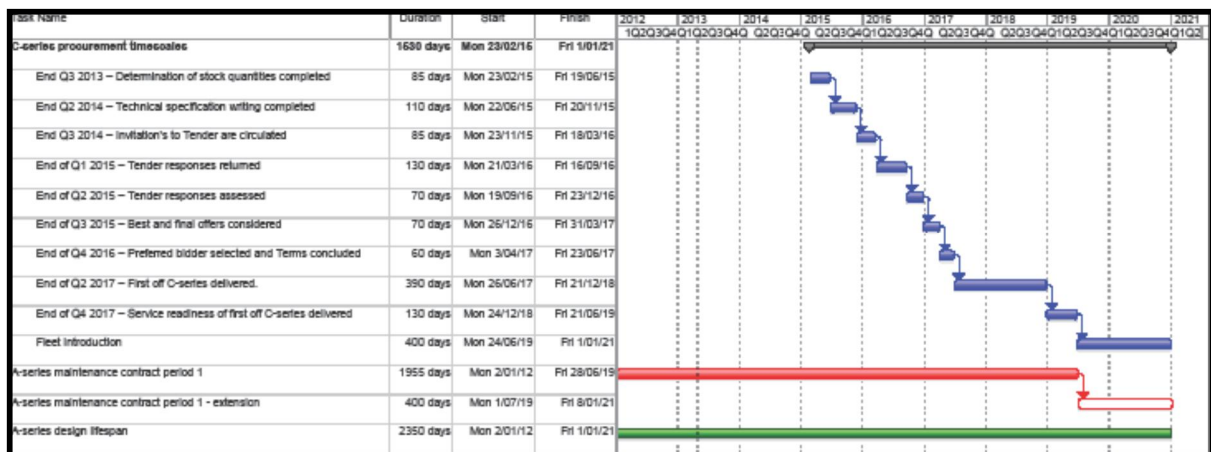
- New rolling stock is most likely to require a new maintenance facility.

Both items above inherit additional risk if the A-series fleet's operation is continued in parallel with new rolling stock. In the case of the procurement of new rolling stock, more sizable order quantities are likely to return better financial terms for PTA due to economies of scale. In the case of the maintenance facilities, a future depot would require facilities and plant which is compatible with both rolling stock types, A-series and new rolling stock. These issues are mitigated by phasing out the A-series fleet during the commissioning of a new rolling stock fleet.

7.1.7 Schedule of works

A schedule of these activities is demonstrated in Figure 30.

Figure 30 Projected schedules for Option 1



7.1.8 Cost analysis

It should be noted that due to the conditions of the existing maintenance contract, that many of the initiatives discussed in Section 7.1.2 is likely to be undertaken by the maintenance service provider under the terms of the existing maintenance regime. Indicative costs for Option 1 are presented in Table 17

Table 17 Indicative costs for Option 1

Option 1 Maintenance contract	Indicative cost for maintenance contract (\$AUD)	Notes on costing assumption
Completion of the contract to mid-2019 including contingency	\$102,362,050	Based on current maintenance contract option pricing and all other works being undertaken by maintenance service provider
Completion of the maintenance contract to 2021	\$38,982,750	Extension of maintenance contract cost for 18 months
Total	\$141,344,800	

7.2 Option 2 – Life with Existing Technology and or Minor Enhancements of the Railcar

During discussions with PTA, Option 2 – life with existing technology and or minor enhancements is considered to mean the operation of the assets beyond the specified design life until such time the units are reasonably expired and is to be achieved through minimal financial investment. To this end a life extension of five to ten years is considered a reasonable term for continued operation of the A-series with low financial investment in performance and asset health modifications.

Two particular life extensions were selected for Option 2 since they coincide with planned major maintenance intervals, maintenance contract duration and other such events.

- Option 2a – 5 year extension beyond 30 years (life expiry 2026)
- Option 2b – 10 year extension beyond 30 years (life expiry 2031)

The directive for Option 2a is that an extension to design life of five years is achieved by undertaking critical investments to sustain the operation of the A-series railcars through maintaining safety systems and realising satisfactory reliability levels succinct with on-time running targets.

The directive employed for Option 2b is that a longer asset life extension to 10 years beyond design life (40 year service life) would warrant modifications to improve the A-series image and public perception through aesthetic improvements as well as undertaking the works required to maintain appropriate safety and reliability levels.

The results of the Phase 1 FEA fatigue life study are set aside during the discussion of this Option. The results will ultimately have significant bearing on the feasibility of Option 2, but validation of the results should be sought through practical testing before omitting Option 2 from consideration entirely.

7.2.1 Assumptions

The following assumptions are made in the context of a minor (5-10) year life extension of the A-series railcars:

- B-series railcars currently on order will facilitate rolling stock capacity expansion in the near future and new rolling stock procurement can be postponed until 2025;
- B-series railcars are not a suitable replacement for the A-series;
- Replacement railcars are phased in with replacement where timescales align rolling stock – New rolling stock;
- New rolling stock will require new maintenance facilities;
- It is assumed that both the first and second batch will be decommissioned in the same programme; and,
- Option 2 employs the same reliability predictions as used for Option 1 until 2021, thereafter further analysis was undertaken to predict future events.

7.2.2 Asset health

Section 7.1.2 describes the recommended practices to maintain good asset health for the period of operation up to 2021 (end of intended design life of the A-series). Option 2 is broken down into two possible sub-options, and the recommendations for continued operation and justification for inclusions are further defined below.

7.2.2.1 Option 2a – 5 year life extension

The objective of employing the recommendations below is to preserve the reliability of the railcars for a short to medium term period.

In addition to the recommendations and requirements prescribed in Option 1, the following practices should be applied:

Recommendations

It is recommended the following activities should be implemented in addition to the activities outlined in Option 1:

- All DC traction motor armatures should be re-wound with new main and equaliser coils. During overhaul it is recommended that traction motors undergo motor pinion shaft inspections and testing in order to verify longevity of the motors.

- The auxiliary converters are of an age where it would benefit from regular minor overhauls between major overhauls resulting in an improved reliability of the system for an additional 5-10 years beyond design life. The materials required in supporting this programme are currently in stock at Claisebrook.
- The fan motors and control components of the HVAC system be replaced to maintain the life of the system. Condenser coils should be replaced on a condition basis.
- Smoke detection (VESDA) on board has been investigated previously, but not implemented. This is a result of development of system design over time resulting in various challenges for VESDA installation such as enabling communication between railcars. PTA has informed AECOM that it is their present understanding that smoke detection is not a requirement of DDA compliance on legacy rolling stock. However provision of VESDA should be revisited for the A-series fleet, since it is becoming a standard installation on modern rolling stock including the B-series. It will reduce asset loss risk from arson, increase passenger safety from fire, and reduce service disruption caused by overheating electrical equipment.
- LED saloon and dashboard lighting will generate improved illumination in comparison to the current incandescent lighting used which should in turn improve passenger and driver comfort. CAPEX costs associated with LED fittings are likely to be countered by a far greater lifespan and reduced energy usage leading to reduced OPEX costs. Custom fit LED saloon and cab lighting are readily available. Diffusers should also be replaced and are available from the OEM.
- The emergency door release is currently located above the passenger doors and may require relocation to provide better accessibility to people with reduced mobility. The DDA requirements are subject to interpretation and PTA is recommended to approach the DDA council to seek clarity.
- The current AM/FM radio has always had reception issues as a result of the overhead wiring; replacement with better reception should enhance driver comfort and may indirectly reduce driver related LTIs (cost not sought).
- Condition based replacement of underframe equipment cases for those suffering exceptional corrosion and/or significant wear. For those boxes being replaced it would be advisable to integrate a secondary retention system into the equipment case design.
- It is assumed that for this Option an interior refurbishment will be required. The scope of the interior refurbishment is assumed to form part of the existing maintenance scope and thereby nil cost is incurred by PTA. However, it is noted that the period of extension associated with Option 2b may require further modifications to the interior in order to comply with relevant DDA requirements.

Table 18 shows the individual and cumulative total cost for the modifications and practices recommended above.

Table 18 Option 2a - Life extension of 5 years

Minor upgrades and modifications with existing technology	Indicative cost to PTA for materials and labour (\$AUD)	Notes on costing assumption
Re-wind existing DC traction motors fleet wide*	\$4,752,000	Scope of maintenance contract
Perform minor overhaul of auxiliary systems every 840,000km. To include replacement of capacitors, circuit breakers, thyristors, and circuit discs	\$192,000 (Material only)	Assumed that maintainer will bear labour costs and PTA to provide equipment. Schedule aligned with brake system overhauls leading to shared gains for both parties.
On HVACs, replace fan motors and control components fleet wide, and replace condenser coils where necessary	\$287,000	Assumed that maintainer will bear labour costs for removing and attaching HVAC unit, and PTA to provide equipment and offsite labour costs. Schedule aligned with brake system overhauls leading to shared gains for both parties.
On board smoke detection – Very Early Smoke Detection Apparatus (VESDA)	\$576,000	\$6000 material per VESDA, 80 labour hours per railcar
LED saloon lighting	\$493,000	Quotation supplied by ART (see Appendix G) 5 hours per railcar – to confirm cost with supplier
LED dashboard lighting	\$116,000	Quotation supplied by ART (see Appendix G) 90 minutes per railcar using two technicians.
Relocation of the emergency door release	\$348,000	Relocated to the side of door and 32 hours for installation per railcar
Condition based replacement of underframe equipment boxes	\$317,000	Assume 2 boxes replaced per year suffering exceptional corrosion over last 5 years, 80 hours per box
Contingency at 15%	\$1,066,000	
Total Additional Cost to PTA	\$8,172,000	

* The cost associated with the traction motor re-wind covers 30% of the fleet, since an estimated 70% of motors are provisioned for in the F-service presently.

Improvements to the activities recommended in Option 1, which should feature in a standard scope of works for a 5 year life extension are identified below:

- Conduct structural analysis through NDT and strain testing of carbody this should also include destructive testing of welded joints to determine S-N curves;
- Conduct testing of the motor pinion shaft to analyse structural integrity; and,
- Conduct fatigue life analysis of bogie.

7.2.2.2 Options 2b – 10 year life extension

Recommendations

Option 2B builds upon the enhancements and improvement programmes defined for Option 2a and seeks to enhance the aesthetic impression of the railcars through low cost initiatives to improve passenger perception of the aged railcars.

This is a process which was fundamentally applied by New Zealand Rail Limited from 1993 upon acquisition of the ADL class DMU fleet formerly of Perth. The railcars, originally manufactured in the early 1980's were purchased by NZR in 1993, in 2002 the railcars received a refurbishment focussed on enhancing the aesthetic appearance of the railcars through facelifting the frontage (new GRP), new seat moquettes, new interiors (grab poles and flooring), electric destination displays and painting of exterior body shells. The investment of approximately \$8.8 AU (\$8.5M NZ in 2003, allowing for exchange rate and inflation adjustments) for the refurbishment works, the railcars were received by the public as if they were new trains.

The recommendations for modifications and improvement programmes pertinent to extending A-series life by 10 years of service operation are identified below:

- Installation of a cab HVAC will provide conditioned air directly to the cab, improving the climate control of the cab environment and improving the ambience for driver comfort. This may also prevent associated workers union disputes in regards to this issue particularly throughout summer periods.
- Traction brake controller upgrade to improve sensitivity. The controllers are reported to be 'notchy' and inconsistent between railcars and during the course.
- Modernisation of the cab frontage will improve and enhance the aesthetics of the fleet markedly. It may also give rise to increased patronage and acknowledgment of the PTA in their role of provider of public transport to the community. The estimates for cab frontage development are based on the values available for the B-series GRP.
- The A-series design does not incorporate anti-climbers on the carbody/cab. Anti-climbers are a safety feature inherent in the design of most modern rolling stock which aid in reducing the risk of one car riding over a second car during collisions subsequently reducing the risk of injury to passengers during such events.
- It is understood that vacuum circuit breakers (VCB) have not been overhauled since commissioning and should be replaced or overhauled periodically due to their age under this option.
- Fleet wide installation of secondary retention to the underframe equipment cases to improve security of equipment cases (cost not sought).
- It is expected that only minor modifications to the headstock and solebars will be required and this work could be incorporated into the development of a modernised cab frontage.

Table 19 Option 2b - Life extension of 10 years

Minor upgrades and modifications with existing technology	Indicative cost for materials and labour (\$AUD)	Notes on Costing Assumption
Option 2A 5 year minor upgrades and modifications	\$7,324,000	Accounts for additional Auxiliary Converter minor overhauls (\$218k)
New cab frontage	\$5,360,000	Labour at 80 man-hours per cab end
Installation of cab HVAC	\$2,144,000	Excludes ducting materials and assumes 155 hours per HVAC unit
Anti-climbers	\$696,000 (material cost only)	Does not account for potential additional modification to sole bar
Vacuum Circuit Breakers	\$2,008,000	3 hours per unit, to be done during planned maintenance
Traction controller	\$2,328,000 (material cost only)	Excludes installation cost
Contingency at 15%	\$2,979,000	
Total Cost to PTA	\$22,839,000	

7.2.3 Market analysis

The QR EMU fleet was introduced from 1979 and are approaching 35 years of service operation. The fleet will continue in operation until replacement rolling stock is sought. 75 six-car units are expected to replace the existing EMUs, though new rolling stock is not expected to be available until the beginning of 2017 at the earliest if a

contract is commissioned in late 2013. By this time the existing QR EMU fleet will be approaching 40 years of age. There is no indication that timescales for new rolling stock procurement are being hurried due to degraded condition of the existing stock. Due to the similarities existing in the QR EMU fleet and the A-series it would be reasonable to assume that the A-series should achieve a similar lifespan. It is known that the A-series design uses a greater proportion of stainless steel in the exterior panelling and certainly for the underframe. Whilst the QR EMUs are reported to be in a good state of health for the age, corrosion of the underframe is evident (see Appendix I). Corrosion of the underframe is not expected to pose a similar risk to the A-series railcars due to the employment of stainless steel throughout the underframe and an argument could be made that the railcars would achieve a better service life by comparison as a result of this and the less precipitous conditions in Perth by comparison to Brisbane.

The reliability of the QR EMU fleet is noticeably less than that of the A-series EMU fleet which is perhaps partly due to the fleet's age. The QR EMUs achieve in the order of 8,000 km per LTI (where an LTI is a delay even of greater than or equal to five minutes).

7.2.4 Reliability and availability target achievement

It is unlikely the works proposed for Option 2a will require railcars to be off line for any period of time significant enough to immediately impact availability. Instead it is likely that the scope can be incorporated into down time for the railcars. The works should not require facilities other than those already available at Claisebrook.

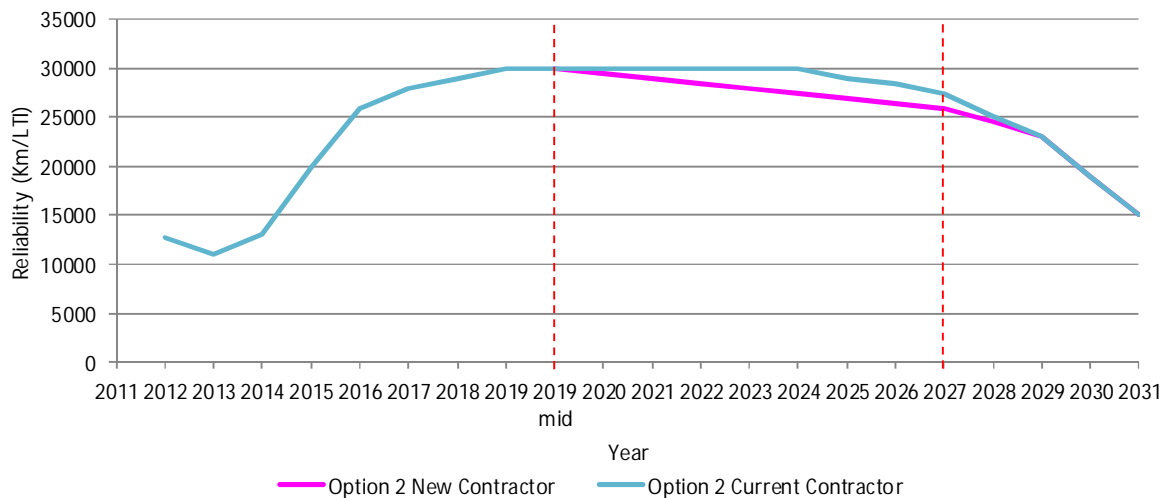
It is considered a reasonable assumption that as the fleet ages, the reliability of the railcars will become increasingly difficult to maintain and will therefore decrease over time. The train systems are expected to incur further mechanical wear, electrical degradation and interferences associated with ageing componentry. This has been reflected in the reliability forecasting for the future operation of the railcars. The future forecasts presented in Figure 31 account for the recommendations outlined in Section 7.1.2 (those which relate to reliability rather than aesthetics in relation to the scope of work for Option 2b), and employment of a rigorous maintenance and overhaul programme which avoids deferral of or omitting of overhaul. The reliability forecasts also assume that maintainer asset knowledge is not lost in the future.

It is worth noting that if PTA packaged work up and incorporated it into a maintenance contract as currently employed, PTA is able to have reliability 'guaranteed' even if it isn't actually achieved.

Figure 31 demonstrates the predicted reliability curves for the fleet during the periods of continued A-series operation associated Option 2a and 2b. Figure 31 also shows the potential effect of the introduction of a new maintenance contractor for the second maintenance contract period. Reliability is observed to decrease for a period of time before stabilising to a more gradual decline. The two stages of reliability reduction are associated with the initial lack of knowledge of the maintainer and the inevitable wear and tear incurred by the fleet which is unlikely to be compensated through the installation of minor upgrades.

The prediction of future reliability until 2021 is largely based on the data presented in Section 7.1.4 for Option 1.

Figure 31 Option 2a/b (Replacement at end of year 2026) Expected Reliability over Time



The works associated with Option 2b are likely to have a slightly greater impact on train availability by comparison to Option 2a, nominally due to the nature of the work for replacing the cab front end. The heavy maintenance facilities in the DMU shed will suffice to complete the works. It is estimated that the replacement of the cab frontage will be the longest linear duration of works and the remainder of the scope can be undertaken synchronously. It is expected that five days is a conservative estimate for the duration works in completing the scope of Option 2b. It should be noted that the programme assumes working Monday to Friday working Saturday's and Sunday's available as contingency.

7.2.5 Maintenance contract

There is an option with the existing maintenance contract to continue with the existing supplier for a second term of 7.5 years after the completion of the first term (also 7.5 years). The second phase would expire on December 31, 2026. It is apparent that the timescales for the maintenance contract are largely succinct with end of service life for Option 2a. Therefore there exists an opportunity to decommission the fleet leading up to the completion of the maintenance contract in a similar way as described in Option 1. A potential schedule for decommissioning is presented in Figure 32.

It is worth noting that PTA is not obligated to proceed with the second phase of the maintenance contract and has the option to end the contract after completion of the first period is complete. In this event two alternatives are considered workable. The first is that PTA takes ownership for maintenance delivery of the A-series in-house. The second alternative is that another maintenance service provider is employed. In this instance it would appear most practicable that the selected supplier of new rolling stock receives a novated maintenance contract. It is thought that there are greater levels of risk inherent with the first options (discussed further in Section 8). If the PTA chooses to end the existing maintenance contract, the break period in between Phase 1 and Phase 2 of the contract is a prudent time, especially if the preference is for novating the lease to a new rolling stock manufacturer.

Since Option 2b requires the railcars remain in operation for 10 years beyond the intended design life (until 2031), which is a period of years after the completion of both phases of the existing maintenance contract. This means there is no influence from the existing maintenance contract impacting the schedule for decommissioning.

The costs associated with extending a maintenance contract over the remaining 5 year period of operation for Option 2b are provided in Table 20. The costs have been escalated by 20% to account for the age of asset and potentially degenerated condition. There is also a risk that a maintenance service provider takes a more pessimistic view of the asset health and increases fees according to the perceived risk.

Table 20 Option 2b Maintenance contract cost to PTA

Option 2B Maintenance contract	Indicative cost for maintenance contract (\$AUD)	Notes on costing assumption
40 year operating life	\$ 349,708,000	Based on current maintenance contract option extension pricing and escalation consistent with asset age

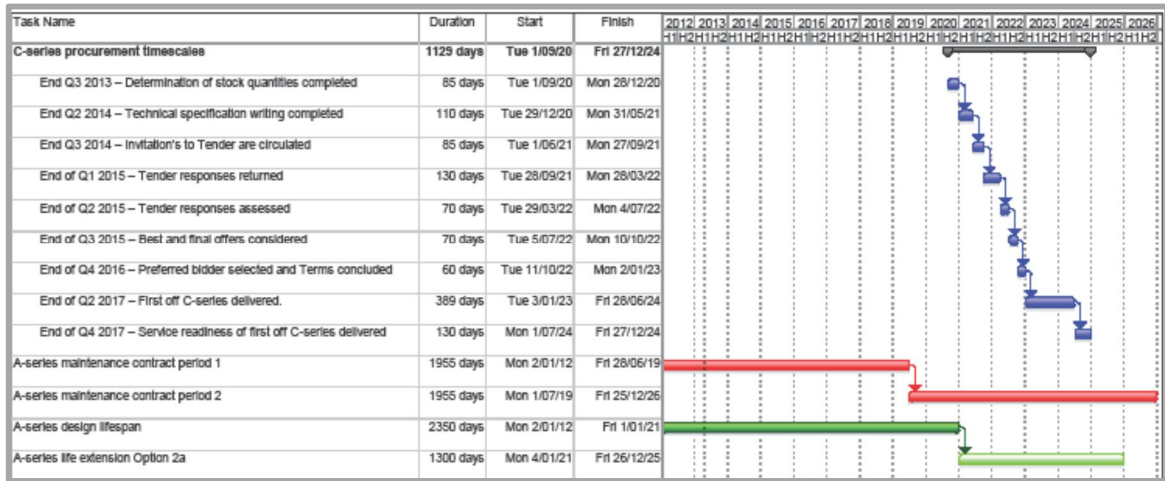
The indicative cost for maintaining the A-series fleet for the period of operation associated with Option 2b is based on the existing maintenance contract rates for Phase 1 and Phase 2 and a 5 year extension of the contract with a 20% premium applied for the final five years of operation. The escalated rate represents the additional maintenance and materials expenditure associated with the ageing fleet. The cost has not been adjusted for inflation or net present value.

7.2.6 New rolling stock introduction

It is assumed that the B-series rolling stock will not serve as the replacement for the A-series and capacity expansion employing a new rolling stock will be required in the future. It is also assumed that a new rolling stock will be required to supplement the A-series fleet if not replace it.

In the event that procurement of new rolling stock can be postponed until 2025, the schedule for undertaking Option 2a appears very favourable as illustrated in Figure 32.

Figure 32 Indicative schedules for Option 2a



It is highly likely that the A-series fleet will not be sufficient to serve a growing ridership demand through to 2031 (life expiry of railcars according to Option 2b) without supplementation. It is likely a new rolling stock order will take place before 2031 and it is therefore likely the decommissioning of the A-series will only be co-ordinated with a 'follow-on' order. Either alternative is less favourable than that described for Option 2a. A further point worth noting is that an additional rolling stock maintenance depot is most likely to be required for a New rolling stock. Continuing to operate the A-series synchronously will require the upkeep of two maintenance facilities.

7.2.7 Cost analysis

Table 21 presents the indicative maintenance contract costs for Option 2a. The existing maintenance contract price has been projected over the schedule term for Option 2a with the direct costs of the minor modifications and enhancements outlined in Section 7.1.2.

Table 21 Indicative costs for Option 2a

Option 2a Maintenance contract	Indicative cost for maintenance contract (\$AUD)	Notes on costing assumption
Continue with existing maintainer til end of service life	\$ 239,776,500	Estimate based on Schedule 16 in Maintenance Agreement
Technical enhancements	\$ 8,172,000	Table 18
Total	\$ 247,948,500	

Life extension for a further 10 years as defined for Option 2b may require the deployment of an additional five year maintenance contract. The alternatives already described remain relevant, the existing maintenance supplier could continue to maintain the fleet, PTA may select to return maintenance to an in-house operation or a new maintenance supplier could be employed.

Indicative costs for Option 2b are presented in Table 22.

Table 22 Indicative costs for Option 2b

Option 2b Maintenance contract	Indicative cost for maintenance contract (\$AUD)	Notes on costing assumption
40 year operating life	\$ 349,708,000	Based on current maintenance contract option extension pricing
Technical enhancements	\$ 22,839,000	Table 19
Total	\$372,547,000	

7.3 Option 3 – Re-engineering Life

The objective applied to the development of a model succinct with the scope requirements for Option 3 has been to identify those modifications and activities which will enable continued operation of the A-series railcars on the Perth urban network for a sustained period of time.

Since there is likely to be a significant capital investment required to re-engineer the A-series to fulfil the objective, the lifespan of the railcars is extended to 20 years for Option 3 which optimises the time available for realising a return on the investment.

In conducting the investigations for suitable re-engineering schemes, it was decided that the traction system should be the focus of the analysis in this Option due to the likely cost for modifying the system. Two scenarios were investigated comprehensively which were; retain DC traction motorisation or replace DC motors with an AC traction system. These scenarios become:

Option 3a – Retain and upgrade DC traction system, operate railcars for 20 years beyond design life

Option 3b – Install an AC traction system, operate railcars for 20 years beyond design life

A broad range of other system enhancements and modifications were considered and are further discussed in this section but their application or feasibility is not altered by the application of a DC or AC traction system.

The results of the Phase 1 FEA fatigue life study are set aside during the discussion of this Option. The results will ultimately have significant bearing on the feasibility of Option 3, but validation of the results should be sought through practical testing before omitting Option 3 from consideration entirely.

7.3.1 Assumptions

The following assumptions are made in the context of a major life extension:

- B-series units not currently on order will facilitate rolling stock capacity expansion in the near future and New rolling stock procurement can be postponed until 2025;
- Works will occur during the period of the first phase of the maintenance contract and disruption to the contract is considered manageable;
- New rolling stock will require new maintenance facilities;
- It is assumed that both the first and second batch of the A series will be decommissioned in the same programme;
- Reliability predictions are based on Options 1 and 2 in addition to achievements of fleets in the UK;
- Re-engineering works will not be able to be undertaken on any existing PTA site;
- DC traction and AC traction modernisation costs have been provided by Alstom Transportation and in accordance with the assumptions and exclusions specified in Appendix G, with the exception of labour rates;
- Labour rate costs have been adjusted to account for the utilisation of local Western Australian workforce and overheads associated with leasing facilities suitable to conduct the scope of the re-engineering; and
- The Traction re-engineering costs provided by Alstom Transportation were benchmarked against those provided by Vossloh Kiepe.
- Comprehensive analysis of the power consumption of the A-series rolling stock has been conducted during the course of this study. It has been identified that the total power consumption of the A-series rolling stock is in the order of \$10.1 million per year (based on 2012 statistics).
- It is assumed that the train interiors will be maintained under the conditions of a maintenance contract to the current standards and are excluded from PTA's cost estimate.

7.3.2 Asset health

Section 7.1.2 describes the recommended practices to maintain good asset health for the period of operation up to 2021 (end of intended design life of the A-series). This section identifies the modifications associated with Option 3a and Option 3b, and provides a summary of the recommended modifications, works and initiatives which should be undertaken independently of traction system upgrades. The generic modifications are identified in the subsection for Option 3a and are assumed to carry-over for Option 3b.

The recommendations for modifications and improvement programmes pertinent to extending A-series life to 50 years of service operation are identified in the following sub-sections.

7.3.2.1 Option 3a

The recommendations which are made herein are considered to support sustained operation of the A-series beyond the intended design life and for an extended period of time.

The recommendations made below are expected to optimise the safety, reliability and investment in the assets. Some recommendations will overwrite or supersede previous recommendations for Options 1 and 2a. This has been accounted for in scope costing.

It is advised that the recommendations as prescribed by Option 2b should be undertaken and deployed on a fleet wide basis where not already recommended, as well as the following items:

- The DC traction motorisation is retained and enhanced through the integration of a DC regenerative braking system. This will involve replacement of the rectifying thyristors with IGBT to improve voltage waveform and power factor. It is important to note that the DC regenerative braking system control proposed by the supplier is an unproven system for service operation, though extensive laboratory testing has been conducted. In laboratory testing conditions it has been able to generate up to 35% energy savings through regenerated energy returned to the main power supply, however it is considered that a more appropriate value for energy saving is 20% (systems in Europe have been reported to return between 18-22% usable energy to a system. Refer to the Appendix G for a full system proposal made by Alstom Transportation. The DC traction modernisation scheme should encompass as a minimum a traction motor re-wind so that motor condition is known for installation.
- New brake system components should be installed. The callipers are in a non-uniform state and subsequently the OEM refuses to overhaul the callipers and accept warranty responsibility. As a result fleet wide replacement of callipers is recommended. Polymeric bushings on callipers can also be replaced with those that have steel pinions for improved longevity, or an alternative that is optimised for the application. There is an opportunity to integrate new wheel slip/slide protection with the installation of new brake control unit enabling improved integration between the two systems and enhanced fault diagnostics from a new BCU. This enhancement will reduce obsolescence risk of the braking system in future.
- Oil free compressors are recommended and are becoming common as retrofit systems in aged fleets which will remove oil contamination in components (doors, brakes) and should reduce the compressor maintenance burden.
- Modern HVAC systems incorporate improved automatically adjustable temperature control making them more sensitive to passenger thermal energy and distribution. This makes them more energy efficient. Long term running and maintenance cost savings are expected with an upgraded HVAC asset. It would be feasible to develop a split cab/saloon HVAC system with installation of additional ducting to the cab. Existing ducting should be checked for corrosion and replaced where necessary. If HVAC system replacement is not affordable, pipes, hoses perishable or corroded items should be replaced.
- Communication upgrades to improve passenger safety through CCTV enhancements with live wireless offload of captured CCTV footage at multiple locations along the route and upgrade of the PA/Intercom system. This feature may be expanded to provide better train condition monitoring performance (costs not sourced).
- Provided the current ATP system continues to be operated in the long term, it is recommended PTA upgrade the cabling and transmission racks. These have been changed fleet-wide and on condition basis since first implemented in 1990 -1994, however there are a high volume of transmission faults monitored up to early 2012 and are still been experienced, and should be further investigated by PTA. Upgrade to the protocol of the system should be suspended until a system wide decision is taken on the future operation of ATP or an alternative is sourced. A new passenger door system with an intelligent DCU capable of self-learning closing, opening profiles and door obstruction system may reduce station dwell times. Obstacle detection systems are not recommended unless mandated in future by DDA or other standards. If necessary door overcurrent devices are recommended rather than sensitive edge technology or similar, which have proven to be very unreliable on other rail systems. Improved diagnostics should enable more accurate fault detection and d location identification. Passenger counting detection through sensory door equipment can also be incorporated to better monitor train loadings against capacity.

- Hearing augmentation in the form of hearing aid frequency induction loops will require extensive modifications to the current interior as discussed in Section 5.7 (DDA section). PTA will need to discuss this requirement further with the DDA to determine its necessity given life extension of 20 years.
- NDT and ultrasonic testing of the autocouplers and drawbars should be undertaken. It is likely that the electrical coupler heads will have degraded to a state where their replacement becomes necessary due to worn flexible components and seals or damaged electrical contacts. Unless evidence of fatigue is presented in the findings for the coupler mechanical testing the continued operation has been assumed.
- It is likely a new train management system will be required to incorporate the above mentioned ATP and control unit upgrades. Additionally, a new TMS will provide better integration protocols, faster transfer of data, increased functionality and a modern driver's interface.
- Train aesthetics are improved through the installation of a new GRP cab frontage as described by Option 2b, the passenger environment would benefit from an enhanced infotainment system. Existing PIS and communications systems can be improved upon by replacing dot matrix displays with LCD systems and renewed announcement units. Provision of Wi-Fi and even on-board entertainment could be made available through the installation of LCD/LED screens on interior panels. A-series railcars do not suffer from significant graffiti and advertising revenues would go some way to covering the APEX and OPEX investment.

Costs associated with the upgrades are provided below in Table 23.

Table 23 Option 3a Life extension of 20 years with DC regenerative braking

Major upgrades	Indicative cost for materials and labour (\$AUD)	Notes on costing assumption
Option 2b 10 year minor upgrades and modifications	\$15,161,000	Accounts for additional Auxiliary Converter minor overhauls, removal of replacement of HVAC fan motors (incorporated in New HVAC system replacement), and excludes 30% traction rewind
DC traction modernisation with a new traction system allowing regenerative braking	\$21,014,016	Price excludes new motors and re-winding of existing traction motors. Quote from Alstom will entail two years for fleet upgrade
Re-wind DC traction motors for fleet	\$12,960,000	Assumes maintainer is not incentivised to conduct partial re-wind programme due to traction upgrade and all motors are re-wound in upgrade programme.
New brake and air system	\$8,106,000	
New HVAC system for the saloon	\$6,144,000	
Upgrade ATP system	\$680,000	Includes only cables and transmission racks. Excludes system cards or a system wide upgrade
New passenger door system	\$2,688,000	
Hearing aid loops in line with DDA requirements	\$1,048,000	For railcars 1-43, 44-48 have been fitted already. PTA would need to review necessity of equipment with DDA.
Replace electrical coupler heads on condition	\$2,560,000	Assumes 60% of couplers will be replaced over the 30 years
New train management system (TMS)	\$8,606,000 (materials only)	Exclusive of labour

Major upgrades	Indicative cost for materials and labour (\$AUD)	Notes on costing assumption
Contingency at 15%	\$11,845,050	
Total Cost to PTA	\$90,812,050	

It is worth noting that the price for DC traction modernisation assumes the existing traction motors can be retained. A fixed price for a fleet wide overhaul of the DC motors incorporating a rewind is included in the price of this Option. Alstom has indicated that the estimated cost of a motor overhaul and rewind can be completed for approximately AU\$45,000 per motor if a fleet-order is placed. Alstom also indicated during discussions an estimated cost of \$60,000 for a new DC motor for a fleet order. On this basis the DC traction modernisation could escalate. For the purposes of comparison the indicative estimates provided by Alstom Transportation for new DC motors are presented in Table 24.

Table 24 Option 3a DC motor re-wind and re-motorisation costs

Option 3a Maintenance contract	Indicative cost including DC motor re-wind	Indicative cost including new DC motors
Technical enhancements	\$66,007,000+ \$12,960,000*	\$66,007,000+ \$17,280,000**
Contingency	\$11,845,000	\$12,493,000
Total	\$90,502,000	\$95,780,000

*Accounts for re-wind of DC motors for whole fleet

**Accounts for new DC motors for whole fleet

7.3.2.2 Option 3b

Option 3b retains the recommendations made for Option 3a above, however the DC motorisation will be replaced with an AC regenerative tractive system. The AC system proposal is further described in the Appendix H, but in summary it involves the following works:

- Replacement of the DC traction motors with AC motors
- Removal of:
 - Main converter
 - Main reactor
 - Power factor correction unit
 - WSP
- Introduction of:
 - Traction control unit
 - Brake resistor
 - WSP

Renewal of the auxiliary converter and battery charger could be undertaken also to further enhance system performance and based on the existing performances this is also recommended. However, the prices for these items have not been sought and are not included in the estimates presented.

Table 25 Life extension of 20 years with AC regenerative braking

Major upgrades	Indicative cost for materials and labour (\$AUD)
Option 3a 20 year major upgrade excluding DC regenerative braking	\$44,993,000
AC regenerative braking system upgrade	\$79,390,000
Contingency at 15%	\$18,657,400
Total cost to PTA	\$143,040,400

*Given the age of the fleet, a higher risk premium is likely to be requested from the maintainer in this scenario

Regenerative braking is more commonly proven with AC traction systems. AC traction systems require less maintenance in comparison to the DC counterpart with commutator and contact brushes often being problematic. Also introduction of an AC traction system removes the potential risk of failure of the original casing and pinions used in the re-wound DC traction motors. Energy savings from the regenerative braking are likely to be consistent than those discussed for the DC traction option (in the order of 20% energy saving).

Table 26 below conveys the indicative cost for an additional 20 year life extension beyond design life. The maintenance contract cost in Table 26 below is equivalent to that in Option 3a. However, the maintenance costs for Option 3b could, in reality be slightly lower since it is broadly accepted in industry that AC traction systems are less maintenance intensive than the DC counterparts. To remain conservative in the estimation a cost saving has not been incorporated into the indicative contract pricing.

Table 26 Option 3a/b - Maintenance contract cost to PTA

Option 3A and 3B Maintenance contract	Indicative cost for maintenance contract (\$AUD)	Notes on costing assumption
50 year operating life	\$545,360,000*	Based on current maintenance contract option extension pricing – linearly adjusted

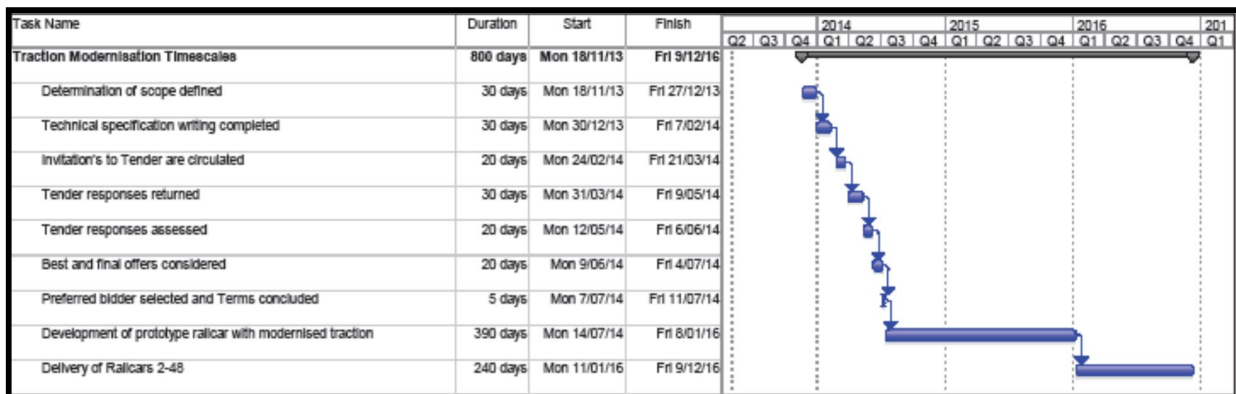
*Given the age of the fleet, a higher risk premium is likely to be requested from the maintainer in this scenario

The maintenance contract cost is based on the existing contract cost and allows for cost uplift for the extended asset life. A 40% premium above Phase 2 of the existing maintenance contract has been applied for the life extended period beyond Option 2b. Note the maintenance contract costs do not factor in inflation or net present value.

7.3.3 Schedule

PTA has indicated that in order to maximise the benefits of the modifications that the re-engineering works would be undertaken in the near future if it is the preferred option. It is reported that the programme for the traction modernisation packages is consistent for each option. The programme of works is provided below in Figure 33 and assumes a commencement during the current maintenance contract period.

Figure 33 Indicative schedule of works for traction modernisation (AC or DC)



The programme assumes there is a scope development period for PTA and a tendering period up front. The schedule of works for the traction modernisation was provided by the supplier as part of their budget estimate and technical proposal. The programme projects a development time of 14 months for development of the solution and a first off prototype, thereafter the railcars will be completed in a two week cycle rate.

It is expected that the generic scope of re-engineering work can be accommodated in the programme length of traction modernisation works.

The programme of work requires two railcars off line at any period of time with a one week phase shift in the works. The railcar availability required to meet this programme will impact on the PTAs system requirements currently for releasing 45 of 48 railcars in peak times (with the spares being allocated to maintenance and overhaul). It is highly likely therefore that this programme will impact on the network services.

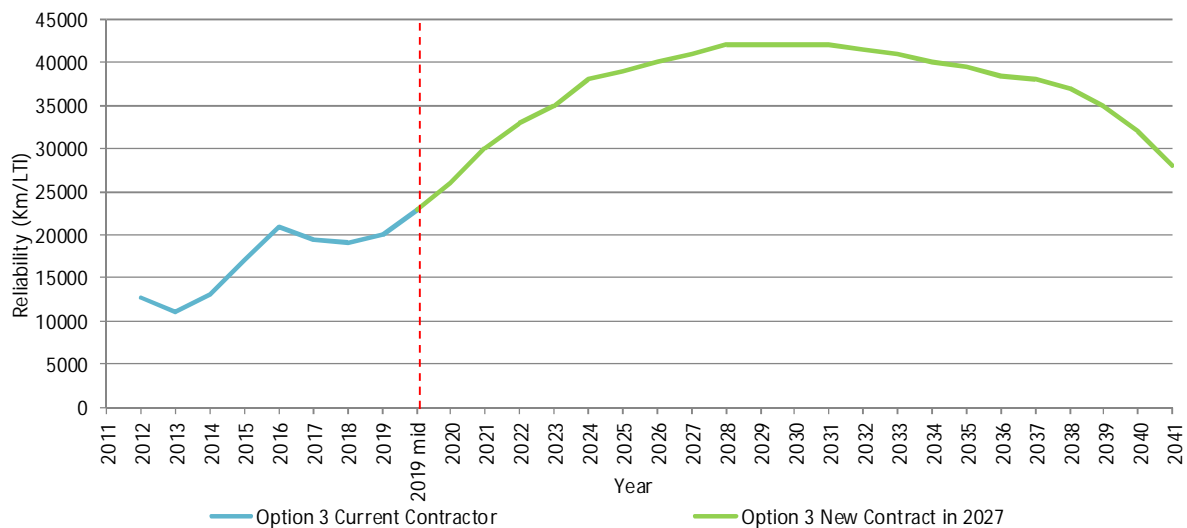
7.3.4 Reliability and availability target meeting

There is an assumption that the re-engineering works will be undertaken in the near future to enable the greatest return on investment to be realised through having the modernised railcars in operation for as long a period as feasible.

The schedule in Section 7.3.3 forecasts an introduction of equipment to take place from June 2016. It is expected that there will be a period of reduced reliability during the first few years whilst integration and compatibility issues are resolved. After which a period of improved reliability is seen reflective of the new train systems. A conservative estimate of 20% increase in reliability measured as improved LTIs per kilometre. Figure 34 illustrates the forecasted estimate of reliability.

It is expected given the present condition of the A-series and international market analysis that an improved reliability is achievable. Reliability figures for the UK were considered in the long term predictions of the A-series. EMUs of a similar age to that of the A-series are achieving between 22,000 km (9,000 miles) per LTI (where an LTI is measured as mean distance between 3 minute delays) and 65,000 km per LTI.

Figure 34 Option 3a/b (Replacement at end of Year 2040) Expected Reliability over Time



The supplier has informed AECOM that there will be negligible difference in reliability between the AC and DC traction modernisation schemes.

The curves in Figure 34 follow the reliability growth expectations presented for Option 1 and build in an improved reliability for the new system installation. It can be observed that there are expected to be some initial issues with integration and compatibility of new and old systems immediately after installation before reliability can be improved upon. Inevitably though, it is expected that train reliability will decrease with age due to the effects of newly installed ageing componentry and the existing unmodified equipment becoming life expired over a long period of operation.

It is evident that the introduction of the new train systems enables the railcars to remain at a higher level of reliability for an extended period of time, though there is a period of underperformance initially, associated with integration and compatibility issues.

7.3.5 Maintenance contract

Due to the schedule of modifications it is likely that the existing maintenance contract will require amendment to reflect the modifications to the rolling stock. Maintenance contract values were assumed to remain constant since there would be shared benefits for both PTA and the maintenance services provider associated with the implementation of the enhancements.

The maintenance contract continuation period ultimately depends on the schedule for new rolling stock. It has already been identified a new maintenance depot will be required for the provision of servicing to new rolling

stock. It has also been discussed that the future of Claisebrook is unclear due to its development potential. If new rolling stock is required to increase service capacity on the Heritage lines before the decommissioning of the A-series, it would be prudent to maintain the fleets at a single depot and arrange for the maintenance to be conducted by a single provider to avoid industrial disputes or other such risks.

It is recommended that PTA avoids attempting to synchronise the re-engineering works of the A-series, delivery of new rolling stock and completion of the maintenance contract and that the programmes for each activity are phased methodically to reduce risk of low availability.

7.3.6 New rolling stock introduction

It is concluded in the previous subsections that it would be preferable to coincide the decommissioning of the A-series with the completion of the Maintenance Service Contract which is completed at the end of Q2 2019 or the second maintenance contract completion in 2026, the timescales for the procurement of the New rolling stock are unlikely to benefit the programme of works of either Option 3a or 3b.

It is noted that the PTA might incur additional cost in the procurement of new rolling stock if it continues to operate the A-series and is unable to realise the benefits of economies of scale through bulk purchasing in a new rolling stock order.

7.3.7 Cost analysis

Table 27 and Table 28 present the indicative maintenance costs for Options 3a and 3b respectively, together with the capital investments associated with the re-engineering (technical enhancements) scope for these Options.

Table 27 Indicative costs for Option 3a

Option 3a Maintenance contract DC traction modernisation	Indicative cost for maintenance contract (\$AUD)	Notes on costing assumption
Continue with existing maintainer til end of service life	\$545,360,000	Estimate based on Schedule 16 in Maintenance Agreement
Technical enhancements	\$90,812,050	Table 23
Total	\$636,172,050	

For the purposes of estimating Option 3a assumes a fleet wide traction motor re-wind is undertaken in the traction modernisation scope.

Table 28 Indicative costs for Option 3b

Option 3b Maintenance contract AC traction replacement	Indicative cost for maintenance contract (\$AUD)	Notes on costing assumption
Continue with existing maintainer til end of service life	\$545,360,000	Estimate based on Schedule 16 in Maintenance Agreement
Technical enhancements	\$143,040,400	Table 25
Total	\$688,400,400	

It was suggested by Alstom Transportation that both the DC and AC traction modernisation schemes identified in this study are able to achieve in the order of 30% energy savings for the rolling stock. A value of 30-40% was promoted by Vossloh Kiepe regarding energy savings attributable to regenerative braking technology.

The total energy consumption attributed to the A-series was estimated to be in the order of AU\$10 million per year. If it is assumed that the railcars reduce energy consumption by 20% per year and the reduction in energy is directly proportional to a reduction in the energy cost, a reasonable estimation for the energy saving over the duration of the asset life following installation is AU\$44 million at 2012 energy prices, assuming installations are complete for 2019.

The net effect of the energy saving from the regenerative braking is factored into Table 29.

Table 29 Indicative costs for Options 3a and 3b including value of energy saving attributed to the regenerative braking

Cost description	Option 3a costs – DC modernisation	Option 3b costs – AC traction replacement
Maintenance cost	\$545,360,000	\$545,360,000

Cost description	Option 3a costs – DC modernisation	Option 3b costs – AC traction replacement
Technical enhancements	\$90,812,050	\$143,040,400
Energy saving value	-\$44,000,000	-\$44,000,000
Total	\$592,172,050	\$644,400,400

7.3.7.1 Further notes on cost analysis for Option 3b

A comprehensive quotation was provided by Alstom Transportation for the works scope associated with the traction modernisation works both DC and AC upgrades for Options 3a and 3b. The full quotation together with assumptions and exclusions are included in Appendix G.

The costs provided by Alstom were benchmarked against those estimations provided by Vossloh Kiepe a supplier base in Europe and UK. Labour rate adjustments were made to provide a better comparison.

It was noted that a significant exclusion of both cost estimates was the lack of provision of facilities to undertake the works. AECOM identified two potential suppliers with appropriate facilities in the Perth region:

- UGL Rail Ltd
- Gemco Ltd

AECOM was able to acquire a quotation for utilisation of UGL's facilities on the basis they would be involved in a programme of works. The quotation was provided for a series of labour rates which included the overheads associated with the use of a venue and its facilities appropriate to conduct the aforementioned scope.

Utilisation of existing workshops and facilities to conduct the major re-engineering works in this way was thought to be more cost effective than It is expected to be economically beneficial than having a dedicated facility constructed.

8.0 Strategic Risk Assessment

During the course of completing this study AECOM held two internal Strategic Risk Workshops. The purpose of the workshops was to identify the future business risks posed to the PTA pertaining to the options discussed in Section 7. Therefore this risk assessment focuses not on the specific technical risks but more so, on the risks presented to the PTA business. However the risk assessment has not entirely excluded technical risk since there were a series of technical issues identified during the workshops which presented broader business risk to PTA.

A full risk register is presented in Appendix J.

The key strategic risks associated with each of the Options are discussed in the following subsections together with the potential consequences as well as feasible mitigations.

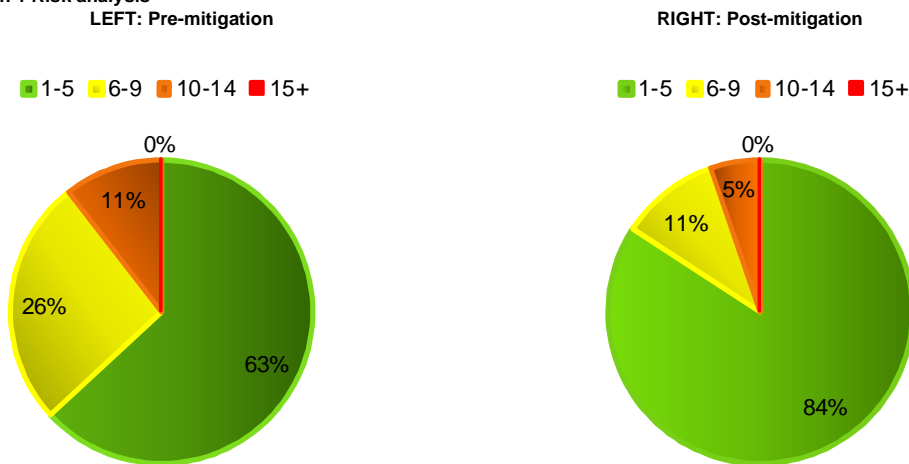
8.1 Results of Strategic Risk Assessment

The PTA Risk Management Policy - 9502_000_001 Rev4.00 has been adopted as the template for the risk analysis conducted during this study. The criteria, ratings and classifications have been adhered to in order to present PTA with risk information consistent with its own documentation and procedures.

8.1.1 Option 1

Figure 35 shows the distribution and seriousness of the risks identified for Option 1. It is noticeable that there are no risks of a Level 15 or over pre mitigation. It is observed that due to the relatively short duration of continued operation of the assets and the presence of the current maintenance contract that much of the risk for Option 1 is either of low impact or offset to the maintenance contractor.

Figure 35 Option 1 Risk analysis



The main risks associated with selection of Option 1 are predominantly driven by the schedules of various works. The existing maintenance contract (Phase 1) and the planned end of design life do not synchronise. A suitable mitigation would be to align the timescales associated with decommissioning and maintenance contracting (with little impact on the terms of engagement) and furthermore the supply (if demand and capacity expansion warrants it) of new rolling stock could also be aligned with termination of a maintenance contract and A-series decommissioning.

A more significant risk is perhaps the failure of the fleet to achieve a desired reliability in line with the terms of the maintenance contract. The risk to PTA is predominantly an impact to reputation resulting from any underperformance. This may occur due to component obsolescence or underperformance of the maintenance contractor. It is thought that the existing maintenance contract provides incentive enough for the maintainer to endeavour to achieve the required level of reliability for the fleet. Furthermore, there is considered to be an increased risk associated with early termination of the existing maintenance contract and commissioning of a new service provider. This is due to the risk of unfavourable terms, increased cost burden as a new maintainer that is more pessimistic about asset health and potentially short to middle term reduced reliability associated with the initial learning curve of the new service provider. Completion of the existing maintenance contract would appear

preferable and should alleviate low reliability risk if the maintainer commits to undertaking a comprehensive maintenance optimisation scheme.

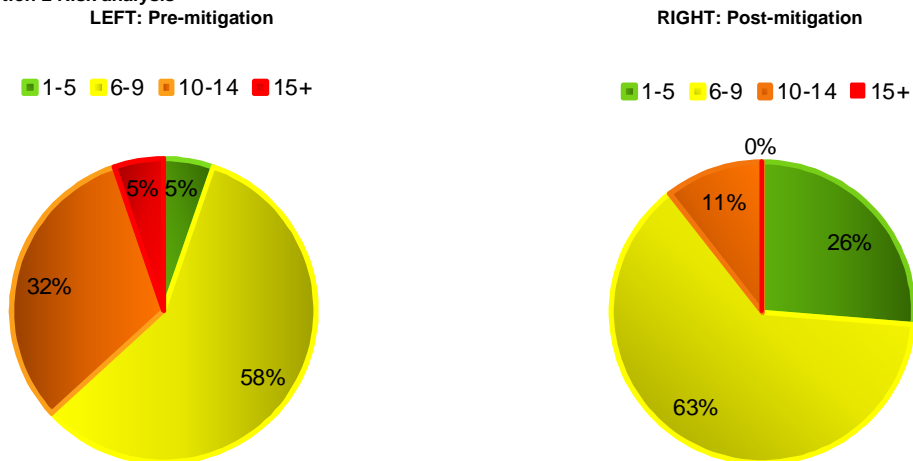
Structural integrity of the carbody and bogies are risks inherent with all Options due to a failure to achieve the desired asset lifespan. Early identification of structural issues should be identified through regular inspections and non-destructive testing of 'at-risk' areas. Structural reinforcements and repairs can be undertaken to weakened elements of the carbody and bogies and many examples of rolling stock undergoing or that have undergone this treatment are available.

8.1.2 Option 2

Figure 36 Show the distribution and seriousness of the risks identified for Option 2. It is noticeable that there are far less risks in the 'acceptable' levels of 1-5 and an increased proportion of risks in the higher bands for both pre and post mitigation.

Structural integrity of the carbody and bogies and failure to achieve the desired asset lifespan exist with Option 2. However, both the impact and likelihood of the risk occurring are increased due to the extended operating life of the asset and the increased financial investment which may have taken place and not be realised.

Figure 36 Option 2 Risk analysis



The risks for Option 2 are largely similar to those discussed for Option 1. However due to the extended period of operation the risks are of greater significance due to an increased likelihood and severity associated with the extended railcar operation.

The main areas of strategic risk to PTA for Option 2 result from the lack of enhancements, modifications, and re-engineering that takes place. Seeing as the railcars continue operation for a period beyond the intended design life with a low capital investment it is reasonable for the trains to be at an increased risk of component obsolescence and mechanical wear and electrical failure. The scope of works identified for each sub package is selected to mitigate the greatest of risk but further mitigation necessary to reduce the levels to an acceptable level comes with a significant dollar value which would not likely be justified in a short extension of life.

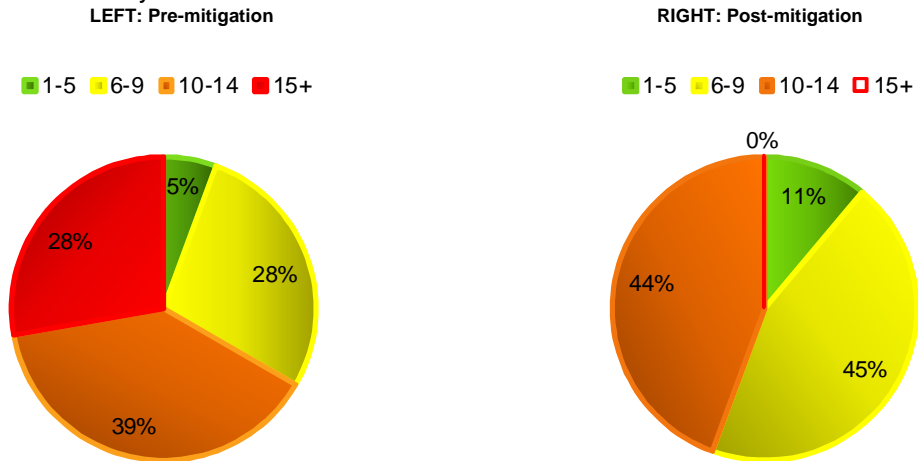
It is expected that the aesthetic improvements packaged in Option 2b should go some way to improve passenger perception of the railcars and cab HVACs may alleviate some driver complaints and issues, however, it is thought that the scopes associated with Option 2 would benefit a shorter life extension – consistent with that identified for Option 2a.

Whilst the data in Figure 34 does not distinguish between options 2a and 2b, it is logical to assume that the lower capital investment and shorter operational period for Option 2a enables a lower risk profile. Whereas the scope of work associated with Option 2b balances the reduced risk of Option 2a with greater risk levels associated with increased capital investment and a longer period of operation.

8.1.3 Option 3

Figure 37 shows the distribution and seriousness of the risks identified for Option 3. It is noticeable that there are a far greater proportion of risks in the higher bands than for the previous options and this is true for statistics of pre and post mitigation.

Figure 37 Option 3 Risk analysis



The long-term operation of the fleet potentially poses the greatest risk to PTA. There are many risks inherent with continued operation of the fleet for Option 3 and undertaking recommended works.

Newly installed systems may reduce reliability through compatibility and integration issues may lead to less than desired reliability which ultimately reduces the availability of trains and ultimately impacting on train services and operations. Benefits from improved reliability, energy saving, reduced maintenance may not be realised and a failure to do so may negatively impact the reputational credibility of PTA. Extensive prototype testing and proven product selection is recommended to reduce the risk. DC traction modernisation incorporating regenerative braking is thought to be of greater risk in this instance than an AC traction modernisation since regenerative braking systems are more common on modern rolling stock.

Whilst the A-series interiors are of an excellent condition and the exterior stainless sheeted bodyside panels show little signs of age, it is expected that the cab frontage of the railcars may be poorly perceived by the public in the middle to long term (Option 3a did not include aesthetic enhancements). Similarly so, without a focus on enhancing the cab environments there is a risk of driver disputes with ageing interiors lacking the ergonomic design influence of more modern driver stations.

Railcars are not operable on the North-South lines and failure to conform to 'system needs' reduces the flexibility of asset allocation on the system. The current design of the A-series railcars does not optimise passenger flow and capacity growth in the existing configuration and layout (2 cars, 2 doorsets per side, longitudinal seating, and 110km/h max speed).

The timescales for decommissioning the fleet for this Option are likely to be far in advance of the requirement for new rolling stock, therefore there is no opportunity to align the decommissioning of A-series railcars with the commissioning of replacement rolling stock order. This may lead to reduced purchase power of new rolling stock through low procurement volumes. There is also a financial risk associated with ensuring future maintenance facilities remain compatible with A-series railcars and new rolling stock.

Most of the risks inherent with the two previous Options are also relevant to Option 3 but likelihoods of occurrence increase due to the greater age of the fleet. This is true of the following technical risks; obsolescence, low reliability resulting from worn components, catastrophic failure of the bogies or carbody, endemic failure manifestation, underframe equipment boxes. Many of the mitigations for these risks will result from expanding the re-engineering scopes and conducting further train modifications though this ultimately will have a cost penalty attached.

9.0 Options comparison

9.1 Fatigue life analysis

The results of the finite element analysis study of the fatigue life suggest that the A-series carbody has a very short fatigue life and should have already experienced fatigue cracking around door and window aperture corners if the inputs are assumed to be accurate representations of the loadings experienced by the A-series. Inspection for cracks has not been feasible during the course of this study. However it is known that the railcars have never experienced a catastrophic failure of the carbody. There are examples of fatigued railcars in operation on other rail systems long after cracks appeared on the carbodies and research suggests that stainless steel carbodies are particularly resilient.

On the basis of the results generated to date it would be prudent not to pursue a life extension to the A-series (Options 2a, 2b, 3a or 3b). However, the results of the fatigue life study warrant further investigation through practical verification before definitive conclusions can be drawn regarding the residual life of the rolling stock.

9.2 Financial impact

This section of the report summarises the key points of the Options discussion and presents them together for the purposes of enabling the audience to benchmark and compare the advantages and disadvantages of each Option at a very high level.

Table 30 provides the financial investment required for each option and the level of strategic risk.

Table 30 Options Comparison

Option	Life extension period	Decommissioning date	Indicative total cost	Strategic risk level
1	0	2021	\$141,344,800	Low
2a	5 years	2026	\$247,948,500	Medium
2b	10 years	2031	\$372,547,000	Medium/High
3a	20 years	2041	\$592,172,000*	High
3b	20 years	2041	\$644,400,400*	High

*The regenerative braking energy reduction is factored in at AU\$44 million.

The rate of maintaining the A-series fleet increases over time. The rate of increase is not proportional to the passage of time and instead increases at a greater rate.

Little investment is required for Options 1 and 2a in addition to that which is expended on the existing maintenance contracts.

The scope of refurbishment, enhancement and re-engineering grows with time in order to reduce the risk of component obsolescence, low reliability and endemic failures.

The cost of modernising the traction systems in line with the scope of Options 3a and 3b is offset by a degree when the value of the regenerative braking energy savings are factored into the cost of continued operation.

For the purposes of comparison, indicative estimates have been presented for the costs of procuring and maintaining a new rolling stock fleet in Table 31. Both existing and new rolling stock are assumed to benefit from regenerative energy savings and as such the values are included in the table.

Table 31 Indicative costs for operation of new and old rolling stock

Option	Decommissioning date	CAPEX cost	OPEX cost	Indicative total cost
Matangi	2043	\$153,600,000	\$415,000,000	\$568,600,000
A-Train	2043	\$384,000,000	\$415,000,000	\$799,000,000
Option 3a	2041	\$90,812,000	\$ 545,360,000	\$592,172,000
Option 3b	2041	\$143,040,000	\$ 545,360,000	\$644,400,400

It was reported by associates involved in the GWRC rolling stock renewal programme that the cost of maintaining the new Matangi fleet was over 50% less than that of the Ganz Mavag units they replaced during the first 15 years

of operation. Table 31 approximates the OPEX costs for the new fleet rolling stock by applying a 50% reduction to the existing maintenance contract values for a period of 15 years summed with 100% of the value of the maintenance contract values for the remaining 15 years of an assumed 30 year life – representative of an aging fleet. Inflation and net present values are not factored in the other costs presented in the table.

It can be observed from Table 31 that the cost of procuring new rolling stock varies significantly depending on the origin. It can also be seen that the cost of the DC re-engineering works is substantially less than the cost associated with new rolling stock procurement (even the inclusion of new DC motors at a cost of approximately AU\$17 million is unlikely to affect this). However, the cost of the AC motorisation upgrade is similar to the value of a replacement Matangi fleet. Furthermore the operating costs for the new rolling stock are substantially less than those of the A-series projections even after the re-engineering is factored in and regenerative braking energy efficiencies are accounted for in the A-series. The table suggests there is not only a business case but potentially a whole life cost saving (attributed to maintenance) associated with commissioning a new rolling stock fleet.

This is a high level and crude cost summary and further consideration of a new rolling stock versus A-series should be considered in more depth before determining the most appropriate course of action for continued operation of the A-series.

9.3 On-time running performance

It is observed from the data presented in part one of the report that given the current system performance an on-time running target of 95% is not being achieved. Improvements to rolling stock reliability alone are insufficient to enable a 95% target to be achieved. This is true of both existing rolling stock and following the introduction of new rolling stock. A reliability of approximately 2,000,000km per LTI would be necessary for an on-time running target of 95% to be achieved, where all other factors remain constant. 2,000,000km per LTI is not a realistic reliability target. Other factors such as 'weather' and 'passenger' are far greater contributors to the on-time running performance.

It is evident that of the Options discussed in this report the greatest improvement to reliability is likely to come from the implementation of Option 3 (either a or b), however the cost implications associated with this are significant as already discussed.

It is believed a significant reliability improvement can be achieved through the implementation of a reliability centred maintenance regime and avoidance of overhaul deferrals. It is expected that reduced down time of railcars, achieved through maintenance exam balancing and maintenance task blocking, will lead to greater availability of assets. This process can be undertaken with minimal financial impact.

9.4 Summary

The feasibility of continued operation of the A-series is uncertain given the results of the initial FEA study. However, there are many factors which allude to the retirement of the A-series fleet occurring in the short to middle term being preferable.

10.0 Conclusions

The A-series can be considered in a good state of repair given their age. However there are a series of technical issues which were identified during the course of this study that should be addressed. Reliability has been maintained at a level lower than that normally expected of a similar aged fleet. Availability of trains in terms of on-time running performance is below target but the contribution of rolling stock incidents to the network performance is relatively small by comparison to other factors such as 'weather'.

The finite element analysis results for the fatigue life estimate suggest that the A-series railcars have a very short fatigue life due to the high concentrations on welded joints and may already have experienced fatigue cracking. Sensitivity analysis showed that small adjustments to the modelling impart a significant effect on the stresses experienced and ultimately the damage incurred and residual fatigue life of the carbody. It is feasible that the input assumptions are overly conservative and have produced an unexpected result. Further validation of the inputs is necessary before planning for continued operation of the A-series railcars.

Continued operation of the A-series rolling stock was investigated exclusive of the fatigue life study. Four packages of work were identified for each of the following scenarios:

Option 1 – Straight replacement at end of service life

Option 2a – 5 year life extension with minor enhancements/existing technology

Option 2b – 10 year life extension with minor enhancements/existing technology

Option 3a – 20 year life extension re-engineered systems with DC traction

Option 3b – 20 year life extension re-engineered systems with AC traction

From a financial perspective, values associated with the packages range from AU\$141 million to AU\$645 million and typically the period of life extension drives the investment. However, these values should be taken into consideration given the depth of analysis and the scope of work.

It is apparent that the strategic risk exposure to PTA also increases with the term of life extension.

Based on the analysis conducted in this report, the following conclusions are made:

- LTIs relating to rolling stock contribute only 13% of the total LTIs and improvements to rolling stock reliability are insufficient to enable a 95% on-time running target to be achieved. If PTA strives to achieve an on-time running target of 95% rolling stock reliability improvement should form part of a broader system improvement plan which aims to improve the LTIs resulting from Weather, Passenger, Electrical, Driver and Special Events.
- It is expected that the deployment of a comprehensive maintenance optimisation scheme which coordinates the results of RCM studies, exam balancing and maintenance blocking and avoidance of overhaul deferrals will contribute to improved asset reliability for the A-series.
- The results of the FEA study suggest that the fatigue life of the carbody are very low and if the manufactured railcars reflect design they could have already experienced fatigue cracking localised to the door and window aperture corners. The results of the FEA fatigue study are likely to be comprehensive and many of the assumptions and inputs are expected to benefit from practical validation.
- The level of risk inherent with continuing the operation of the A-series increases with the extension of operable time
- Market analysis suggests that Australian rolling stock is far more expensive than that available from the rest of the world and valued in the order of AU\$4 million per vehicle, whereas stainless steel alternatives are available from Korea (Hyundai Rotem) for approximately AU\$1.6 million per vehicle or aluminium vehicles from Europe at approximately AU\$1.8 million per vehicle.
- The works necessary to re-engineer the A-series consistent with the requirements of long term operation of the assets are likely to make Option 3 cost prohibitive when comparing the re-engineering costs against the cost of internationally available new rolling stock.

- Option 1 appears to present a relatively low risk to PTA and the projected timescales associated with decommissioning the A-series consistent with Option 1 align well with the end of the first phase of the maintenance contract and the introduction of a new rolling stock fleet.
- Similarly so, Option 2 has relatively low risk and the suggested schedule for decommissioning aligns with the completion of the second phase of the maintenance contract, postponed introduction of new rolling stock and continued operation with minimal financial investment.
- The A-series lack some fundamental modern safety features, such as energy absorption elements of the carbody design and anti-climbers, the railcars were not specifically designed for sustained operation on the North – South lines of the network and may lack the versatility and compatibility in design required for extended periods of continued operation on all elements of the network, but might be if re-engineered.

11.0 Recommendations

In addition to the recommended packages of work associated with each of the Options, the following recommendations are made in light of the conclusions of this study:

- The areas of the vehicle where this report has identified a life lower than the 30 year design life should be subject to inspections and non-destructive testing for the presence of cracking .This includes the spot welds.
- Conduct a comprehensive maintenance optimisation programme which identifies appropriate maintenance periodicities and tasks through reliability centred maintenance investigations, balancing of exams to avoid extensive maintenance durations and maintenance blocking is incorporated into services to further improve efficiencies.
- Conduct component and system overhauls at the prescribed periodicities and avoid deferring heavy maintenance work.
- Improve traceability of component or system overhauls – this may result from an enhanced configuration management system.
- Conduct validation of the FEA assessment by undertaking practical testing of accelerations and loads as well as component and railcar masses and CoG analysis. This will allow the high stress areas of the carbody identified during this analysis to be strain gauged so that more accurate life predictions based on actual vehicle loadings can be made. The findings of this work will also allow adjustment of the FEA based load cases if the on track loadings are significantly different to those estimated.
- It is recommended that a thorough dimensional investigation using a weld gauge is carried out for the critical welds identified in this report. This may allow the Class 36 welds to be re-categorised as Class 80 welds, which will return a significantly higher fatigue life in these areas.
- Review the FEA input assumptions and seek to better the accuracy through improved measurement or calculation techniques.
- Seek to improve on-time running performance through improving all aspects of the network, of which rolling stock is a factor.
- Evaluate the requirements for new rolling stock in terms of quantities and timescales.

12.0 References

12.1 Fatigue Life Analysis

- Fatigue Load Cases Document for the A-series Railcar C3262-001 – Issue D.
- Eurocode 3: Design of steel structures- Part 1-9: Fatigue BS EN 1993-1-9:2005
- 3EAM 0-0052 “Description of Traction Control System for Perth EMU”
- PTA Drawing 60232 issue B & 60234 issue B, “Outline Drawings for Railcars”
- PTA A-series Floor Area Diagrams, (included as appendix A of [Ref. 1])
- Excel Spreadsheet from AECOM “FEA Mass Inputs as at 270213.xlsx”
- Walkers Ltd Drawing: Layout, Misc Under frame Eqt B1-W45104
- BS EN 12663, Railway applications. Structural requirements of railway vehicle bodies
- BS7608:1993 “Fatigue Design and Assessment of Steel Structures”.
- Maddox S J: 'International conference on the performance of dynamically loaded structures'. IIW 50th Annual Assembly Conference 1997

12.2 Study

- Personal correspondences as received from PTA
- Various data received from PTA, including but not limited to:
 - 2010051 A Series Depot License Final 21 Jul 11;
 - 2001-09 Measurement EMU Bogie Rubber Components Report01;
 - A-series Perth EMU Body and Interior Equipment manuals;
 - Westrail EMU Maintenance Guide;
 - Perth EMU System Description DR 89514PERTH;
 - A-F Service sheets;
 - A-service - Form No. 4030-109-001.3 Rev. 25;
 - B-service - Form No. 4030-109-001.4 Rev 29;
 - C-service - 4030-109-001.5 Rev 43;
 - D-service - Form No. 4030-109-001.6 Rev 40;
 - E service - Form No. 4030-109-001.7 Rev 40;
 - F service part 1 - Form No. 4030-109-001.9 Rev. 32;
 - F service part 2 - Form No. 4030-109-001.9 Rev. 32;
 - F service part 3 - Form No. 4030-109-001.9 Rev. 32;
 - Narrow Gauge Mainline Code Of Practice Document No. 8190-400-002 Rev 2.01;
 - Reliability data downloads from EMU asset management system
 - The Western Australian Government Railways Commission Contract No. 2299 for the Design, manufacture, Supply and Delivery of 21 Electric Multiple Unit Car Sets for use on 25 kV a.c. 1067 mm Gauge Suburban Railway
 - Smartrider ridership data

- Train timetables
- A-series Maintenance Agreement
- Delay Minutes
- Vehicle parameter list
- Strategic Review of the A Series Railcar Fleet's Future, Report No.ITPLR/TA2010/1
- QR EMU Report

Appendix A

Preventative Planned Maintenance Gap Analysis

Appendix B

Train System Study

Appendix B Train System Study

Overview

The development of this appendix has relied on a number of information sources, including train data, site visits and technical discussions.

Reliability data were compiled based on the following files as provided by PTA:

- AEA-AEB railcar Delays in Traffic 2000 to 2012.xlsx – this set of data contains information of train sub-system faults that have resulted in train delays. It should be noted that full data for 2012 is unavailable. Hence data were compiled over 12 years from 2000 – 2011.
- Work done on railcars 2000 to 2012.xlsx – this set of data contains information of faults and observations as recorded by the drivers that may or may not have caused a train delay. It also contains information regarding work carried out across the fleet from 2000 to 2012.
- EMU A Series Components.xlsx – this data contains information of train components installations and removal.

Observations made and issues identified were based on a number of site visits. Visual inspections of the A-series railcars 236 and 246 whilst undergoing General Overhaul and several other railcars (namely 201, 247, and 237) whilst in for routine inspections, A or B exams, were conducted on the following dates:

- 25th January 2013
- 14th February 2013
- 8th April 2013
- 18th April 2013

Traction and traction control

System description

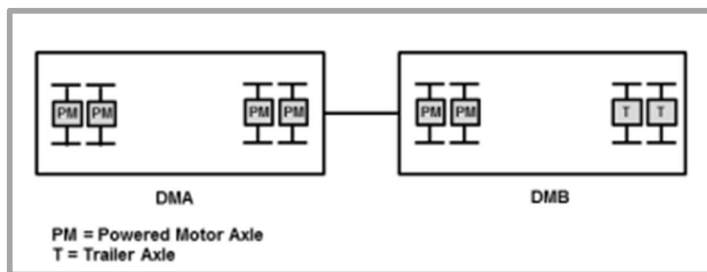
The power configuration for the A Series fleet consists of 75% motorisation of the 2-car units. That is each 2-car unit has 6 traction motors distributed amongst the two cars. The units use axle mounted 195kW DC traction motors, with current drawn from the 25kV overhead electrification system.

The units have the following car configuration:

- The first car, driver motor car (DMA) with 1 x pantograph and 4 x 195kW DC traction motors; and
- The second car, driver motor car (DMB) with 2 x 195kW DC traction motors.

Distribution of traction is illustrated in Figure 38.

Figure 38: Traction motors of the 2-car units



Observations and issues identified

Table 32 outlines the observations made and issues identified on the EMU traction and traction control system during site visits to Claisebrook train maintenance depot.

Table 32: Traction and traction control observations and issues identified

Components	Observations or Issues Identified
Traction control system	<ul style="list-style-type: none"> - System is old and experiencing a number of faults such as leaking capacitors, ageing and worn insulation, thyristor failures. - It was noted that PTA had purchased a sizable amount of semiconductors and capacitors spares prior to contract handover to BT/Downer.
Converter	<ul style="list-style-type: none"> - Converter experiencing micro-arcing issues resulting from poor insulation of coils and this has contributed to a number of earth faults. - Insulation failures have occurred. It is understood failures result from the original insulation material being too voluminous and not enabling sufficient heat to transfer to the outer heat sink.
Traction motor	<ul style="list-style-type: none"> - Typical overhaul is every 8 years. Reactive maintenance program is currently being carried out where motors are re-wound. -
Line reactors	<ul style="list-style-type: none"> - Experiencing earthing faults due to poor insulation performance resulting from age. - Reactors were re-varnished without re-winding of copper wire.
Semi-conductors	<ul style="list-style-type: none"> - Replaced on failure. - Semi-conductors are experiencing heat sink conducting issues.

Reliability issues

Traction Control System

Traction control system failures amount to 3% of the fleet total number of failures during the 12 years of data analysis, refer to Figure 39. The current system is approximately 20 years old and the trend for increased faults is likely due to the aged system.



Figure 39: Total traction control system faults across entire fleet



Figure 40: Image of traction control unit and thyristor converter

Faults of the traction control system are contributed to, by a number of sub-systems, refer to Figure 41.

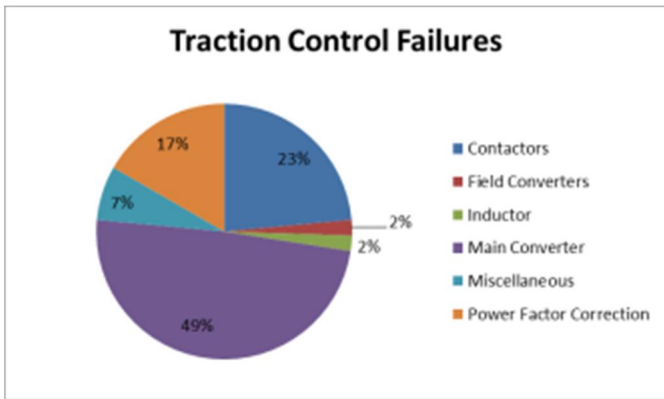


Figure 41: Traction control sub-systems faults

Main converter failures contributed to 48% of the total traction control failures, refer to Figure 42. The overall trend in failures is increasing with the maximum number of faults recorded in 2010.

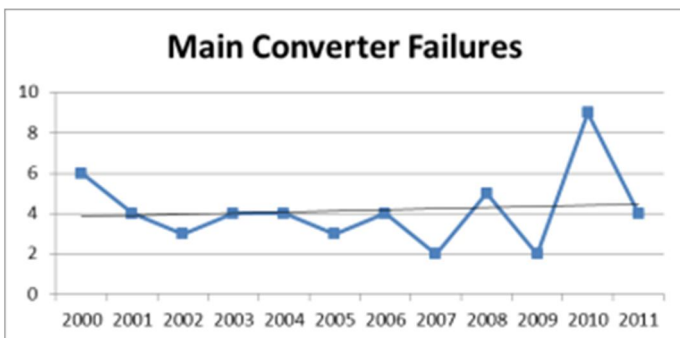


Figure 42: Total main converter faults across entire fleet

Contactors faults amount to 23% of the total traction control failures, refer to Figure 43. The overall trend for failures is increasing and closer examination of data reveals that a large proportion of faults were related to forward and backward contactor faults. Typically the faulty contactor was replaced during service. Other faults such as broken switch springs were noted and these were rectified by spring replacements.

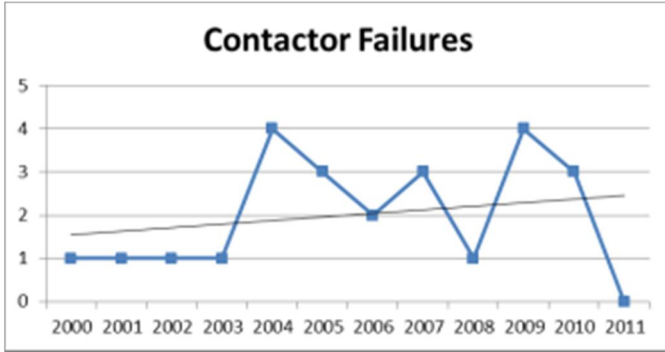


Figure 43: Total contactor faults across entire fleet

Traction Motor System

Traction motor failures amount to 9% of the fleet total number of failures over the past 12 years of data, refer to Figure 44. The data shows that the overall trend of failures increase with time and the maximum number of faults occurs in 2011.

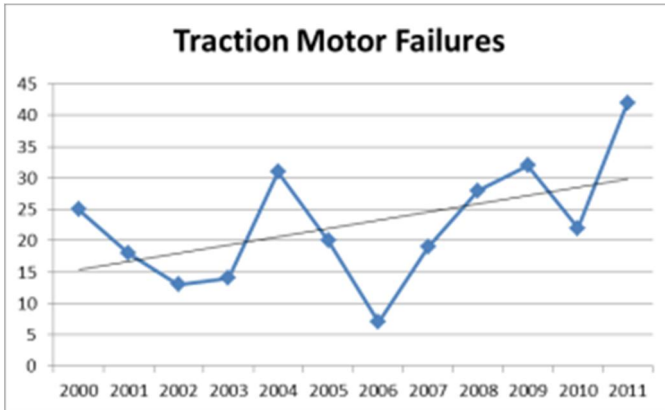


Figure 44: Total traction motor faults across entire fleet

The total traction motor faults are comprised of the breakdown illustrated in Figure 45.

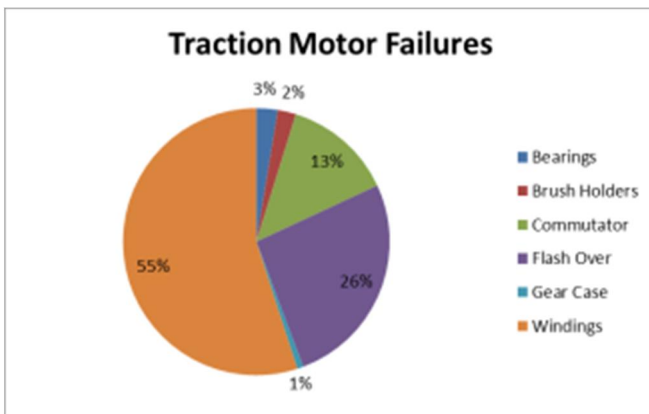


Figure 45: Traction motor sub-systems faults

Winding faults contributed to 55% of the traction motor failures, examination of data reveals that large proportions were apportioned to earth faults.



Figure 46: Total windings faults across entire fleet

Figure 46 shows an increased number of earth faults in 2004 and a number of traction motors were replaced to rectify the issue. This may have contributed to the improved reliability during 2004 – 2006 as reflected in Figure 44.

Reliability of traction motors worsened during 2006 – 2009 and this trend is also reflected in the installation data. From the discussion with PTA, it was understood that decreased reliability was likely due to the running of A Series railcars on the Mandurah and Clarkson train line. The increase of failures may have been due to traction motors being at higher running speeds for sustained periods of time on North-South line, where the units operated at 110km/h compared to 90km/h on the Fremantle line. It is understood from discussions held between AECOM and PTA that the number of traction motor flashover reports increased whilst the A-series was in operation on the Mandurah-Clarkson line during 2008-2009. Flashovers are not reportedly endemic with operations on the East-West lines.



Figure 47: Image of traction motor and a burnt traction motor that occurred during operation

Air and brakes

System description

The A series fleet employs an electro-pneumatic disc braking system manufactured by Faiveley (formerly Davies and Metcalf). The EMUs also have rheostatic braking capabilities.

The key brake components are:

- Compressor
- Air reservoirs
- Brake pipes and hoses
- Brake cylinders

- Brake blocks
- Brake valves

Observations and issues identified

Table 33 outlines the observations made and issues identified with the brake system during site visits and discussions with PTA.

Components	Observations or Issues Identified
Park brakes	<ul style="list-style-type: none"> - The rubberised spring covers are aged and show signs of UV degradation through material splits and cracks. - Fleet wide park brake replacement was carried out 3 years ago. - Some brake ratchets are experiencing corrosion, causing some brakes to remain on when the release mechanisms are actuated.
Brake manifolds	<ul style="list-style-type: none"> - Corrosion identified during overhauls and maintenance services - causing air leaks.
Callipers	<ul style="list-style-type: none"> - Calliper design lacks bushing and suspension support on bracketry to aid shock absorption. Noise issues have been noted.
Air dryer	<ul style="list-style-type: none"> - Experiencing obsolescence issues and oil leaking into the desiccators.
Bearings	<ul style="list-style-type: none"> - The steel bearings have been replaced by polymer bearings under direction of OEM, reduced longevity from polymer bearings.
Electronics	<ul style="list-style-type: none"> - Ageing system and require replacement.
Main air compressor	<ul style="list-style-type: none"> - Experiencing oil carry over issues. - Overhaul of compressors commenced from 1999 and was only completed in in 2009. - 6 pole motor was installed due to low duty cycle and this induced milky water to the system.

Table 33: Brake system observations and issues identified

Reliability issues

Brake System

The brake system amount to 15% of the total EMU faults. The trend is increasing with significant increase of faults during 2006 – 2008 as illustrated in Figure 46. This is further investigated and discussed below.

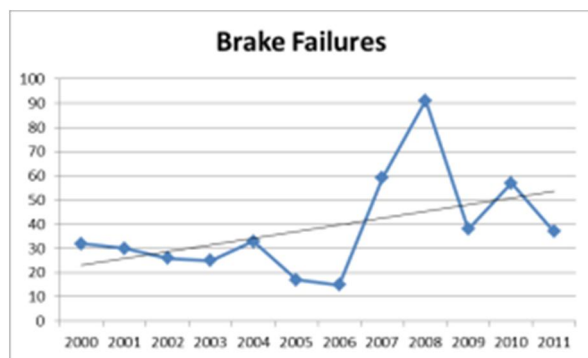


Figure 48: Total brake faults across entire fleet

The recording of brake system faults comprises a number of sub-systems, with the highest contributors being active component faults and electronic faults, refer to Figure 49.

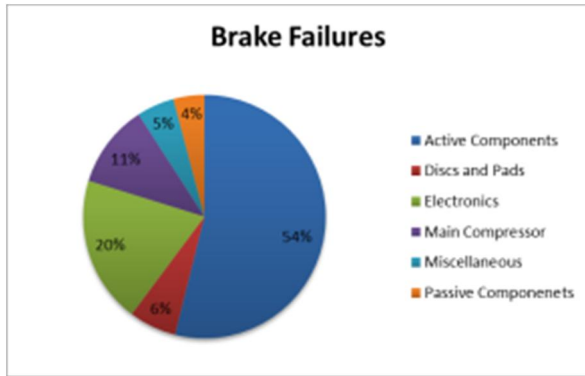


Figure 49: Brake sub-systems faults

Active components comprising of brake assist, traction control systems and electronic stability control systems amount to 54% of the total brake system faults, refer to Figure 50. Reliability worsened during 2006 – 2008, examination of data reveals that a large proportion of faults were associated with park brakes remaining ‘on’ despite release being selected. It was noted that a park brake replacement scheme was initiated during 2008/2009 and this is reflected as a decrease in the number of faults during 2009 to 2011. Other main contributors to decreasing reliability were related to Wheel slip/Slide Protection (WSP) system and smoke resonating from the brake pads. A program of WSP system resets and brake pad renewal mitigated much of these issues.

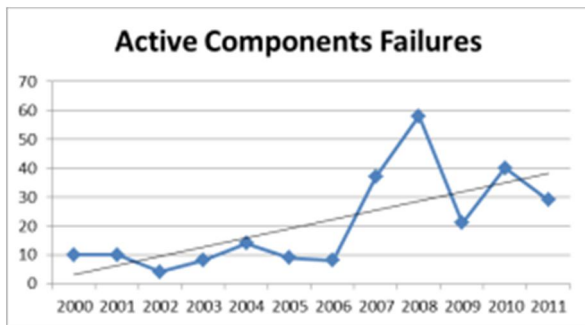


Figure 50: Total active components faults across entire fleet

Electronic faults comprising of electrical brake control system amount to 20% of the total brake faults, refer to Figure 51. Although the trend in electronic brake failures is decreasing with time, the highest number of faults occurred in 2012. Close examination of 2012 faults data revealed that large amounts of faults were associated with electronic brake control system (EBC 5). This issue is rectified when the system is re-set by the driver and was further investigated during train service. This observation is supported by discussions held with maintenance personnel during depot visits in that issues with ageing electronics are present.

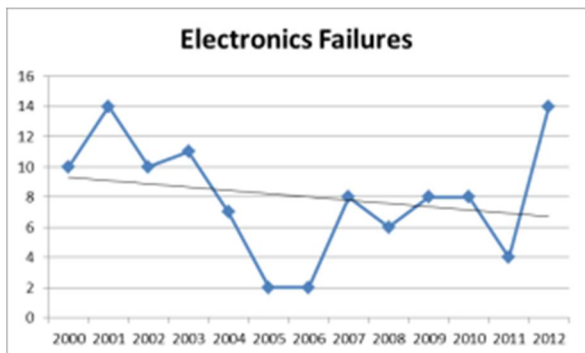


Figure 51: Total electronics faults across entire fleet



Figure 52: Image of brake control unit

Main compressor faults amount to 11% of the total brake faults, refer to Figure 53. The trend is increasing and examination of data reveals a large proportion of faults were associated with tripping of the compressor motor.

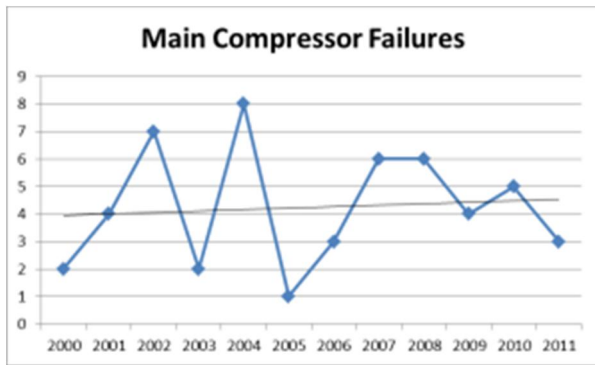


Figure 53: Total main compressor faults across entire fleet



Figure 54: Image of main compressor of brake system

Faults related to brake discs/pads amount to 6% of the total brake faults, refer to Figure 55. There was a significant increase in the number of faults in 2007 and 2008; examination of data reveals that the majority of faults can be attributed to reports of air leaking from the brake cylinder. Reliability improved significantly in 2009. Brake pad replacements are ongoing as part of the A service. All brake cylinders were replaced as part of a special program in 2008/2009

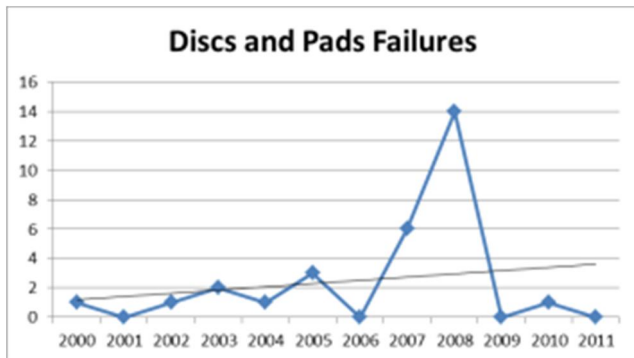


Figure 55: Total brake disc/pad faults across entire fleet



Figure 56: Image of brake disc and calliper

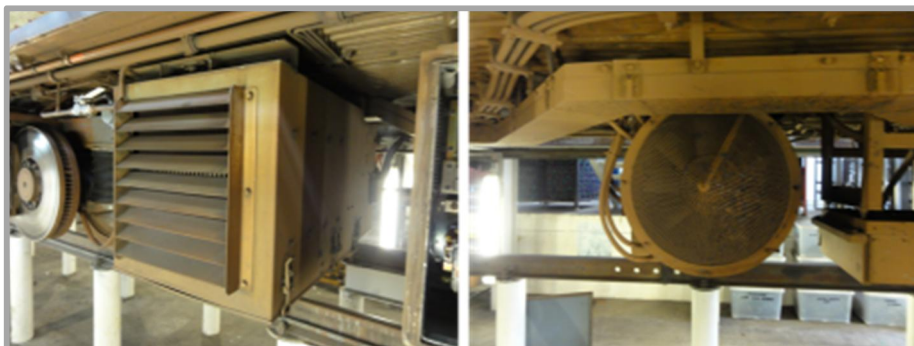


Figure 57: Image of brake resistor and fan

Dynamic Brake System

Dynamic brake faults amount to 1% of the total EMU faults, refer to Figure 58. The overall trend is decreasing and faults are generally related to earthing faults, many of which are rectified by renewing the dynamic brake grid. Reports of high temperature of the dynamic brake resistors were also noted.

The highest number of faults occurred during 2002 - 2004. Material usage data revealed that a number of dynamic brakes were installed/exchanged during 2005 and 2006, which may have contributed to a more consistent reliability performance during the period 2006 - 2011.

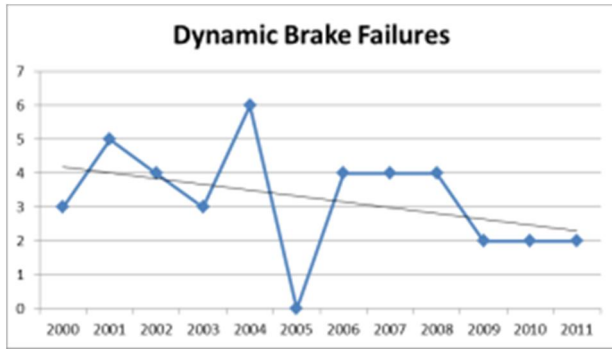


Figure 58: Total dynamic brake faults across entire fleet

Bogies

System description

The A series bogie consists of the following key components:

- H-frame structure
- Two wheel sets per bogie
- Chevron spring primary suspension
- Airbag and damper secondary suspension
- Outboard pneumatic disk brake system
- Cylindrical roller bearings
- Two motors and two driven axles per bogie (motor bogie)

Observations and issues identified

Table 34 outlines the observations made and issues identified with the A series bogie during visit to Claisebrook depot.

Components	Observations or Issues Identified
Bogie Structure	<ul style="list-style-type: none"> - No instances of structural problems or cracking of bogie frames have been reported. - Bogies were last overhauled in 2008.
Wheels	<ul style="list-style-type: none"> - Wheel turning takes place on an 18 months periodicity - Hollow tread is typically the reason for wheel turning, rather than flange wear or other wheel wear symptoms. - Wheelsets are currently being changed out on an 8 year cycle, however it is understood that wheels may last up to 12 years. - A consistent wear rate has been observed across fleet. - Wheel slide issues are experienced and believed to originate primarily from driver errors during braking, poor weather conditions or unsuspended axle probe.
Bearings	<ul style="list-style-type: none"> - No issues observed.
Primary suspension	<ul style="list-style-type: none"> - Rubber is degraded and extensively cracked due to UV exposure and requires replacement. - No issues reported with the condition of the springs.
Secondary suspension	<ul style="list-style-type: none"> - An airbag replacement programme was undertaken where a Phoenix secondary suspension system was installed. Refer to Figure 59.

Table 34: Bogie observations and issues identified



Figure 59: Image of bogie and secondary suspension

Reliability issues

The bogie system amounts to less than 1% of the total EMU faults refer to Figure 60. Further examination of data indicates that the majority of faults are related to air suspension issues such as loud noise and blown airbags. Examination of material usage data indicates that a number of bogies were overhauled in from 2002 to 2011. There are conflicting reports that 5, 18, or 24 bogies were overhauled during this period by PTA.

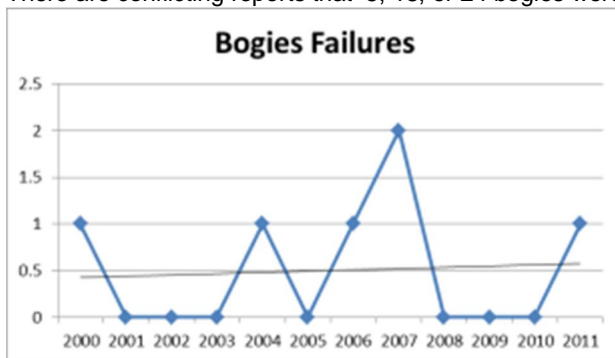


Figure 60: Total bogies faults across the entire fleet

Figure 61 shows the number of work orders completed across the entire fleet for primary suspension. The trend is decreasing and the works carried out were related to air bags splitting and vibration issues. The type of work performed on the primary suspension correlates to the faults identified on bogies.

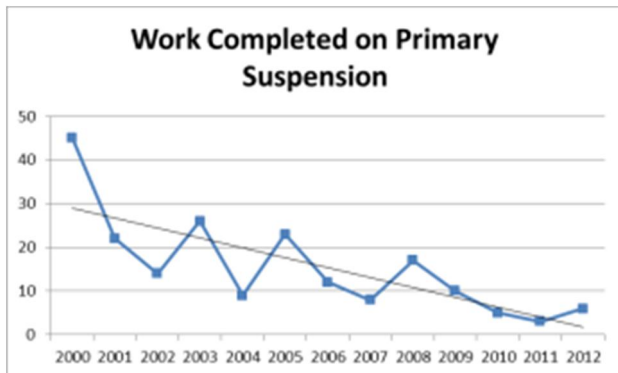


Figure 61: Total primary suspension work done across entire fleet



Figure 62: Image of primary suspension

Axle and wheel faults amount to less than 1% of the total EMU faults. Very few axle and wheel faults were noted which provides indication of their robustness and the appropriateness of the maintenance regime for this system.

Auxiliaries system

System description

The auxiliaries system is used to power all on-board systems except for the traction motors. The main components of the auxiliary system are the:

- Converter
- Batteries
- Compressor

Observations and issues identified

Table 35 outlines the observations made and issues identified with the A series auxiliaries system during visit to Claisebrook depot.

Components	Observations or Issues Identified
Converter	- Capacitor leakage has been observed.
Batteries	- Batteries have been replaced within the last 2 years.

Table 35: Auxiliaries system observations and issues identified

Reliability issues

Auxiliary system faults amount to 5% of the total EMU faults, refer to Figure 63. Reliability seems to be consistent over the years; however reliability seems to have worsened between 2009 and 2010. This will be further discussed below.

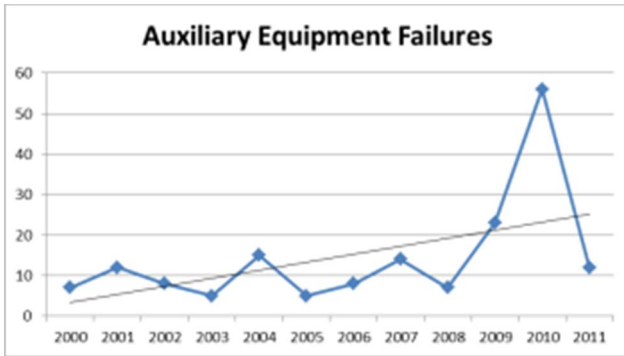


Figure 63: Total auxiliary equipment system faults across entire fleet

The recording of auxiliary equipment system faults comprises a number of sub-systems, refer to Figure 50.

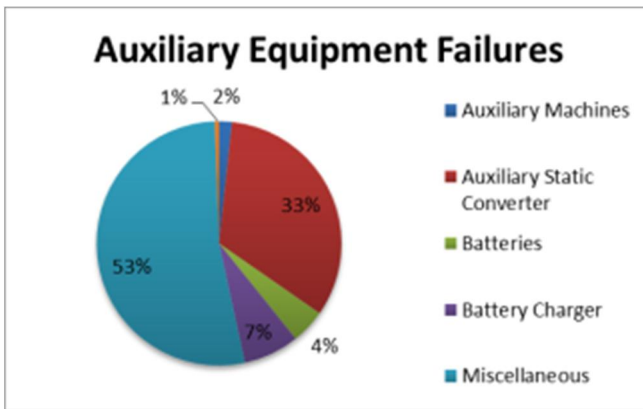


Figure 64: Auxiliary equipment sub-system faults

Miscellaneous amount to 53% of the total auxiliary equipment faults, refer to Figure 65. There is a significant increase in the number of faults in 2010. Examination of data reveals that a large proportion of faults were related to reports of ‘two cabs–activated’ faults. This issue was rectified by renewing the relays, However it was later reported that the relays were not at fault but drivers complaints instead... A number of motor contactor faults were also noted.

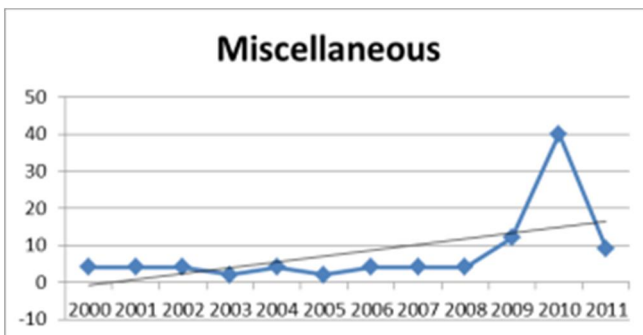


Figure 65: Total miscellaneous faults across entire fleet

Auxiliary static converters amount to 33% of the total auxiliary equipment faults, refer to Figure 66. Though the number of faults fluctuates historically, the overall trend is increasing. Examination of data reveals that these are related to internal fault of the auxiliary converter, converter disc faults and tripping of the circuit breaker.

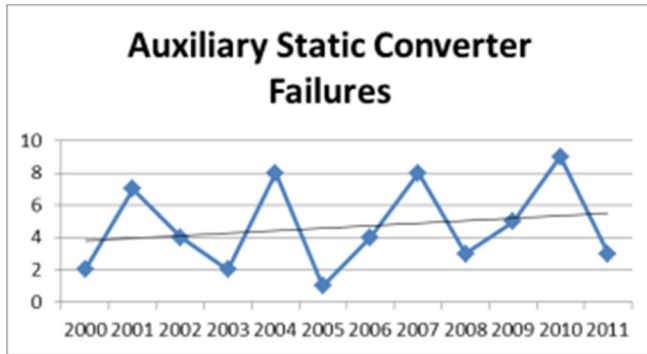


Figure 66: Total auxiliary static converter faults across entire fleet



Figure 67: Image of auxiliary converter, capacitors and contactor, leaking capacitor, damaged plastic backing

Faults of the battery charger amount to 7% of the total auxiliary equipment faults, refer to Figure 68. Close examination of data reveals that the majority of faults are related to defects occurring on the charger leading to battery's not being charged.

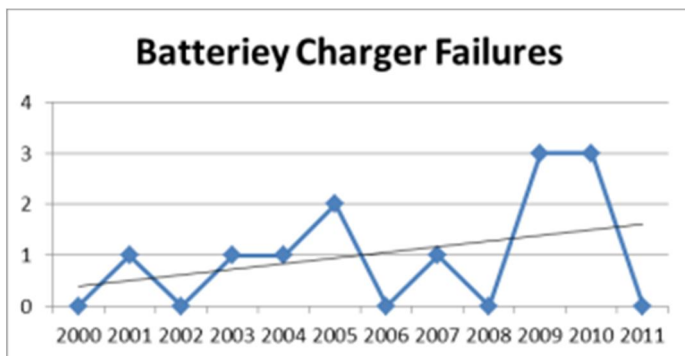


Figure 68: Total battery charger faults across entire fleet



Figure 69: Image of battery bay

Passenger doors

System description

The A series EMUs consist of two door pairs per car, which are air (pneumatic) operated sliding door. The doors are operated by passengers with door pushbuttons. The closing operation is initiated in the driver cab.

Observations and issues identified

Table 36 outlines the observations made and issues found on the passenger doors during discussions held during visits to Claisebrook depot.

Components	Observations or Issues Identified
Door operating mechanisms	<ul style="list-style-type: none"> - Door tracks and leafs are 20 years old and showing signs of wear. Tracks are warping and difficulties in door opening and closing are being experienced. Door tracks are being replaced on condition during the General Overhaul programme. Refer to Figure 70. - Breaking of door runner causing the leaf to fall away. - Door track material break-out and material thickness decreased. - Door piston needs to be renewed. - Substantial contamination around door piston and tracks resulting from oil leakage
Passenger emergency door release button	<ul style="list-style-type: none"> - Unreachable for passengers with reduced mobility.
Door leafs	<ul style="list-style-type: none"> - De-laminating skins affecting door operations. - Honey comb construction of aluminium covered by stainless steel panels. - Honeycomb structure degenerated and heavily corroded. - Corroded doors are replaced on condition.
Door cylinder	<ul style="list-style-type: none"> - Door cylinders are renewed or replaced as part of an F service.
Door control	<ul style="list-style-type: none"> - Replaced on average every 5 to 6 years. Refer to Figure 72. - Serial bus system results in taking longer to notify driver of door situation. On occasion, door closed is not recognised. <p>Door control units installed for railcars 201-243 starting in 2000 and completed in 2010. Earlier units are now due for replacement due to obsolescence. Railcars 244-248 already equipped with DCUs at time of commissioning, however will also be due for replacement.</p>

Table 36: Passenger door system observations and issues identified

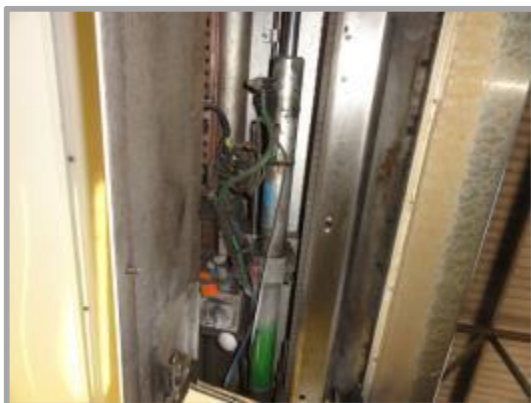


Figure 70: Image of EMU door mechanism



Figure 71: Image of door push button release and de-lamination of leaf aluminium skins



Figure 72: Image of door control unit

Reliability issues

Saloon door failures amounted to approximately 8% of the total number of failures over the past 12 years of data, refer to Figure 73. The number of faults is high in comparison to other systems, which is not unusual for a commuter rail system.

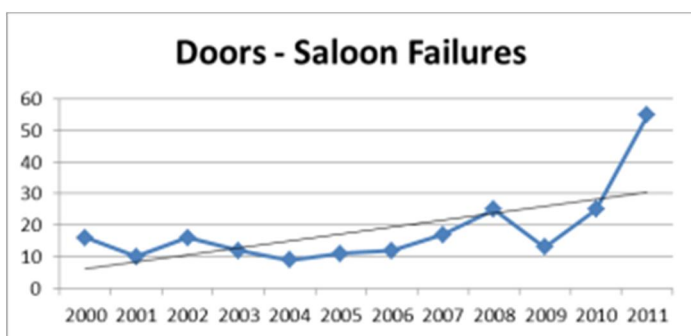


Figure 73: Total saloon door faults across entire fleet

The overall trend for failures shows an increase during 2011 the number of faults has approximately doubled in comparison to the previous year. It has been noted that the majority of faults were related to mechanical failures of the door control system such as sticky doors and door opening/closing failures.

Problems with the platform detection system were also experienced. From the discussions held with PTA on 15/02/2013, it is understood that the increase in faults during 2011 was due to the introduction of the platform detection system and a series of introduction and integration issues were experienced.

Air conditioning (HVAC)

System description

Each A Series EMU car incorporates two heating, ventilation and air conditioning (HVAC) units on the roof. The units provide temperature controlled air and ventilation for passengers. There is a ventilation system which recirculates conditioned air from the saloon into the drivers cab. The HVACs for each railcar unit has synchronised on and off control, however temperatures are set locally to each HVAC and there is no synchronised temperature control across the unit.

Observations and issues identified

Table 37 outlines the observations made and issues found on the HVAC system during discussions held during visits to Claisebrook depot.

Components	Observations or Issues Identified
Compressors	<ul style="list-style-type: none"> - Experience electrical faults that are difficult to trace such as earth faults. - Electrical obsolescence issue and mechanical fatigue issues will likely lead to overhaul of compressors soon, possibly change to rotary compressor. Overhaul is generally on average 8 to 10 years. - Experiences oil carry over from the crankcase occasionally. - Piping shows signs of age.
Cab Fan	<ul style="list-style-type: none"> - Additional blower fans were installed in between the cab and saloon to increase the air ventilation for the driver; however drivers report the modification has not been effective in providing cooling air to the cab. - Fans are experiencing earthing faults of the 3 phase system.
Refrigerant	<ul style="list-style-type: none"> - Currently undertaking gas change over from R22 to R134A. - Refrigerant leaks have been experienced.

Table 37: HVAC system observations and issues identified



Figure 74: Image of HVAC unit

Reliability issues

HVAC failures amount to less than 1% of the total fleet failures, refer to Figure 75. The overall trend for failures is decreasing and examination of data reveals that the majority of faults were mainly related to earth faults of the 3 phase system.

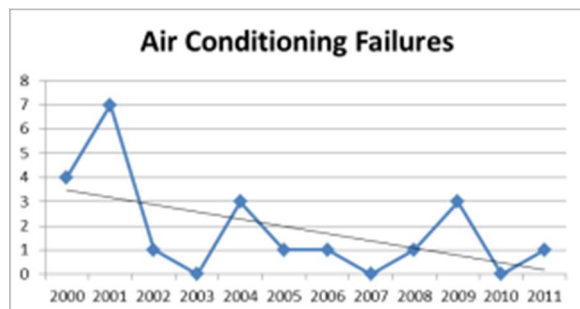


Figure 75: Total HVAC faults across entire fleet

Automatic train protection (ATP)

System description

The A Series fleet uses the L10000 ATP system manufactured by Ansaldo STS (formerly known as Ventura Projects, who were Australian agents for SRT Sweden).

Observations and issues identified

Table 38 outlines the observations made and issues identified with the ATP system during visit to Claisebrook depot.

Components	Observations or Issues Identified
ATP System	<ul style="list-style-type: none"> - Mechanical failures such as damaged buttons on drivers cab panel. - Transmission rack is experiencing signal problems with the antenna. Refer to Figure 76. - A number of transmission faults occurring at the DMA end. - Card and cables were originally fitted during 1990-1994 and have been replaced on fleet wide and condition basis. - Currently experiencing issues due to aging equipment.

Table 38: HVAC system observations and issues identified



Figure 76: Image of ATP antenna

Reliability issues

ATP system failures amount to 14% of the fleet total number of failures, refer to Figure 77. The overall trend is increasing where reliability decreased from 2004 – 2008. Examination of data reveals a large proportion were ‘H2’ faults which correspond to ATP recording unit faults. This issue is rectified by re-setting the system by the driver and was further investigated during train service. It was noted that a number of ATP antenna, driver display panel and ATP console were renewed during 2008 and 2009.

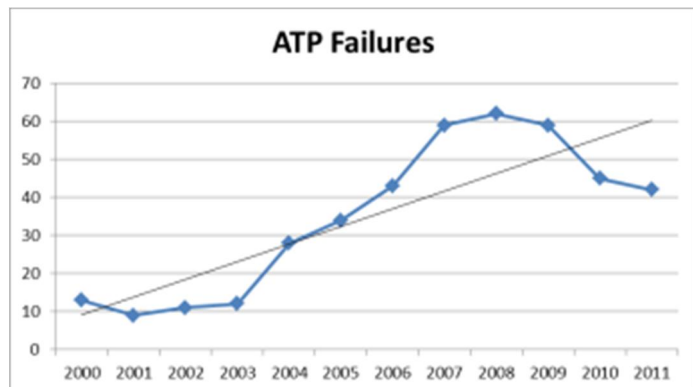


Figure 77: Total ATP system faults across entire fleet

ATP failures data provided by PTA is shown below in Figure 78. The overall trend is also increasing with the highest number of faults reported in 2011. Panel faults appears to have increased significantly in 2011, data suggests that these reports result from damaged buttons on drivers cab panel.

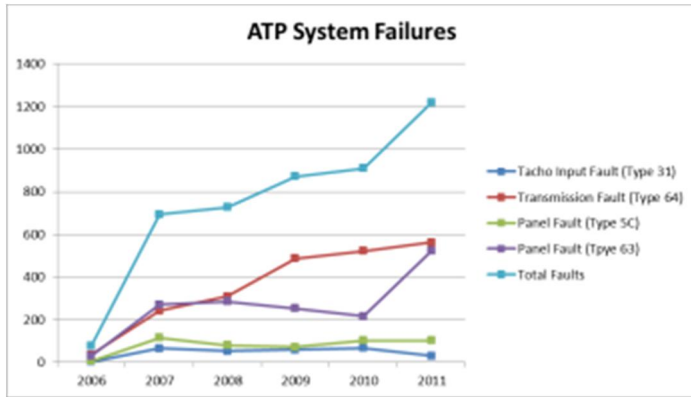


Figure 78: Total ATP system faults from 2006 – 2011

The recording of ATP system faults comprises a number of sub-systems, with the highest contributors being transmission faults and panel faults, refer to Figure 79.

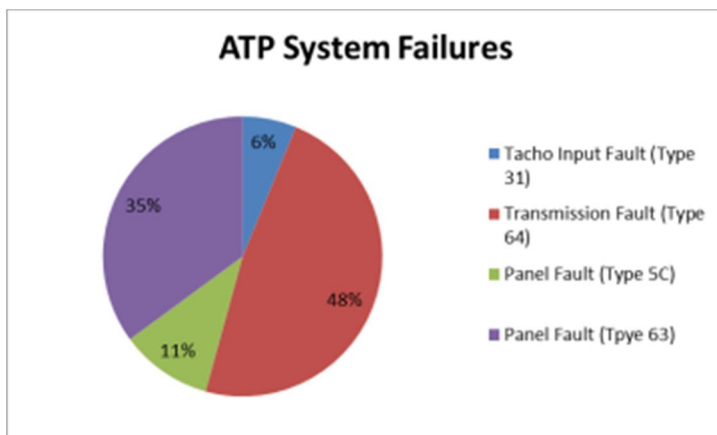


Figure 79: ATP sub-system faults

Communication systems

System description

The Communications units for the A Series consist of the following key sub-systems:

- Exterior destination displays on the front and back of each 2-car set
- Public address (PA) system
- Advertising and network map poster displays
- CCTV

Observations and issues identified

Table 39 outlines the observations made and issues found on the communication and PIS system during discussions held during visits to Claisebrook depot.

Components	Observations or Issues Identified
RAPID	<ul style="list-style-type: none"> - Experiencing system crashes frequently, rectified upon resetting of software. - System displaying and/or announcing incorrect station. - Loss of GPS signal was reported historically, however the GPS system has been replaced to rectify this issue.
Electrical	<ul style="list-style-type: none"> - Motherboard and hard drives are obsolete items. - Costly to replace motherboard, relays are readily available however motherboards are not.
CCTV	<ul style="list-style-type: none"> - CCTV analogue system installed recently, four cameras per 2-car set. Refer to Figure 81.
Radio system	<ul style="list-style-type: none"> - AM/FM radio has interference issues as a result of overhead wiring. - Train radio experiences intermittent failures. - Roof mounted antenna experiences corrosion issues. - Cables degeneration due to constant manipulation.
Mobile phone	<ul style="list-style-type: none"> - Obsolete item and very few spares remaining.

Table 39: Communication and PIS system observations and issues identified



Figure 80: Image of EMU showing external destination display



Figure 81: Image of EMU CCTV camera

Reliability issues

Failures related to Communication and PIS system amount to 7% of the total number of fleet failures, refer to Figure 82. It is evident from Figure 81 that the number of PIS and communications related failures is growing with time, significant increases in failures are visible in in 2007 and 2010.

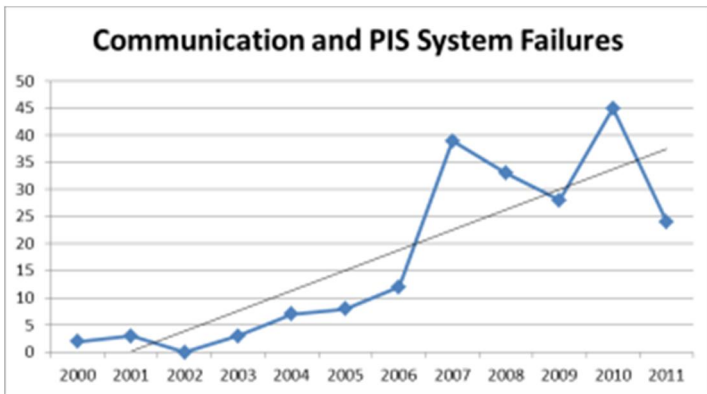


Figure 82: Total communication and PIS system faults across entire fleet

The communication and PIS system faults comprise a number of sub-systems, with the highest contributors to low reliability being the RAPID system, passenger intercom and radio system, refer to Figure 83.

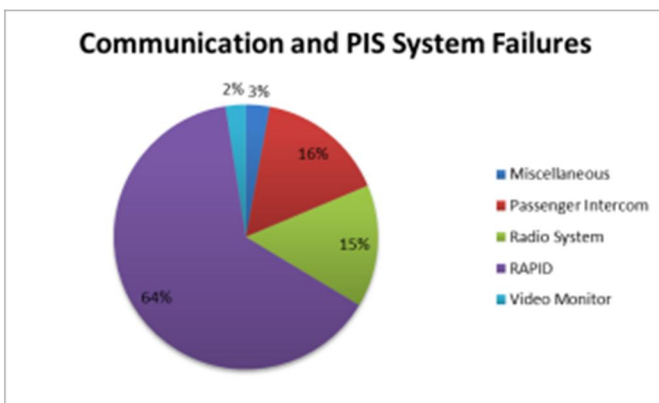


Figure 83: Communication and PIS sub-system faults

RAPID system amounts to 64% of the total communication and PIS system faults, refer to Figure 84. The system was introduced in 2005 – 2007 and the trend appears to be increasing. It was understood from meeting with PTA on 15/02/2013, that the increasing trend of faults from 2006 was due to introduction and integration issues. Examination of data reveals that a large proportion of faults are related to RAPID system crash and faulty PA

system. This observation is supported by the discussion held with PTA and maintenance personnel during site visits.

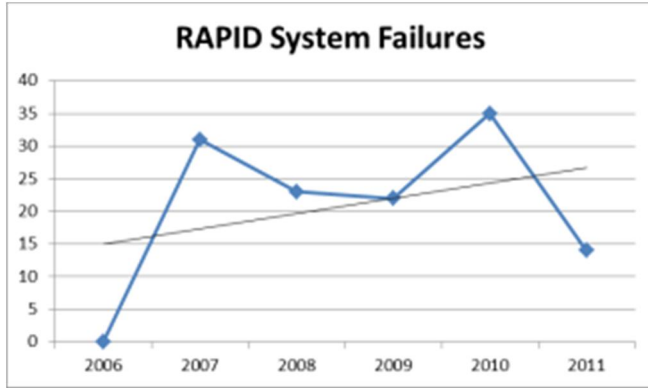


Figure 84: Total RAPID system faults across entire fleet from 2006 to 2011

Passenger intercom system amounts to 16% of the total communication and PIS system faults, refer Figure 85. The worst reliability years for passenger intercom system occurred in 2006 and 2010 and a high proportion of them were related to the faulty message announcement system and lack of door gongs.

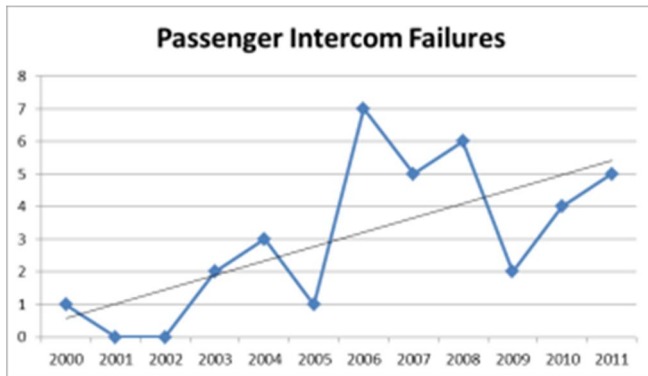


Figure 85: Total passenger intercom faults across the fleet

Carbody

System description

The A-series carbody comprises of a stainless steel carbody shell and stainless steel sheeting on the exterior. The structure includes inter-carriage gangways and inter-car doors for passenger movement between each car. Most major train systems (with the exception of the HVAC and pantographs) are hung from the underframe of the carbodies using bolts inserted to the threaded lugs welded to the carbody underframe.

Observations and issues identified

Table 40 outlines the observations made and issues identified with the A-series carbody during site visit to PTA depot.

Components	Observations or Issues Identified
Outer skin	- Stainless steel sheeting is in good condition with no visible signs of corrosion.
Saloon windows	- Corrosion to the aluminium window frames. Window frames and rubber sealing surrounds are replaced currently during general overhaul. Refer to Figure 86.
Underframe equipment boxes	<ul style="list-style-type: none"> - Much of the bracketry for the underframe equipment is hidden from view. - Where underframe components have been removed no significant corrosion is reported or observed for the mounting lugs. - Generally the mounting of the underframe equipment is in reasonable condition. Interior compartments to the equipment boxes are well painted and in good condition as are door hinge and bracketry. However the exterior of several boxes are beginning to show signs of progressive corrosion. Refer to Figure 88. - Cracks were observed in transformer mounting brackets, it is understood the cracks originate from welding issues. It is not known whether this will become an endemic defect. - Some of the equipment boxes were taken out for re-welding. - Corrosion to bolts and fixings was observed. Refer to Figure 89. - No secondary retention is present for the majority of underframe equipment boxes.
Inter-car gangway	- Original rubber gangway canopies have performed well. Gangways bellows are beginning to show signs of wear due to age. Refer to Figure 87.
GRP cab exterior structure	- Signs of cracking observed. Refer to Figure 92.
Roof panels	<ul style="list-style-type: none"> - Original panels were welded and riveted. Rivets adjacent to the cab GRP structure were changed to stainless steel for most of the fleet. Some spot welds for the roof panels were showing light corrosion from what is understood to be heavy cleaning on the roof panels with the use of scouring pads and wire brushes. Refer to Figure 90. - Some cars show evidence of roofs warping and corrugations forming.

Table 40: Carbody observations and issues identified



Figure 86: Image of corrosion residue on carbody structure after aluminium window frames are removed



Figure 87: Image of inter-car gangway bellows

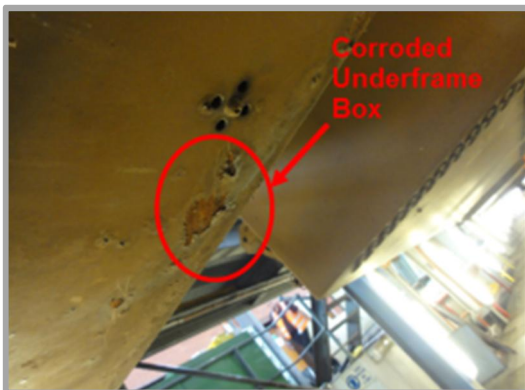


Figure 88: Image showing corrosion to underframe box



Figure 89: Image of corroded bolts of underframe equipment



Figure 90: Image of roof panels

Reliability issues

Failures due to external carbody amount to less than 1% of total EMU failures, refer to Figure 91. Very few failures and issues were noted. Issues such as objects collision and loosened wiper arms were noted. It has been noted that the majority of works performed on the carbody exterior were related to fibreglass cleaning and repairs.

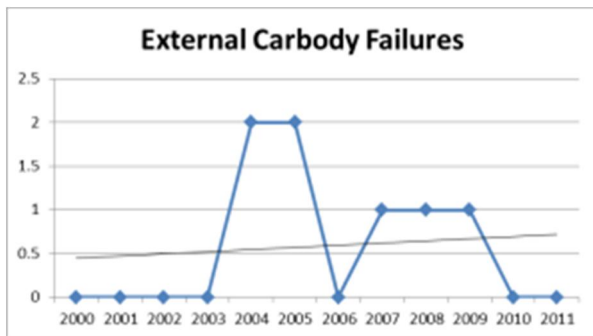


Figure 91: Total number of failures due to external carbody



Figure 92: Image of fibreglass fatigue cracks

Train delays due to vandalism amount to approximately 3% of the total EMU failures, refer to Figure 93. The trend is increasing with the highest number of occurrence in 2007. A large proportion of faults were related to door errors due to activation of emergency release as well as objects interference during door operations. Other issues such as broken/damaged door glass and windows as well as train collision with objects were also noted.

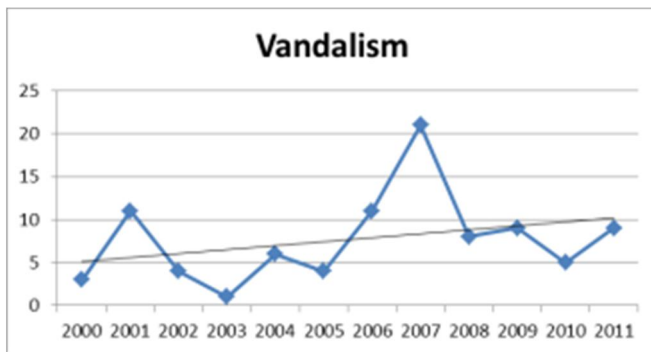


Figure 93: Total number of vandalism causing a train delay

Interior

System description

The A series interior consists of the following key components:

- Seats
- Standing areas with hand rails
- Wheelchair spaces
- Carpet flooring
- Fluorescent lighting

Observations and issues identified

Table 41 outlines the observations made and issues identified with the A-series interior during site visit to PTA depot.

Components	Observations or Issues Identified
General interior	<ul style="list-style-type: none"> - Interiors are in good condition. - Seats are stripped out and replaced on general overhaul.
Lighting	<ul style="list-style-type: none"> - The periodicity for saloon lighting renewal 144 weeks, Saloons are well lit and tubes seem well maintained - Inverters experience earthing faults. - Power supply system for the lighting is being modified currently and it operates on 50V DC at 200Hz. Modifications were undertaken due to inverters failing which caused power surges subsequently tripping the main circuit breaker.
Carpet flooring	<ul style="list-style-type: none"> - Units feature carpeted floors; these are replaced on condition during the general overhaul. A fleet wide replacement occurred from 2002 to 2007.

Table 41: EMU interior observations and issues identified



Figure 94: Image of saloon interior with seats stripped out

Reliability issues

There are few reliability issues on the A series which relate to the car interior. The saloon lighting failures in 2009 were resulted from delayed departure from the depot due to light replacement, refer to Figure 95.

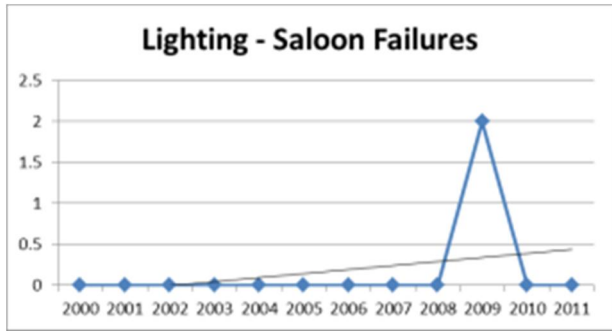


Figure 95: Total saloon lighting failures across entire fleet

Cabs and cab equipment

System description

The EMU cabs contain the following key components:

- Train controller
- Information displays for speed, brake pressure, air pressure etc.
- Switch panel
- Communication equipment
- Destination display control
- PA system control
- HVAC control
- CCTV recording system
- Lighting switches
- Relay boxes
- Driver seat

The driver cabs are located at the 1 and 2 ends of the DMA and DMB cars respectively, allowing it to be driven in either end.

Observations and issues identified

Table 42 outlines the observations made and issues identified with the A-series cab and cab equipment during visit to PTA depot.

Components	Observations or Issues Identified
Controller	<ul style="list-style-type: none"> - Controller is due for overhaul as the rubber componentry have failed due to age. Overhaul has commenced in 2010, 20 controllers have been changed to date and 28 more to go. - Controllers were initially a 4.5kg force spring and new spring were replaced in 2009/2010 which resulted in decreased number of failures. However drivers find controller is notchy and lacks consistency in operation and this issue is currently being looked with the OEM (Faiveley).
Cab glass	<ul style="list-style-type: none"> - Delamination of cab glass, hinges and seals are fracturing leading to corrosion.
Cab doors	<ul style="list-style-type: none"> - Frames are corroded and loose hinges. - Honeycomb interior deteriorating. - Door locks have no interlocking to the system.
Mobile phone	<ul style="list-style-type: none"> - Obsolete item and low number of spares.
Cab seat	<ul style="list-style-type: none"> - Were replaced fleetwide in 07/08 and then fully overhauled in 2011

Table 42: Cab and cab equipment observations and issues identified



Figure 96: Image of EMU cab (unit 36)



Figure 97: Image of relay box within drivers cab (unit 36)

Reliability issues

Failures due to controllers amount to approximately 2% of the total EMU failure, refer to Figure 98. The overall trend is increasing with the maximum faults reported in 2008. Examination of data reveals majority of faults were due to faulty controllers causing park brake to remain on upon release. This issue was rectified by replacing the controller. It was noted that controllers were overhauled/changed in 2009 – 2010 and this may have resulted in the improved reliability.



Figure 98: Total controller failures across entire fleet

General issues

Observations and issues identified

Table 43 outlines any general observations made and issues found on the A series during site visit to PTA depot.

Components	Observations or Issues Identified
Couplers	<ul style="list-style-type: none"> - Electrical interface issues were experienced. - Corrosion of the couplers as well as wear was noted. - Couplers are re-lubricated every 12 weeks.
Wiring and looming	<ul style="list-style-type: none"> - Wiring has not been changed on EMUs. - Generally in good condition.
Pantographs	<ul style="list-style-type: none"> - Experiencing wear and tear of the rams and seals as well as corrosion to the copper contactor. - Cracks to the mounting points and centre band fatigues were observed. Cracks may cause the roof to leak during the wet season. - Overhaul of system is planned to be carried out in the near future.

Table 43: General observations and issues identified



Figure 99: Image of EMU's coupler



Figure 100: Image of wiring inside the cab



Figure 101: Image of the pantograph

Reliability issues

Couplers faults amount to 1% of the total EMU failures, refer to Figure 102. Coupler faults are generally linked to 'stuck' couplers where there were problems coupling and uncoupling.

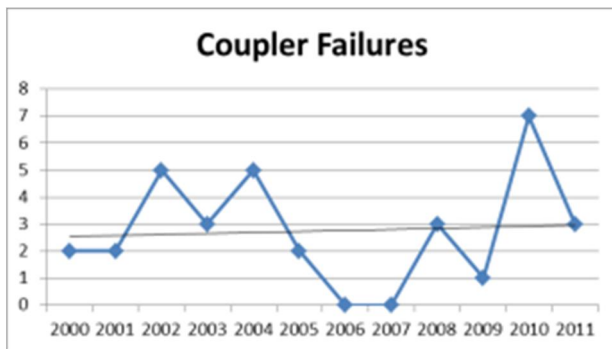


Figure 102: Total number of couplers failures across entire fleet

Appendix C

Market Analysis

Appendix C Market Analysis

12.3 NEW Zealand Ganz Mavag

12.3.1 Objective

The Wellington Regional Rail Plan (RRP) titled 2010 – 2035 'A Better Rail Experience' provides for the long term development of the region's rail network. The RRP's objective is to address specific problems facing the Wellington rail network and leverage opportunities to move more people and freight from road to rail transport.

Key issues experienced on Wellington rail network had included; poor reliability, lack of capacity across the network, low frequency of services, ageing train fleet and infrastructure, in which many of these issues are a result of historically inadequate investment in the network.

12.3.2 Background

The Greater Wellington Regional Council (GWRC) unveiled a plan for the upgrade of the Wellington commuter rail system to increase capacity and service frequencies. Part of the RRP involved determining a business case for the procurement of the Matangi units to replace ageing Ganz Mávag rolling stock, which is over 30 years old. As part of determining a business case for these units, an assessment of future investment was conducted, which considered whether heavy maintenance / refurbishment intervention of the existing fleet was preferred over fleet replacement.

Until the recent introduction of the Matangi units, the English Electric units have been operating since 1938 and Ganz Mávag EMUs since 1979 on the Wellington passenger network. A brief history/background of each of fleet is summarised below.

English Electric EMU

The New Zealand DM/D class, also known as English Electrics were a class of Electric Multiple Units (EMU) used on the rail passenger network of Wellington, New Zealand. The railcars were built by English Electric in the United Kingdom between 1938 to 1954. The units entered service in 1938. After 40 years of service, the majority of English Electrics were replaced by EM/ET class, also known as Ganz Mávag railcars in 1982 – 1983.

Due to traffic growth on the rail network, the English Electric cars continued to operate to meet capacity. The remaining railcars underwent life extension refurbishment during 1984 – 1986 and again in the early 2000s. The last English Electric cars were replaced by the Rotem Matangi units in 2012.

Ganz Mávag EMU

The Ganz Mávag railcars were built in 1979 – 1982, a type of EMU that were constructed of 'weather resistant steel'. A total of 44 two car units were introduced into service in Wellington, later only 42 units remained available for operational service due to train collisions.

The fleet was refurbished in 1995 which involved the painting of exterior car body, as well as interior upgrade such as flooring and seat replacement. During the life of the railcars, the electrified infrastructure has never been upgraded and as a result, the electrification system has degraded over time and subsequently caused the motors to degrade at a similar rate.

The fleet has become more sensitive to power surges and susceptible to overloading/blowing motors since the network power upgrade was undertaken for supporting the introduction of the Matangi fleet. As the units have aged, they have ultimately become less reliable (average of 12,000km MDBF at present). There are also significant obsolescence risks with train system componentry.

When Rotem Matangi units were introduced into service from 2010, Ganz Mávag units were either to be replaced or refurbished at the end of its operation life. Four business cases were developed by GWRC to convey cost/benefit analysis of refurbishment versus replacement by Matangi units. In 2010, a prototype refurbishment Ganz Mávag unit was completed to ascertain more accurately the unit costs for a fleet refurbishment and assist with a decision to refurbish/replace the entire fleet.

Matangi EMU

The FP/FT Matangi class are a type of EMU that are currently being introduced for the commuter rail network of Wellington. The Matangi's are constructed with stainless steel carbodies, built by Hyundai Rotem/Mitsui in 2008 and entered into service from late 2010. A total of 48 two car units are currently operating on the Wellington network.

The Matangi units have enabled an increase in the capacity of the Wellington network and have allowed the retirement of the remaining English Electric units. The Matangi units are the preferred units for the bulk of operations both peak and off-peak and will eventually replace the Ganz Mávag units entirely.

12.3.3 Relevance to PTA

There are several aspects which are of specific relevance to the PTA and the life extension study for the A-series railcars:

- Business case investigation involving technical and economic considerations of complete replacement and extension of asset life.
- Purchased new rolling stock to replace the existing EMUs, as EMUs have reached and in some cases exceeded their operational life expectancy.

12.3.4 Work undertaken

GWRC developed business cases comprising of 4 options:

- Option 1: Replace Ganz Mávag fleet at the end of life (present time)
 - The first batch of Matangi units cost is in the order of \$205 million for 96 cars.
 - The second batch of Matangi units cost is in the order of \$140 million for 35-36 two car units (final figures to be announced).
- Option 2: Retain Ganz Mávag fleet and operate for further 5-10yrs
 - This option was unattractive as the units are experiencing a high frequency of failures. It was predicted that future reliability would decrease over the next 5 to 10 years to approximately ~8,000km MDBF.
- Option 3: Retain Ganz Mávag fleet and undertake a mechanical reliability and safety focussed refurbishment
 - The approximate cost is in the order of \$55 - \$65 million across the fleet.
- Option 4: Retain Ganz Mávag and invest in mechanical and interior refurbishment
 - A prototype of this option was carried out.
 - The approximate cost is in the order of \$90 million across the fleet.

The scope of the refurbished Ganz Mávag prototype unit (Option 4) includes the following features:

- Structural integrity and life extension
 - Carbody – replacing corroded material and refresh corrosion protection system; inspect and restore as required the structural integrity of underframe mounting points.
 - Bogies – Non-destructive test (NDT) and ultrasonic test programs were carried out to detect and rectify cracks.
- Reliability improvement
 - Traction control system – full system overhaul was carried out to enable better control of wheel slipping during acceleration and better traction control.
 - Auxiliary power supply – full system overhaul and specific modification carried out to restore and improve the motor/alternator set; replaced existing life expired standby batteries.
 - Brake system – full system overhaul was carried out.

- Passenger door – additional feature including obstacle detection, passenger door controls and doors opening and closing times improved.
- Safety and accessibility improvement
 - Emergency brake over-ride – new system installed.
 - CCTV – new system installed similar to the Matangi system.
 - Fire safety – improved through the use of better fire performance materials in seat fabric, floor covering and side panel insulation as well as installation of smoke detector.
 - Emergency escape – installation of break window hammers in saloon interior and door step-well lights.
 - Anti-climb device – installation on the cabs to improve passenger safety in an event of collision.
 - Cab windscreen – replaced windscreens.
 - Wheel chair spaces – installation of individual flip-up seat arrangement to improve space available for wheelchair parking.
- Passenger/train crew comfort and amenities improvement
 - Passenger communications – installation of new Public Address (PA) and Passenger Information Display (PID) system.
 - New passenger seats – installation of new seats with Matangi style seat fabric.
 - Interior fit-out – cosmetic upgrade to be consistent with Matangi units.
 - Driver interface – replaced existing pneumatic wiper with electric wiper; removal of obsolete switches and installation of new controls.
- Vehicle aesthetics/finish
 - Painting and branding – painted new to ensure weather tightness; co-branded livery fitted to create consistent feel with the Matangi fleet.

A whole of life cost estimate was developed to compare the continuing operation of the Ganz Mávag beyond their 30 year design life and the maintenance costs of Matangi units. It was estimated that the Ganz Mávag is approximately 2.5 times more expensive to maintain than the Matangi with life cycle cost of Ganz Mávag in the order of \$2.5 million and \$1 million for the Matangi.

12.3.5 Conclusions

The four options in the business case were assessed and the preferred scenario was identified as Option 3 in which it proposed to undertake system modernisation and mechanical upgrade to increase reliability and to ensure safe operation of train. However, the funding of the ongoing maintenance costs of the Ganz Mávag railcars present an issue for the New Zealand Government. After further consideration with operating costs being the drive factor, the final decision was changed to Option 1 being fleet replacement. The capital cost to fund the fleet replacement is justified by the operational savings.

Table 44 provides a summary of the advantages and disadvantages of each option.

Options	Advantages	Disadvantages
Option 1 – Replace Ganz Mávag fleet at end of life	<ul style="list-style-type: none"> - Capital gains from increased patronage and ticketing revenue, arising from: <ul style="list-style-type: none"> • Increased reliability; • Improvement in system wide timeliness as a result of improved reliability; and • Improved passenger comfort and amenities. - Standardising on a single fleet type may provide for 	<ul style="list-style-type: none"> - Uncertainty of project funding as it is unlikely that the Government would be willing or able to meet capital cost. - Capital losses from decreased patronage and ticketing revenue, arising from: <ul style="list-style-type: none"> • Declined reliability of fleet until replacement; • Decreased in system wide timeliness as a result of declining

Options	Advantages	Disadvantages
	<p>maintenance efficiencies.</p>	<p>reliability; and</p> <ul style="list-style-type: none"> • Unattractive, out-dated interior and seating as well as lack of passenger communication systems would discourage some passenger from using metro rail. <p>- Unplanned maintenance costs would increase due to increasing of mechanical failures.</p>
<p>Option 2 – Retain Ganz Mávag fleet and operate for further 5-10yrs</p>	<p>- No financial impact arising from capital expenditure to purchase new railcars.</p>	<p>- Long term capital losses from decreased patronage and ticketing revenue, arising from:</p> <ul style="list-style-type: none"> • Declined reliability of fleet until replacement in 5 – 10 years; and • Decreased in system wide timeliness as a result of declining reliability. <p>- Unattractive and out-dated interior and seating as well as lack of passenger communication systems would discourage some passenger from using metro rail.</p> <p>- Unplanned maintenance costs would increase due to increasing of mechanical failures.</p>
<p>Option 3 – Retain Ganz Mávag fleet and undertake a mechanical reliability and safety focussed refurbishment</p>	<p>- Capital gains from increased patronage and ticketing revenue, arising from:</p> <ul style="list-style-type: none"> • Increased reliability; and • Improvement in system wide timeliness as a result of improved reliability. <p>- Capital gains available sooner as refurbishment would be achieved sooner than replacement.</p> <p>- Project funding available as Government has indicated its willingness to co-fund payment.</p>	<p>- Capital gains from patronage and ticketing revenue may potentially be constrained, as passengers would not tolerate:</p> <ul style="list-style-type: none"> • Unattractive and out-dated interior and seating; and • Lack of passenger communication systems. <p>- Passenger may avoid Ganz Mávag railcars by altering their travel patterns. This may lead to overcrowding on Matangi services.</p>
<p>Option 4 – Retain Ganz Mávag and invest in mechanical and interior refurbishment</p>	<p>- Capital gains from increased patronage and ticketing revenue, arising from:</p> <ul style="list-style-type: none"> • Increased reliability; • Improvement in system wide timeliness as a result of improved 	<p>- Replacement of Ganz Mávag is still required due to life extension design limit to approximately 15 years.</p> <p>- Reliability of refurbished Ganz Mávag trains is still less than the new Matangi fleet. (Ganz</p>

Options	Advantages	Disadvantages
	<ul style="list-style-type: none"> reliability; and • Passenger satisfaction as a result of improved passenger comfort and on-train communication systems. - Capital gains available sooner as refurbishment would be achieved sooner than replacement. - Project funding available as Government has indicated its willingness to co-fund payment. 	<p>Mávag ~35,000km MDBF, Matangi >50,000 MDBF).</p>

Table 44: Advantages and Disadvantages of Options

In 2012, the GWRC had placed a second order for further Matangi units, a total of 35 – 36 (final figure to be announced) two car units with improved specification such as upgraded traction motors.

The Ganz Mávags are planned to be retired when the next Matangi units enter into service. However a residual 11 – 12 two car units will be retained to be brought out for special events to provide additional network capacity.

Note – costs are based on New Zealand Dollars.

12.4 Hong Kong KCR Metro Cammell EMU life extension project by Alstom.

12.4.1 Objective

Alstom were commissioned by Kowloon-Canton Railway Corporation (KCR), in 2006, later becoming part of Mass Transit Railway Corporation (MTR), to consider the scope of a life extension refurbishment program on the Metro Cammell EMU trains used on the East Line in Hong Kong. The life extension investigation included:

- Assessment of technical and commercial viability of rolling stock for life extension to 40 or 50 years of further service;
- Identification of critical upgrades to meet train service requirements, reliability requirements, improved maintenance and operational costs, and updated legislation for life extension; and,
- Identification of solutions to provide high reliability and low cost.

12.4.2 Background

The railcars were commissioned between 1982 and 1992 forming a fleet of 351 railcars. A refurbishment was undertaken over the period from 1996 to 1999. The refurbishment was performed to increase interior space in order to meet the increased ridership demand. The refurbishment scope included replacement of transverse seating with longitudinal bench seats generating more space for standing passengers, removal of toilets, increasing the number of doorways from 3 per side to 5 per side of each railcar, removal of the freight compartment between driving cab and first class compartment along with the inter-car doors, removal of intermediate driving compartments and the removal of gangway doors excluding first class.

Additional legislative requirements introduced in 1994 required train lengths to be a minimum 12 car configuration. Thus, these particular railcars originally of 3 car configuration were converted to a 12 car configuration.

Safety systems have been enhanced from the original train design with improved Automatic Train Protection systems.



Figure 1: MTR Metro Cammell EMU (DC)

12.4.3 Relevance to PTA

There are items of relevance to the PTA from the QR study conducted by AECOM, they are as follows:

- Required a life extension investigation involving technical and economic considerations of complete replacement and extension of fleet life over a number of different durations.
- Performed Finite Element Analysis (FEA) on the carbody and bogies
- DC traction system and longitudinal seating

12.4.4 Work undertaken

Alstom's study included the following works:

Train structural integrity of carbody and bogies using strain measurement testing and FEA:

FEA of the carbodies included consideration of future changes to passenger mass loadings, and subsequently tested for the service and crush loads for both the current and potentially upgraded Metro Cammell trains. Carbody design fatigue loads were verified using strain measurement testing of door apertures, window surrounds, and the car body frame in both loaded and unloaded states.



Figure 2: Design fatigue loads verified through car body strain measurements

The three cases modelled were the 'design', 'as-built design', 'current operating design', and 'life extended design' with increased passenger loading. Each case was tested using design specified vertical vibration accelerations of $\pm 0.15g$ for 10^7 cycles and the unloaded tare mass case was modelled using design specified vertical vibration accelerations of $\pm 0.30g$ for 10^7 cycles. Each case was also tested using peak vertical vibration accelerations of $\pm 0.22g$ for loaded and $\pm 0.45g$ for unloaded.

The 'life extended design' was modelled with a higher design vertical vibration acceleration equivalent to the current peak vertical vibration accelerations. It was also modelled with an increase in passenger average masses and passenger standing density during crush loading.

Based on the Carbody FEA results presented in Figure 3 below, it was concluded that continuing under the current operation would allow the railcars to achieve an additional 10 years beyond their 30 year design life. Note, the underframe mountings were already being upgraded at the time the FEA was performed and was taken into consideration in the analysis. However, it was also identified that any increase in the passenger loadings presents risk to the railcar of failing to achieve the additional 10 years and would subsequently need to be monitored annually through checking of the car body camber. Under the life extension option, an additional 20 years could be achieved for the railcars provided upgrade works occurred at the end of design life to account for future increases in passenger loading and for increased fatigue life.

	Design Life Years	Design Load	Design Vibration	30 Years	40 Years	50 Years	Over Loading Risk
Original Build	30	57 kg 7 to 8.4 per m ²	± 0.15 g	✓	✓	×	No
Rolling Stock	30	57 kg 7 to 8.4 per m ²	± 0.15 g	✓	✓	×	No
Current Operation	30+	62 kg 7 to 8.4 per m ²	± 0.15 g	✓	✓	×	Yes
Life Extension 2015-2035	40+	65 kg 7 to 9 per m ²	± 0.22 g Recommended	✓	Upgrade needed		

Figure 3: Results from Carbody FEA

The FEA conducted on the bogies required input loadings from on-track testing. The track loadings exceeded those specified in the bogie design limits. At the time of study, the service design life for motor bogies (15 years) and trailer bogies (20 years) had already been exceeded and the bogies were undergoing heavy maintenance and weld repairs to ensure structural composition was maintained. It was identified that to achieve a 20 year life extension of the bogies to match that of the car bodies, post complete fleet inspection of bogies, replacement of the motor frames would be required and the trailer frames would need to be further validated before identifying if they would need replacement.

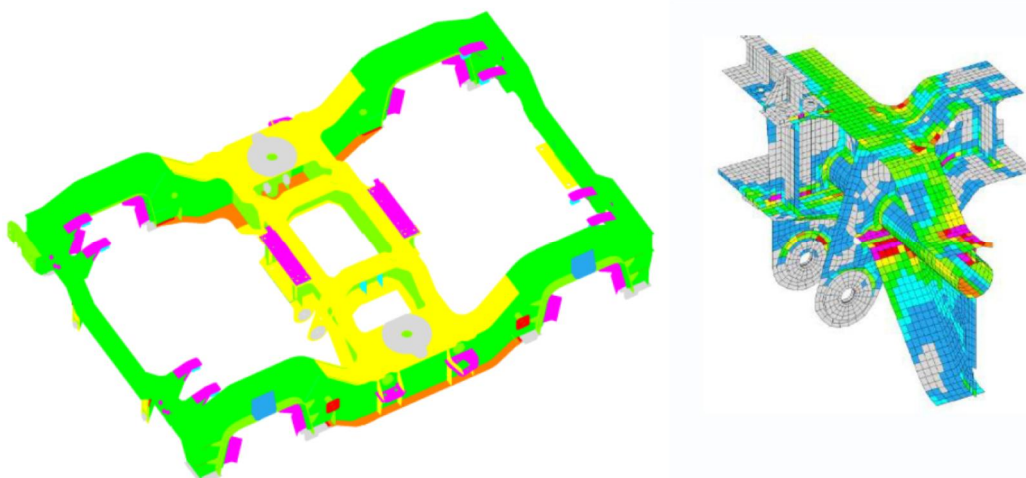


Figure 4: FEA of Bogies

Life extension of cars:

Four life extension options were considered:

- That with the lowest lifecycle cost,
- That with maximum reliability, and
- Replacement at end of life with new train,
- An optimal solution that achieved a balance of reduced lifecycle costs, and improved reliability, and economical period for life extension (or none) before replacement of current trains with new trains.

Key systems for renewal or upgrade were determined based on consideration of the costs and benefits. Benefits included improved structural integrity for life extension, removal of equipment nearing obsolescence, and improving the performance of equipment to achieve better reliability and efficiency. This is outlined in Figure 5 below.

	Key Systems	Cost Incurred For
Structural Integrity	- Car body - Bogie	- Life Extension
Expired Equipment	- Electrical - Interior - Traction	- Routine Maintenance - Overhaul
Equipment Performance	- Doors - Traction - Control	- Reliability - Efficiency

Figure 5: Key systems identified for renewal and upgrade

Phasing of key systems identified for upgrade or renewal for life extension is as below:

	2007-2008	2007-2010	2012-2015
Structural Integrity	- Car body	-Bogie - Bolster	-
Expired Equipment	- Gears	- Power Equip - Axles	- Electrical - Interior - Traction motor
Equipment Performance		- Traction upgrade	- Doors - Control

Figure 6: Key systems to renewal or upgrade over a period of 8 years

Of note, AC traction with/without brake boost system was investigated to replace the existing DC traction system. Benefits of AC traction boost included higher accelerations from stop position, maximising regenerated energy with up to 40% energy savings, minimising use of pneumatic brake and brake pad wear by as much as 90%, and the additional circuitry required for AC traction was considered simple and not software based. See Figure 7 below for the capabilities of the AC traction braking system with and without boost compared to DC traction braking and friction braking.

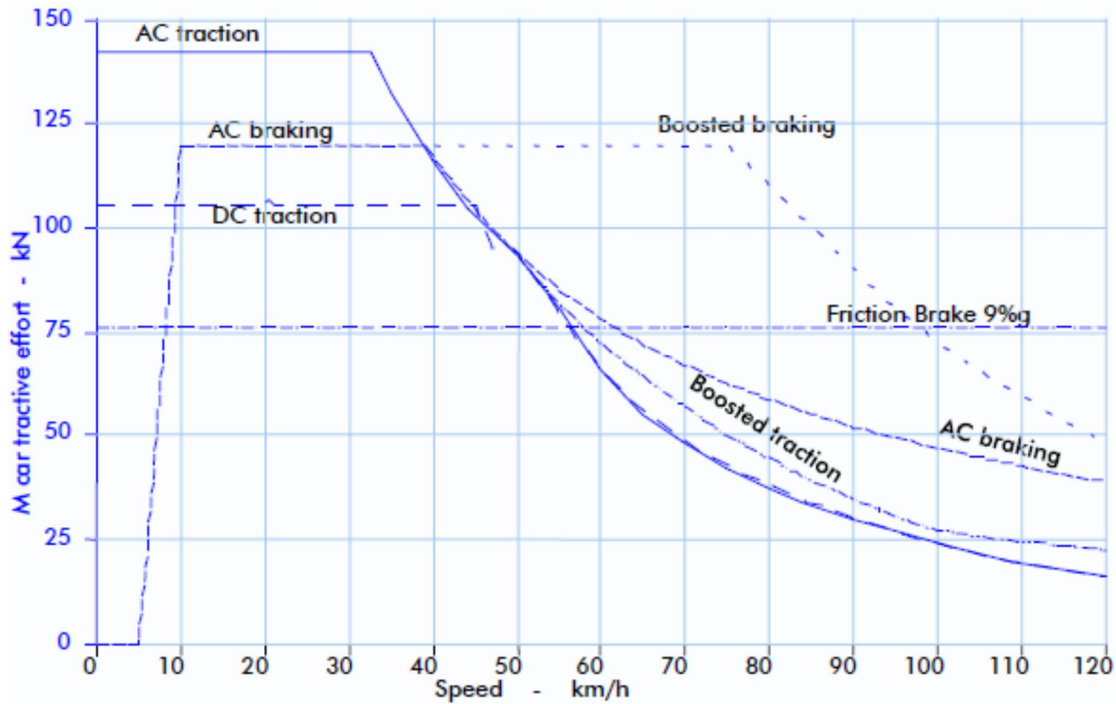


Figure 7: Tractive and braking effort curves for AC and DC traction systems and friction braking

Figure 8 below conveys the results of a simulation run of the DC and AC systems where overall energy used and brake wear are minimal in the case of AC traction systems with regenerative braking compared to its DC counterpart without regenerative braking.

ATO under full service loading 7 passengers per m ²			
	Existing DC	AC traction	AC traction with brake boost
Acceleration	0.5 m/s ²	0.7 m/s ²	0.7 m/s ²
Journey time	79 mins	78 mins	78 mins
Motoring energy	678 kWh	710 kWh	710 kWh
Regen Energy	0	283 kWh	365 kWh
Net Motoring energy	678 kWh	427 kWh	345 kWh
Traction energy	100 %	63 %	51 %
Overall energy reduction	0 %	30 %	40 %
Brake wear	100 %	70 %	10 %

Figure 8: Comparison of DC vs AC traction and braking systems under simulated conditions

12.4.5 Conclusions

The investigation into life extension of the Metro Cammell railcars concluded with the following findings:

- 1) Buying new trains to replace all of the existing fleet was not found to be financially attractive.
- 2) The carbody and bogie structure had the potential to be upgraded cost effectively to achieve a life extension for a total of 50 years in service (til 2035). This estimate accounted for the increased loading factor expected in future.

- 3) The DC traction motors if converted to AC traction motors could achieve good reliability and better train performances such as higher acceleration and less brake pad usage. Less maintenance and material wear costs from components such as brake pads could result in a payback period for the AC traction motors of circa 5 years. Considered "self-financing".
- 4) On-going optimisation of equipment refurbishment and fine-tuning of the maintenance work as part of the maintenance management routine were considered necessary to upkeep the performance and reliability of the train til 2035 economically.

However, in light of the Shatin to Central rail line upgrades, additional Government funding was made available for new 9 car trains starting in 2017 better suited to the upgraded rail lines. These are expected to replace the existing trains by circa 2020 when all new 9 car trains will be available and in service. Subsequently, it was considered no longer attractive for KCR to make significant upgrades to AC traction motors to the existing trains. The car body and bogie structure upgrade and on-going optimisation of equipment refurbishment and maintenance work were however implemented to allow the existing trains to remain in service until circa 2020 when they are expected to be replaced.

12.5 Philadelphia Rapid Transit Commuter EMU life extension project by PATCO.

12.5.1 Objective

The objective of this project was to upgrade the PATCO fleet to extend their design life to an optimal age before replacement.

12.5.2 Background

Companies Budd and Vickers built 120 stainless steel cars in the late 60's/early 70's comprising of single cars, married cars, and Budd English cars. The scope of the refurbishment was driven by obsolescence in equipment such as the braking logics, traction systems, EP braking system and also by the necessity to improve reliability, maintainability, and availability.

12.5.3 Relevance to PTA

There are many items of relevance to the PTA from the QR study conducted by AECOM. As with the PTA, KCR:

- Stainless steel car bodies
- Required investigation involving technical and economic considerations of complete replacement and extension of fleet life.
- Fleet trains are similar with common DC traction, 2 car door per side configuration per car, and 2 car-set units.

12.5.4 Work undertaken

- A cost-benefit analysis of the life extension options with consideration for Life Cycle Costs compared to improved reliability for modernisation and new replacement at end of life options.
- Analysis of compliance with relevant US standards
- Inspection of railcars which found:
 - Stainless steel carbodies in good condition with no corrosion despite extreme temperatures, high salinity levels due to gritting and road salt, and high moisture levels.
 - The carbody welding was not to design standards, some ring welding at brackets on side and centre sill show signs of crack propagation but not significant
 - Asbestos in ceiling insulation and on the underframe which required removal
 - NDT performed on bogies to confirm continued use
 - Complete upgrade of cars (approximately 90% new). Implementation of modernisation includes:
 - Upgrade from DC to DC IGBT chopper instead of AC. DC IGBT chopper was preferred over the AC system as a result of cost savings given similar functionality. Original system comprised of 1 traction system per car per, now converted to separate systems per bogie. Allows for easier replacement of bogies.
 - Single cars are being converted to married pairs -external end door closed off. These carbodies had high carbon content making cars susceptible to cracking when exposed to high temperatures i.e. welding. Required welding with suitable temperature and timeframe (refer to shot welding).
 - Some components were retained and overhauled, including the motors and gearboxes, coupler system, air compressor and compressor condenser.
 - PATCO overhauled the bogies and then free issued them to Alstom for installation.
 - Upgrade of ethernet, trucks and bolsters, undercar layout completely new with new looming, emergency door handles mechanically fastened, third rail DC pickup with 688 nominal DC required shoe gear refurbishment
 - The secondary structure had bridging plates inserted. Huckling/pop riveting was performed instead of welding to protect the carbody

- Signalling block re-designed to allow for grade compensation

12.5.5 Conclusions

The life extension expectancy is 15-20 years, and any residual life thereafter is likely to be limited by bogie life.

The total cost of modernisation for each 2 car-set train was ~\$1.5M compared to new purchase of ~\$2-2.3M. Although the cost of modernisation was similar to a new purchase, the project was CAPEX governed resulting in modernisation being the preferred option. Contract value of 120 cars ~\$190M. Some costs of the new purchase include \$300k for car shell, \$150k for new bogies and motors

Eight pilot/prototype cars have been produced over the last 18months, with delivery rate commitment of 4 cars per month.

Using the DC chopper system is expected to improve motorisation providing performance benefits, reduced maintenance burden and extended maintenance periodicities. However, in regards to regenerative braking, it was identified later in the project that the infrastructure (substations and wayside) are highly unlikely to be adequate to support regenerative braking. Thus it is likely these trains will be commissioned without regenerative braking initially until system upgrades are in place.

Reduced dwell time benefits are expected as a result of having the option for 6 to 8 car operations and the improvements in signalling and door micro-processors (screw operation leading to increased speeds).

The data recording systems enhanced in upgrade are expected to result in improvements in trouble shooting and MDS information downloading off the system.

There is likely to be increased reliability and improved maintenance, however the benefits will be unmeasurable as historical data was not recorded

12.6 VIA Rail's RDC Fleet Rebuild Project

12.6.1 Objective

The objective of the RDC fleet overhaul project is to deliver improved accessibility, efficiency and reliable services with a focus on enhancing comfortable travel for passengers.

12.6.2 Background

In 2007, the Government of Canada initiated a \$516 million investment program to strengthen the passenger rail services. In 2009, another \$407 million was added to the program through Canada's Economic Action Plan, the Government's economic stimulus program. VIA Rail's capital investment is a total of \$923 million. The Rail Diesel Car (RDC) overhaul project is part of VIA Rail's capital investment project.

The RDCs operate as 2 three car units and they are constructed of stainless steel car-bodies. The RDCs were built in 1949 – 1962 by the Budd Company of Philadelphia, Pennsylvania. The fleet comprised of 3 car types, coach cars, baggage cars and coach/baggage cars.

The RDC have been operating for over 60 years since the early 1950s exceeding their intended original design life of 30 years. The rail cars are used in low density, short passenger/commuter areas such as the Victoria to Courtenay line on Vancouver Island and the Sudbury to White River line in Ontario.

Past refurbishments of the RDCs generally involved the overhaul of train systems and engines on an average 8 to 10 years interval. The RDC Fleet Rebuild Project is considered the first major overhaul project where the cars were stripped back to the car-bodies and structural assessments were performed.

12.6.3 Relevance to PTA

There are many items of relevance to the PTA, in particular:

- Business case investigation involving technical and economic considerations of complete replacement and extension of asset life.
- Similarities with stainless steel car-bodies and structures.
- The requirement for major system overhauls in order to support the continued operation and extension of asset life.

12.6.4 Work undertaken

The works undertaken have comprised of an exhaustive mechanical and electrical overhaul as well as a comprehensive aesthetic appearance improvement through interior and exterior refurbishments.

The works include but are not limited to the following:

Carbody

- Cars were stripped through the removal of equipment including interior and exterior mechanical systems and wiring.
- Structural evaluation of car-bodies to identify potential fatigue damage and performed Non-Destructive Test (NDT).
- Full visual inspection and condition assessment of railcars.
- Cracks of side sills were repaired by applying new stainless steel splices reinforced by huck bolts.
- Interior of casing was sprayed with water and sound proofed by ceramic coating.
- Wear and tear/damage assessment performed on the exterior doors and repair work was conducted as required.
- Installation of new windows and modified window frames.
- Fibreglass insulation installed in car-bodies.

Modifications and Upgrades

- Installation of new cable looming.

- Installation of new air brake system to the engine.
- Engine castings were stripped down, condition assessments were undertaken and repairs conducted as required.
- Installation of two wheel chair lifts in each car and enhanced washroom facilities to improve accessibility for passengers or reduced mobility.
- Installation of new passenger seats (new foam and new mocquette).
- Installation of 480 Volt generators to run the auxiliary equipment such as lighting, air compressor, heating, refreshment areas and washroom facilities.
- Installation of new HVAC systems and air compressors.
- Installation of new operator controls, LED lighting, CCTV system and batteries.

12.6.5 Conclusions

Structural evaluation revealed that the stainless steel car-bodies were considered in good condition for their age with no signs of corrosion despite Canada's harsh conditions of snow, rain and extreme temperature differences. Fatigue cracking to the side sill found was mainly caused by conducting poor weld repairs and lack of temperature control. It was noted that the structural members of the cars were constructed with stainless steel of 201 and 301 types. To prevent future propagation of cracks due to welding, stainless steel splices were reinforced by huck bolts.

The refurbishment of the RDCs also mitigated several obsolescence issues, in particular the electrical, controls and relay systems. Furthermore, the original wiring was perishing and beginning to crack, it was noted that there had been no systematic replacement over the years.

The scope of the refurbishment/life extension works was extensive, yet the business case existed.

The cost of the refurbishment and life extension works was estimated to be \$2M (+\$150k for bogie overhaul – separate contract) on a per car basis. The cost of car replacing the fleet was quoted at \$4.5M - \$5M (depending on the vendor) on a per car basis. Therefore the refurbishment works are approximately half the cost of new car replacements.

The design life of the cars following the refurbishment/life extension works is expected to be 40 – 50 years, compared to an estimated 40 year design life for the new replacement railcars.

As RDCs operate in low passenger commuter areas, lost time incidents are considered low priority and measured on the basis of delays >15 minutes.

Improved reliability, maintenance periodicity extensions are anticipated following the overhaul.

It is anticipated that the 480 horsepower engine will be more fuel efficient after the overhaul. Furthermore, the engine will be compliant with Transport Canada's exhaust emission standards (Euro II Emission standards). The RDCs were refurbished and built to VIA Rail's specification in terms of fire, electrical and material standards.

12.7 Queensland Rail (QR) EMU fleet assessment by AECOM.

12.7.1 Objective

AECOM were commissioned by QR to assess the viability of refurbishing and continuing to maintain the current fleet of EMUs for an extended period beyond the already exceeded design life expectation, or to retire the fleet in the near future. As part of the study, AECOM were tasked with conducting a cost-benefit analysis and analysis of the following items:

- Current maintenance/operational costs
- Forecast future maintenance/operational costs
- Operating reliability/availability
- Spare part supply chain integrity
- Design for efficient maintenance
- Environmental compliance
- Component obsolescence
- Structural integrity
- Rail safety
- DA compliance
- Train protection compatibility
- Compatibility with future rail car configuration
- Compatibility with infrastructure upgrades
- Detailed commercial and technical risk assessment
- Commercial benchmarking
- Optimal replacement timing
- Impacts on existing facilities and industrial arrangements
- Impacts on stock and contracts
- Regional impacts – other suppliers
- Customer requirements
- Option of retiring a portion of the fleet and using it as spare parts to extend the life of the remaining fleet
- Identify and discuss issues and process associated with retiring the fleet

12.7.2 Background

Queensland Rail was undertaking a project to significantly increase the size of its fleet in the Brisbane city network to meet forecasted increases in patronage growth. This involved determining a business case for the procurement of up to 200 three-car units to replace ageing rolling stock and to add to those to remain in the existing fleet. As part of determining a business case for these additional rolling stock, assessment of the current EMU fleet was required which subsequently led to the project being presented in this document.

The QR EMU Stock have been introduced onto the Queensland Rail passenger network over a number of years since 1979 and have an intended design life of 30 years. The fleet comprises of 87 units and represents approximately 40% of the total Queensland Rail suburban fleet. Having exceeded design life, there has been some deterioration in service and reliability of the fleet resulting in increased costs.

12.7.3 Relevance to PTA

There are many items of relevance to the PTA from the QR study conducted by AECOM. As with the PTA, QR:

- Aims to purchase a new rolling stock fleet to replace existing EMUs nearing, having reached and in some cases exceeded their operational life expectancy.
- Required investigation involving technical and economic considerations of complete replacement and extension of fleet life over a number of different durations.
- Fleet trains are similar with common stainless steel carbodies and structures, and similar operational activities.
- External factors such as environment and demographics are not dissimilar from that of Perth.

12.7.4 Work undertaken

Work undertaken included:

- Condition assessment of 2 EMU trains
- Inspection of EMU underframe for corrosion on 2 trains
- General inspection of train subsystems and component condition
- Review of other similar cases - London Underground and Melbourne fleets for benchmarking of reliability and cost
- Review of current maintenance activities, backlog and associated issues
- Review of current and historical performance issues
- Review of future network requirements, QR aspirations and relevant legislation
- Development of a cost estimate for continuing the operation of the EMUs beyond their 30 year design life which includes:
 - Incremental availability costs,
 - Incremental reliability costs,
 - Additional maintenance regime costs,
 - Incremental wheel rate maintenance costs, and
 - Establishment of EMU modification packages required to efficiently and safely extend the life of the EMUs.

12.7.5 Conclusions

The EMUs were assessed as being in a good state for their age. However, some technical issues were identified and deemed necessary to address. Reliability of the trains was below values achieved by similarly aged fleets. However, availability of trains and percentage of wheels undergoing maintenance per annum was seen to be consistent with the benchmark cases (London Underground and Melbourne Fleets) that were used.

The study calculated that if the EMUs continue in operation, the additional costs due to decreased availability and decreased reliability are likely to be as in Table 1 following:

Additional Costs	1 to 5 years	6 to 10 years	11 to 15 years	16 to 30 years
Decreased availability	\$12,746,000 pa	\$13,397,000 pa	\$13,884,000 pa	\$15,784,000 pa
Decreased reliability	\$2,585,000 pa	\$2,610,000 pa	\$2,417,000 pa	\$2,564,000 pa

Table 1: Additional costs for continued operation of fleet

Business cases for modification works for life extension of the rolling stock were considered feasible. Table 2 shows the four modernisation cases considered and associated costs of respective maintenance regimes and wheel wear rate costs:

Years for Extension	Modification Works	Minimum package budget cost estimate (+/- 30%)	Increased maintenance regime	Increased wheel wear rate
5 years	Emergency door release, replacement of remaining resistor grids, replacement of the EP and main contactors, new exterior displays, new CCTV and new fixings for the items on the underframe	\$14,181,000	\$4,035,000 pa	1.7% pa
10 years	5 year package plus new Traction brake traction controller, new battery system and new interior	\$51,156,000	\$4,564,000 pa	1.9% pa
15 years	10 year package plus new cab electronics, new traction control system, new brake system, HVAC and a re-wire	\$324,597,000	\$2,402,000 pa	2.1% pa
30 years	15 year package plus new bogies, compressors and pipes and fittings on the air system	\$335,994,000	\$1,424,000 pa	3.5% pa

Table 2: Four modernisation options developed

Based on the cost estimates above, total annual cost for each option is estimated as below in Table 3:

	Annual cost
Do nothing option (over 30 years)	\$50,203,000 pa
5 year option	\$34,619,000 pa
10 year option	\$38,113,000 pa
15 year option	\$52,802,000 pa
30 year option	\$44,685,000 pa

Table 3: Total annual cost estimate for options

The 15 year option was most costly as a result of significant capital expenditure and associated length for amortisation compared to the other options. However, whilst it appears the 5 year option is best other factors such as capital and operating costs and system benefits such as power consumption savings of the new Next Generation Rolling Stock fleet would need to be considered.

Recommendations were made in addition to the work packages for the purpose of supporting the management of the fleet and to improve its reliability and general performance. These were:

- 1) Perform non-destructive testing yearly on two bogie frames for early detection of crack propagation
- 2) Full metallurgical examination of a randomly selected gear wheel to identify any wear issues which may need to be taken into account for any extension of life program
- 3) A gearbox oil sampling process to gain a trend of the gearbox condition between overhauls
- 4) New gearbox seal to be identified and implemented (preferably in-situ) to correct seeping gearboxes
- 5) Immediate review of emergency release mechanisms, and then implement testing and monitoring regime
- 6) Revised maintenance regime for doors to be implemented and monitored
- 7) Source new door solenoid valves
- 8) Identify new traction brake traction controllers to be retrofitted across the fleet
- 9) Resistor grid change out and compressor change out programs to be incorporated into overhaul program
- 10) New mini circuit breaker and electro pneumatic contactors to be identified and retrofitted to the fleet

- 11) Contactor boxes to be fully cleaned of all copper residue
- 12) Commence investigations to identify replacement capacitors which carry charge for longer and do not leak
- 13) Revised track motor brush to be fitted with a wear mark linked to the new maintenance cycle and traction motor brushes to be replaced when the wear mark has worn away
- 14) Brake blocks to be changed when the wear mark has worn away or there is uneven wear. If uneven wear occurs, future block wear is to be monitored to establish if there is a problem with the brake cylinder or associated rigging
- 15) Full review of equipment fitted to the underside of the car body and a plan is established for secondary retention to be fitted to that equipment
- 16) EMU fleet not considered appropriate for the Cross River Rail tunnel due to potential engineering risks involving fire life safety, thermal loadings, and power ratings
- 17) If the 10 year work package is pursued, interior and associated facilities are to be fully compliant with the latest Disability Discrimination Act Regulations
- 18) Monthly train management reports to be generated to cover fleet safety, reliability and operational issues
- 19) A visualisation centre to be set up to generate a performance focussed team
- 20) Train failure data recorded is to include the unit associated with the fault and the central database is also adapted to include the root cause of each delay

Appendix D

Phase 2 Methodology

Appendix D Phase 2 Methodology

Phase 2 Fatigue Life Assessment based on Track Testing (OPTIONAL)

Overview

The purpose of the Phase 2 study is to validate results obtained from Phase 1 by retrieving practical results from on board operational railcars. Practical results will be obtained through the implementation of measurement and recording instrumentation on or in the trains. Recordings will include; vehicle accelerations, strain-time histories and speed measurements amongst others. This data will be generated for trains in both tare (empty) and loaded conditions so that a comprehensive validation process can be completed. Practical data recording of strain and acceleration will be conducted concurrently for two reasons, which enables correlation between results for any given time and it should minimise the time which the units are instrumented for.

Once the practical data has been recorded it can be used to check and compare against the results generated from Phase 1. Based on a rain-flow analysis of the strain time histories and the acceleration time histories conducted by the test house responsible for conducting the track testing, an assessment of vehicle life based on manual calculation will be conducted. Rainflow stress cycles counting is the most common and practical form of stress cycle counting. Rainflow counting is used to measure the likely impact of the most damaging stress cycles.

Testing Specification

The recordings of primary interest to be obtained during Phase 2 are the strains imparted on the carbody and the accelerations.

A description of the recording instrumentation and the methodology for instrumentation set up and testing is provided below:

Strain Gauge Testing

For the strain gauge testing there will be an initial preliminary study conducted to identify the peak stress locations from the Phase 1 analysis so that the practical testing can focus on positioning the gauges so that strain time histories can be generated during normal vehicle operation for some areas of peak loading. It is also important that a series of more 'typical' strains and strain locations are tested to provide a thorough validation of the results generated in Phase 1.

It is proposed that there is a single reference channel system is used and that the test team rove the channels inside the train (keeping a fixed reference location) while the train moves. By taking this approach it can be determined exactly how the key points of interest are behaving, as this system setup will enable a magnitude and phase relative to the reference channel. This would provide a very cost effective solution and AECOM can provide in-house DAQ and accelerometers.

AECOM has come to the following conclusions:

- 1) It is believed that the best solution would be to use external, isolated strain amplifiers (datasheet can be provided) whose output can be fed into AECOM's standard Data Acquisition System (DAQ, AECOM's standard DAQ is laptop based). This requires:
 - a) Attended measurements (i.e. a graduate sitting in the train with the laptop on his lap). Connecting leads would have to be run through the carbody panelling.
 - b) Since there are no power-points in the train, the test engineer would have a 60 or 120 Ahr battery at their feet to power the laptop (note, AECOM has conducted similar tests for RailCorp, though the trains did have power points which were used).
 - c) Measurement periods were originally scoped for two full days testing, however this will need further clarification given the results obtained during Phase 1.
- 2) Strain gauging a car and collecting data for longer periods of one week or more is not possible for following reasons:
 - a) It would require a laptop and large hard drive to store all data.
 - b) The use of a laptop for unattended logging would be discouraged because of:

- i) The large power consumptions; and,
- ii) The risk that the laptop crashes and all data is lost following the crash.

It should be noted that AECOM has assumed that the train maintainer (Bombardier Transportation, Downer EDI Rail Group) would undertake the installation of the strain gauging equipment. Due to the intrusive nature of the installation stemming from the requirement to attach strain gauges to the car body shell AECOM considers the maintainer best equipped to undertake this task. AECOM would observe the works as they are undertaken to ensure the instrumentation is installed in the correct locations. As this work is to be undertaken by a third party, it should be noted that PTA may incur additional charges as a result of the train maintainer undertaking this task. An estimate of the fees cannot be provided at this time.

Acceleration Testing

Acceleration testing would be required for trains operating in tare and loaded conditions and it would be advantageous for recordings to be conducted over a period of time where peak and off peak service patronage is experienced as well as weekday and weekend testing.

AECOM considered three potential alternatives for measuring and monitoring accelerations incurred by the train before identifying a preferred method of conducting the acceleration monitoring. The recommended method is described below:

- 1) Accelerometers will be secured to large heavy plates which will, due to their mass and friction, will restrict their movement and avoid the necessity for implementing any permanent fixtures to the floor of the car body. Ideally AECOM would situate the plates and accelerometers inside the vehicles above the secondary suspension at a position to be confirmed with and agreed by PTA. The areas would be cordoned off from the public using barriers. The monitoring would be supervised at all times by AECOM personnel. This method is considered to be advantageous for the following reasons:
 - a) The safety of public and operators is maintained.
 - b) Inconvenience to public and operations staff is minimal; instrumentation can be barriered off causing minimal disruption to commuters.
 - c) The ideal locations for accelerometer placement should be achievable, optimising the validity of results obtained.
 - d) Equipment is supervised throughout and data recording can be checked in progress, any issues can be resolved on the spot.
 - e) No permanent modifications to the vehicle are required and there is not likely to be any intrusive work undertaken.

AECOM considers this methodology most preferable as it optimises safety of the vehicle and passengers, incurs minimal disruption to its services, minimise requirement for modification to the unit and/or propensity for damage. Consideration was given to two further alternatives, which are listed below for PTA's information along with the advantages and disadvantages of each.

- 2) Mounting the accelerometers the exterior of the vehicle body on the underframe using permanent or semi-permanent fixtures. The advantages and disadvantages are described below:

Advantages

- a) Does not impede passenger ingress/egress and patrons should be wholly unaffected by instrumentation.
- b) No interference with interior fittings or fixtures and will not damage the unit floor.

Disadvantages

- c) Locations for accelerometer placement may not be ideal due to space limitations between bogie and underframe.
- d) Mounting the equipment to the unit's underframe would likely require holes to be drilled in order to provide sufficient retention for fixing the accelerometers in place, adhesives have been considered but surfaces are not expected to be optimal.
- e) Complexities of establishing safe surfaces and retention devices would be timely.

- 3) PTA provides a dedicated unit for sole purpose of Phase 2 testing.

Advantages

- a) No physical disruption to patrons on board a train.
- b) Instrumentation could be placed in ideal locations

Disadvantages

- c) Would require possession of a train for a period of approximately a week, minimum of one day for installing load, minimum of two days testing, one day for removing load, minimum of one days further testing in tare condition.
- d) Propensity to damage floor through load installation and removal.
- e) Propensity for service disruption through commandeering a 'test train'.

A number of the team AECOM proposes for this task have prior experience of undertaking acceleration tests on ballasted test units. Based on the experiences of AECOM's team, Approach 3, described above is least recommended due to the time and difficulty associated with the ballasting (addition of sandbags or water tanks) units to obtain the loaded condition of a unit.

It should be noted that our proposal has not considered the costs associated with methodologies 2 or 3 and in the event PTA would prefer one of these two alternatives AECOM would need to adjust the costings for the scope of Phase 2.

For measuring the accelerations experienced by the vehicle, the monitoring of the inputs to the carbody from the bogies are key, ideally accelerometers should be located directly above each of the secondary spring positions. The distribution of accelerometers in this manner will enable the measurement of roll, pitch, yaw, bounce and twist.

In addition it would be useful to place an accelerometer on the centre of the passenger floor, centrally between bogie pivots. This will allow determination of the body bending natural frequency mode for comparison with the FEA model.

AECOM is able to source accelerometers capable of measuring from 0 to 3g, and tri-axial.

Reporting

Upon completion of testing AECOM will assimilate the results in to the Final Report which was submitted on completion of the Phase 1 scope of works.

A draft report will be submitted which will include an additional section incorporating the results identified during Phase 2 as well as amendments to any other sections of the original report affected by the Phase 2 results. Once PTA has provided commentary on the draft report, a final report will be issued.

Appendix E

Options Cost Analysis

Appendix F

Asset Inspection Checklist

Appendix G

Vendor Quotes

Appendix H

FEA Report

Appendix I

QR Corrosion Report

Appendix J

Risk Assessment

Maintenance Contract - Phase 1 and Phase 2

Option 1 Straight Replacement at End of Design Life - Maintenance Contract

		2012				2013				2014		
		0	1	2	3	4	5	6	7	8	9	10
Option 1A	New Contractor											
Option 1B	PTA in-house											
Option 1C	Same Contractor	\$ 7,008,224	\$ 4,903,652	\$ 4,903,652	\$ 4,903,652	\$ 4,903,652	\$ 4,903,652	\$ 4,903,652	\$ 4,903,652	\$ 4,903,652	\$ 4,903,652	\$ 4,903,652

Assumptions

Not indexed

Mobilisation Charge	\$ 2,104,572	Schedule 10, Contract No: 2010051
Quarterly Charge (qtr 1 - qtr 15)	\$ 1,682,420	Schedule 10, Contract No: 2010051
Quarterly Charge (qtr 16 - qtr 30)	\$ 335,753	Schedule 10, Contract No: 2010051
Quarterly Charge (qtr 31 - qtr 45)	\$ 1,497,657	Schedule 16, Contract No: 2010051
Quarterly Charge (qtr 46 - qtr 60)	\$ 497,657	Schedule 16, Contract No: 2010051
Phase 1 quarterly km charge	\$ 3,221,232	max quarterly charge as per contract (133,000km - 147,000km)
Phase 2 quarterly km charge	\$ 3,364,704	max quarterly charge as per contract (133,000km - 147,000km)
		no additional materials included (total cost +10%)

		2012				2013				2014		
		1	2	3	4	5	6	7	8	9	10	11
Mobilisation charge	\$	2,104,572										
quarterly charge 1-15	\$	335,753	\$ 335,753	\$ 335,753	\$ 335,753	\$ 335,753	\$ 335,753	\$ 335,753	\$ 335,753	\$ 335,753	\$ 335,753	\$ 335,753
quarterly charge 16-30												
quarterly charge 31-45												
quarterly charge 46-60												
km charge	\$	3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704
	\$	5,805,029	\$ 3,700,457	\$ 3,700,457	\$ 3,700,457	\$ 3,700,457	\$ 3,700,457	\$ 3,700,457	\$ 3,700,457	\$ 3,700,457	\$ 3,700,457	\$ 3,700,457
				\$ 14,801,828				\$ 15,097,865				
LCC	\$	208,766,874										

	2015				2016				2017				
11	12	13	14	15	16	17	18	19	20	21	22	23	24
\$ 4,903,652	\$ 4,903,652	\$ 4,903,652	\$ 4,903,652	\$ 3,556,985	\$ 3,556,985	\$ 3,556,985	\$ 3,556,985	\$ 3,556,985	\$ 3,556,985	\$ 3,556,985	\$ 3,556,985	\$ 3,556,985	\$ 3,556,985

	2015				2016				2017				
12	13	14	15	16	17	18	19	20	21	22	23	24	25
\$ 335,753	\$ 335,753	\$ 335,753	\$ 335,753	\$ 1,497,657	\$ 1,497,657	\$ 1,497,657	\$ 1,497,657	\$ 1,497,657	\$ 1,497,657	\$ 1,497,657	\$ 1,497,657	\$ 1,497,657	\$ 1,497,657
\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704
\$ 3,700,457	\$ 3,700,457	\$ 3,700,457	\$ 3,700,457	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361
\$ 15,399,822				\$ 16,940,840				\$ 21,052,704				\$ 21,473,758	

New "C" series contractors 25%
 PTA in house price increase 30%

2018			2019				2020				2021		
25	26	27	28	29	30	31	32	33	34	35	36	37	38
					\$ 6,077,951	\$ 6,077,951	\$ 6,077,951	\$ 6,077,951	\$ 6,077,951	\$ 6,077,951	\$ 6,077,951	\$ 6,077,951	\$ 6,077,951
					\$ 6,321,069	\$ 6,321,069	\$ 6,321,069	\$ 6,321,069	\$ 6,321,069	\$ 6,321,069	\$ 6,321,069	\$ 6,321,069	\$ 6,321,069
\$ 3,556,985	\$ 3,556,985	\$ 3,556,985	\$ 3,556,985	\$ 3,556,985	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361

2018			2019				2020				2021		
26	27	28	29	30	31	32	33	34	35	36	37	38	39
\$ 1,497,657	\$ 1,497,657	\$ 1,497,657	\$ 1,497,657	\$ 1,497,657	\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657
\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ 3,364,704	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657
\$ 21,903,233			\$ 12,313,952				\$ 2,332,338						

1991	1992					2023				2024				20	
39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	
\$ 6,077,951	\$ 6,077,951	\$ 6,077,951	\$ 6,077,951	\$ 6,077,951	\$ 6,077,951	\$ 4,827,951	\$ 4,827,951	\$ 4,827,951	\$ 4,827,951	\$ 4,827,951	\$ 4,827,951	\$ 4,827,951	\$ 4,827,951	\$ 4,827,951	
\$ 6,321,069	\$ 6,321,069	\$ 6,321,069	\$ 6,321,069	\$ 6,321,069	\$ 6,321,069	\$ 5,021,069	\$ 5,021,069	\$ 5,021,069	\$ 5,021,069	\$ 5,021,069	\$ 5,021,069	\$ 5,021,069	\$ 5,021,069	\$ 5,021,069	
\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 4,862,361	\$ 3,862,361	\$ 3,862,361	\$ 3,862,361	\$ 3,862,361	\$ 3,862,361	\$ 3,862,361	\$ 3,862,361	\$ 3,862,361	\$ 3,862,361	

40	2022				2023				2024				20	
40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657	\$ 497,657	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232
\$ 2,378,985	\$ 2,426,564				\$ 12,634,365				\$ 16,341,204					

2025		2026			
54	55	56	57	58	59
\$ 4,827,951	\$ 4,827,951	\$ 4,827,951	\$ 4,827,951	\$ 4,827,951	\$ 4,827,951
\$ 5,021,069	\$ 5,021,069	\$ 5,021,069	\$ 5,021,069	\$ 5,021,069	\$ 5,021,069
\$ 3,862,361	\$ 3,862,361	\$ 3,862,361	\$ 3,862,361	\$ 3,862,361	\$ 3,862,361

2025		2026			
55	56	57	58	59	60
\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232
\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232	\$ 3,221,232
\$ 16,668,028		\$ 17,001,389			

Option 2a - Minor Enhancements/Existing Technology

Avg km per year 140,000

End of life + 5 yrs 13

\$	261,076,181	With a new contractor maintaining the new series
\$	267,619,722	With PTA in house maintaining until end of life
\$	228,358,473	until end of Phase 2 of current contract (end 2026)
\$	11,417,923.65	Plus 5% contingency as per AECOM procedures
\$	239,776,396.65	

O/H activities to be undertaken under Option 2a

Task	Interval	Unit	End of life + 5 yrs	Qty per vehicle	Unit cost	Railcar cost	Quote base date	Special note	Labour Est.	Main. + Lab. for upgrade
MCB	1,400,000	km	\$1,076,068.80	1	22,418.10	\$22,418.10	31/12/2011			
Pantograph	1,120,000	km	\$453,792.00	1	9,454.00	\$9,454.00	31/12/2011			
HVAC - conversion	1,120,000	km	\$511,920.00	4	2,666.25	\$10,665.00	31/12/2011			
HVAC	1,120,000	km	\$1,912,502.40	4	9,960.95	\$39,843.80	31/12/2011			
Power/Brake controller	840,000	km	\$960,000.00	2	5,000.00	\$10,000.00	31/12/2011			
Driver's console	140,000	km	\$312,000.00	2	250.00	\$500.00	31/12/2011			
Traction control system	1,120,000	km	\$144,000.00	1	3,000.00	\$3,000.00	31/12/2011			
External passenger doors - heavy	1,120,000	km	\$1,103,155.20	8	2,872.80	\$22,982.40	31/12/2011	Door leaf not included		
Gangway doors - heavy	1,120,000	km	\$184,320.00	2	1,920.00	\$3,840.00	31/12/2011	Bellow not included		
Cab doors	1,120,000	km	\$23,040.00	4	120.00	\$480.00	31/12/2011	Door leaf not included		
Driver's seat	1,400,000	km	\$355,200.00	2	3,700.00	\$7,400.00	31/12/2011			
Main transformer	1,680,000	km	\$655,632.00	1	13,659.00	\$13,659.00	31/12/2011			
Thyristor converter	140,000	km	\$65,971.90	1	105.72	\$105.72	31/12/2011			
Thyristor Converter - heavy	10yr		\$768,000.00	1	16,000.00	\$16,000.00	31/12/2012	Estimate based on life of capacitors and semiconductors		
Contact box	140,000	km	\$276,325.92	2	221.42	\$442.83	31/12/2011	does not include overhaul of internal components		
Auxiliary relay box	140,000	km	\$48,297.60	2	38.70	\$77.40	31/12/2011	does not include overhaul of internal components		
Brake resistor	1,120,000	km	\$573,307.20	2	5,971.95	\$11,943.90	31/12/2011			
PFC unit	140,000	km	\$477,492.60	1	765.21	\$765.21	31/12/2011			
PFC - Heavy	10yr		\$288,000.00	1	6,000.00	\$6,000.00	31/12/2012	Estimate based on life of capacitors (not filter cap)		
Auxiliary converter	1,400,000	km	\$5,529.60	1	115.20	\$115.20	31/12/2011			
Auxiliary Converter Heavy	10yr		\$240,000.00	1	5,000.00	\$5,000.00	31/12/2012	Estimate based on life of capacitors		
Automatic coupler	1,120,000	km	\$1,564,109.76	2	16,292.81	\$32,585.62	31/12/2011			
Semi-permanent coupler	1,120,000	km	\$369,421.44	2	3,848.14	\$7,696.28	31/12/2011			
Auxiliary transformer / reactor	840,000	km	\$29,894.40	1	311.40	\$311.40	31/12/2011			
Wheelsets	1,120,000	km	\$3,426,105.60	8	8,922.15	\$71,377.20	31/12/2011			
Traction motor	840,000	km	\$7,200,000.00	6	25,000.00	\$150,000.00	31/12/2011	Do once, as the other time will be complete re-wind		
Gearbox	1,120,000	km	\$473,932.80	6	1,645.60	\$9,873.60	31/12/2011			
Damper (vert & lat) - first	1,120,000	km	\$774,420.48	8	2,016.72	\$16,133.76	31/12/2011			
Brake disc, motor & trailer	1,120,000	km	\$905,856.00	16	1,179.50	\$18,872.00	31/12/2011			
Bogie, motor & trailer	1,120,000	km	\$5,247,897.60	4	27,332.80	\$109,331.20	31/12/2011			
Air compressor	840,000	km	\$1,071,957.70	1	11,166.23	\$11,166.23	31/12/2011			
Air boxes	1,120,000	km	\$10,368.00	2	108.00	\$216.00	31/12/2011			
Air dryer	840,000	km	\$272,641.92	1	2,840.02	\$2,840.02	31/12/2011			
Brake calliper	840,000	km	\$2,764,800.00	16	1,800.00	\$28,800.00	31/12/2011			
EBC5 brake rack	840,000	km	\$3,240,000.00	3	11,250.00	\$33,750.00	31/12/2011			
Brake system - valves, cocks, general	840,000	km	\$5,018,882.88	1	52,280.03	\$52,280.03	31/12/2011			
Traction motor (100% Re-wind)	1 time (at the s		\$4,752,000.00	6	55,000.00	\$330,000.00	31/12/2011	30% of cost covered by PTA		\$ 4,752,000.00
Auxiliary Systems - minor overhaul	840,000 km (following		\$192,000.00	1	2,000.00	\$2,000.00	AECOM Est 2013	Replace capacitors due to age and Replacement of auxiliary converter circuit breakers and discs - minor overhaul		\$ 192,000.00
HVACS - replace fan motors	1 time (at the s		\$286,875.36	4	1,494.14	\$5,976.57	BT/EDI	Replace fans to reduce earthing faults (additional 15% on top of HVAC O/H)		\$ 286,875.36
Communications/PIS	1 time (at the s		\$9,600.00	2	100.00	\$200.00	Estimate	AM/FM System Upgrade	\$ 15,724.80	\$ 25,324.80
Emergency Door Release (relocation)	1 time (at the s		\$264,000.00	1	5,500.00	\$5,500.00	Interfleet 2010 +5%pa	Relocated to side of doors may be reqd post PTA discussion with DDA	\$ 83,865.60	\$ 347,865.60
LED Saloon lighting	1 time (at the s		\$430,080.00	64	140.00	\$8,960.00	2013 ART quote/AECO	\$50,000 one off cost for diffuser die mould, \$80 per diffuser - standard mkt rate for normal home diffusers are \$40 (1.23m long)	\$ 63,104.00	\$ 493,184.00
LED Cab dashboard lighting	1 time (at the s		\$108,192.00	2	1,127.00	\$2,254.00	2013 ART quote		\$ 7,862.40	\$ 116,054.40
Smoke Detection - VESDA	1 time (at the s		\$288,000.00	1	6,000.00	\$6,000.00	PTA 2013 quote		\$ 288,000.00	\$ 576,000.00
Condition based replacement of equipment boxes	2 boxes per ye	condition bas	\$260,000.00	1	10,000.00	\$10,000.00	PTA 2013 quote RR	Would not do fleetwide - very labour intensive	\$ 56,784.00	\$ 316,784.00
Total Material Cost			\$49,395,591.16						Total Labour Cost	\$ 802,451.20
Material cost of upgrades only			\$6,590,747.36						Labour cost of upgrades only	\$ 515,340.80
			\$7,579,359.46							\$ 7,106,088.16
										\$ 8,172,001.38
										\$ 247,948,398.03

Option 2b - Minor Enhancements/Existing Technology

Avg km per year 140,000

\$	228,358,473.00	until end of Phase 2 of current contract
\$	11,417,923.65	Plus 5% contingency as per AECOM standards
\$	<u>239,776,396.65</u>	
\$	87,247,220.00	Plus 5yrs on top of contract (equal to design life plus 10years). Based on costs of Phase 2 of current contract.
\$	17,449,444.00	Plus 20% on additional 5years to allow for higher risk associated with age of trains
\$	5,234,833.20	Plus 15% contingency as per AECOM standards
\$	<u>109,931,497</u>	
\$	349,707,893.85	Total Maintenance Contract Cost

End of life + 10 yrs 18

O/H activities to be undertaken under Option 2b

Task	Interval	Unit	End of life + 10 yrs	Qty per vehicle	Unit cost	Railcar cost	Quote base date	Material (per component) Special note	Labour Est.	Main. + Lab. for upgrade
MCB	1,400,000	km	\$1,076,068.80	1	22,418.10	\$22,418.10	31/12/2011			
Pantograph - only	1,120,000	km	\$907,584.00	1	9,454.00	\$9,454.00	31/12/2011			
HVAC - refrigerant conversion	1,120,000	km	\$1,023,840.00	4	2,666.25	\$10,665.00	31/12/2011			
HVAC	1,120,000	km	\$3,825,004.80	4	9,960.95	\$39,843.80	31/12/2011			
Power/Brake controller	840,000	km	\$1,440,000.00	2	5,000.00	\$10,000.00	31/12/2011			
Driver's console	140,000	km	\$432,000.00	2	250.00	\$500.00	31/12/2011			
Traction control system	1,120,000	km	\$288,000.00	1	3,000.00	\$3,000.00	31/12/2011			
External passenger doors - heavy	1,120,000	km	\$2,206,310.40	8	2,872.80	\$22,982.40	31/12/2011	Door leaf not included, tracks and pistons replacement included done fleetwide as they come in for GO, otherwise done on failure		
Gangway doors - heavy	1,120,000	km	\$368,640.00	2	1,920.00	\$3,840.00	31/12/2011	Bellow not included		
Cab doors	1,120,000	km	\$46,080.00	4	120.00	\$480.00	31/12/2011	Door leaf not included		
Driver's seat	1,400,000	km	\$355,200.00	2	3,700.00	\$7,400.00	31/12/2011			
Main transformer	1,680,000	km	\$655,632.00	1	13,659.00	\$13,659.00	31/12/2011			
Thyristor converter	140,000	km	\$91,345.71	1	105.72	\$105.72	31/12/2011			
Thyristor Converter - heavy	10yr		\$768,000.00	1	16,000.00	\$16,000.00	31/12/2012	Estimate based on life of capacitors and semiconductors		
Contact box	140,000	km	\$382,605.12	2	221.42	\$442.83	31/12/2011	Does not include overhaul of internal components		
Auxiliary relay box	140,000	km	\$66,873.60	2	38.70	\$77.40	31/12/2011	Does not include overhaul of internal components		
Brake resistor	1,120,000	km	\$1,146,614.40	2	5,971.95	\$11,943.90	31/12/2011			
PFC unit	140,000	km	\$661,143.60	1	765.21	\$765.21	31/12/2011			
PFC - Heavy	10yr		\$288,000.00	1	6,000.00	\$6,000.00	31/12/2012	Estimate based on life of capacitors (not filter cap)		
Auxiliary converter	1,400,000	km	\$5,529.60	1	115.20	\$115.20	31/12/2011			
Auxiliary Converter Heavy	10yr		\$240,000.00	1	5,000.00	\$5,000.00	31/12/2012	Estimate based on life of capacitors		
Automatic coupler	1,120,000	km	\$3,128,219.52	2	16,292.81	\$32,585.62	31/12/2011			
Semi-permanent coupler	1,120,000	km	\$738,842.88	2	3,848.14	\$7,696.28	31/12/2011			
Auxiliary transformer / reactor	840,000	km	\$44,841.60	1	311.40	\$311.40	31/12/2011			
Wheelsets	1,120,000	km	\$6,852,211.20	8	8,922.15	\$71,377.20	31/12/2011			
Traction motor	840,000	km	\$14,400,000.00	6	25,000.00	\$150,000.00	31/12/2011	Performed twice as first time time is re-wind		
Gearcase - main drive gear excludes pinion (4-5k) ok	1,120,000	km	\$947,865.60	6	1,645.60	\$9,873.60	31/12/2011	Replacement		
Damper (vert & lat) - first	1,120,000	km	\$1,548,840.96	8	2,016.72	\$16,133.76	31/12/2011			
Brake disc, motor & trailer	1,120,000	km	\$1,811,712.00	16	1,179.50	\$18,872.00	31/12/2011			
Bogie, motor & trailer	1,120,000	km	\$10,495,795.20	4	27,332.80	\$109,331.20	31/12/2011			
Air compressor	840,000	km	\$1,607,936.54	1	11,166.23	\$11,166.23	31/12/2011			
Air boxes	1,120,000	km	\$20,736.00	2	108.00	\$216.00	31/12/2011			
Air dryer	840,000	km	\$408,962.88	1	2,840.02	\$2,840.02	31/12/2011			
Brake calliper	840,000	km	\$4,147,200.00	16	1,800.00	\$28,800.00	31/12/2011	Reworked/replaced		
EBC5 brake rack	840,000	km	\$4,860,000.00	3	11,250.00	\$33,750.00	31/12/2011			
Brake system - valves, cocks, general	840,000	km	\$7,528,324.32	1	52,280.03	\$52,280.03	31/12/2011			
Traction motor (100% Re-wind)	1 time (at the start)		\$4,752,000.00	6	55,000.00	\$330,000.00	31/12/2011	30% of cost covered by PTA		\$4,752,000
Auxiliary Systems - minor overhaul	840,000 km (following the		\$288,000.00	1	2,000.00	\$2,000.00	AECOM Est 2013	Replace capacitors due to age and Replacement of auxiliary converter circuit breakers and discs - minor overhaul		\$288,000
HVACS - replace fan motors	1 time (at the start)		\$286,875.36	4	1,494.14	\$5,976.57	BT/EDI	Replace fans to reduce earthing faults (additional 15% on top of HVAC O/H)	\$286,875	BT/EDI will cover labour
Communications/PIS	1 time (at the start)		\$9,600.00	2	100.00	\$200.00	Estimate	AM/FM System Upgrade	\$15,725	\$25,325
Emergency Door Release (relocation)	1 time (at the start)		\$264,000.00	1	5,500.00	\$5,500.00	Interfleet 2010 +5%pa	Relocated to side of doors may be reqd post PTA discussion with DDA	\$83,866	\$347,866
LED Saloon lighting	1 time (at the start)		\$430,080.00	64	140.00	\$8,960.00		\$50,000 one off cost for diffuser die mould, \$80 per diffuser - standard mkt rate for normal home diffusers are \$40 (1.23m long)	\$63,104.00	\$493,184
LED Cab dashboard lighting	1 time (at the start)		\$108,192.00	2	1,127.00	\$2,254.00	2013 ART quote		\$7,862.40	\$116,054
Smoke Detection - VESDA	1 time (at the start)		\$288,000.00	1	6,000.00	\$6,000.00	PTA 2013 quote		\$288,000	\$576,000
Condition based replacement of equipment boxes	2 boxes per year condition based		\$360,000.00	1	10,000.00	\$10,000.00	PTA 2013 quote RR	Would not do fleetwide - very labour intensive	\$78,624.00	\$438,624
Anticlimbers - modify sole bar	1 time (at the start)		\$633,600.00	1	13,200.00	\$13,200.00	Interfleet 2010+5%pa		\$62,899.20	\$696,499
New GRP frontage	1 time (at the start)		\$4,898,880.00	2	48,600.00	\$102,060.00	BT/EDI	2004 Quote of "B" series +5% inflation + \$15,000 for all frontage components	\$460,800	\$5,359,680
New Cab HVAC system	1 time (at the start)		\$1,488,000.00	2	15,500.00	\$31,000.00	2013 Thermoking	includes 10% GST	\$655,920	\$2,143,920
Vaccum Circuit Breakers	1 time (at the start)		\$2,000,000.00	1	40,000.00	\$40,000.00	BT/EDI	48 plus 2 spare	\$7,862.40	\$2,007,862
Traction Controller	1 time (at the start)		\$2,328,000.00	2	24250	\$48,500.00	Interfleet 2010 +5%pa			\$2,328,000
Total Material Cost			\$92,951,188.09							\$92,951,188.09
Material cost of upgrades only			\$18,135,227.36							\$18,135,227.36
			\$20,855,511.46							\$20,855,511.46
									\$2,011,772.80	\$94,962,961
									\$1,724,662.40	\$19,859,889.76
									\$1,983,361.76	\$22,838,873.22
										\$372,546,767.07

Option 3a - Major Enhancements with DC re-gen braking

Avg km per year 140,000

\$	228,358,473.00	until end of Phase 2 of current contract
\$	11,417,923.65	Plus 5% contingency as per AECOM standards
\$	<u>239,776,396.65</u>	
\$	87,247,220.00	Plus 5yrs on top of contract (equal to design life plus 10years). Based on costs of Phase 2 of current contract.
\$	17,449,444.00	Plus 20% on additional 5years to allow for higher risk associated with age of trains
\$	5,234,833.20	Plus 15% contingency as per AECOM standards
\$	<u>109,931,497</u>	
\$	130,870,830	Plus 10yrs on top of contract with 5yrs (equal to design life plus 20yrs). Based on costs of Phase 2 of current contract.
\$	39,261,249	Plus 30% on additional 10years to allow for higher risk associated with age of trains
\$	25,519,812	Plus 15% contingency as per AECOM standards
\$	<u>195,651,891</u>	
\$	<u>545,359,784.70</u>	Total Maintenance Contract Cost

O/H activities to be undertaken under Option 2b

Task	Interval	Unit	End of life + 10 yrs	Qty per vehicle	Unit cost	Railcar cost	Quote base date	Special note	Labour Est.	Main. + Lab. for upgrade	
MCB	1,400,000	km	\$2,152,137.60	1	22,418.10	\$22,418.10	31/12/2011				
Pantograph	1,120,000	km	\$1,361,376.00	1	9,454.00	\$9,454.00	31/12/2011				
HVAC - conversion	1,120,000	km	\$1,535,760.00	4	2,666.25	\$10,665.00	31/12/2011				
HVAC	1,120,000	km	\$5,737,507.20	4	9,960.95	\$39,843.80	31/12/2011				
Power/Brake controller	840,000	km	\$1,920,000.00	2	5,000.00	\$10,000.00	31/12/2011				
Driver's console	140,000	km	\$672,000.00	2	250.00	\$500.00	31/12/2011				
Traction control system	1,120,000	km	\$432,000.00	1	3,000.00	\$3,000.00	31/12/2011				
External passenger doors - heavy	1,120,000	km	\$3,309,465.60	8	2,872.80	\$22,982.40	31/12/2011	Door leaf not included			
Gangway doors - heavy	1,120,000	km	\$552,960.00	2	1,920.00	\$3,840.00	31/12/2011	Bellow not included			
Cab doors	1,120,000	km	\$69,120.00	4	120.00	\$480.00	31/12/2011	Door leaf not included			
Driver's seat	1,400,000	km	\$710,400.00	2	3,700.00	\$7,400.00	31/12/2011				
Main transformer	1,680,000	km	\$1,311,264.00	1	13,659.00	\$13,659.00	31/12/2011				
Thyristor converter	140,000	km	\$142,093.32	1	105.72	\$105.72	31/12/2011				
Thyristor Converter - heavy	10yr		\$768,000.00	1	16,000.00	\$16,000.00	31/12/2012	Estimate based on life of capacitors and semiconductors			
Contact box	140,000	km	\$595,163.52	2	221.42	\$442.83	31/12/2011	does not include overhaul of internal components			
Auxiliary relay box	140,000	km	\$104,025.60	2	38.70	\$77.40	31/12/2011	does not include overhaul of internal components			
Brake resistor	1,120,000	km	\$1,719,921.60	2	5,971.95	\$11,943.90	31/12/2011				
PFC unit	140,000	km	\$1,028,445.60	1	765.21	\$765.21	31/12/2011				
PFC - Heavy	10yr		\$288,000.00	1	6,000.00	\$6,000.00	31/12/2012	Estimate based on life of capacitors (not filter cap)			
Auxiliary converter	1,400,000	km	\$11,059.20	1	115.20	\$115.20	31/12/2011				
Auxiliary Converter Heavy	10yr		\$240,000.00	1	5,000.00	\$5,000.00	31/12/2012	Estimate based on life of capacitors			
Automatic coupler	1,120,000	km	\$4,692,329.28	2	16,292.81	\$32,585.62	31/12/2011				
Semi-permanent coupler	1,120,000	km	\$1,108,264.32	2	3,848.14	\$7,696.28	31/12/2011				
Auxiliary transformer / reactor	840,000	km	\$59,788.80	1	311.40	\$311.40	31/12/2011				
Wheelsets	1,120,000	km	\$10,278,316.80	8	8,922.15	\$71,377.20	31/12/2011				
Traction motor	840,000	km	\$21,600,000.00	6	25,000.00	\$150,000.00	31/12/2011	Performed three times as first time is re-wind			
Gearbox	1,120,000	km	\$1,421,798.40	6	1,645.60	\$9,873.60	31/12/2011				
Damper (vert & lat)- first	1,120,000	km	\$2,323,261.44	8	2,016.72	\$16,133.76	31/12/2011				
Brake disc, motor & trailer	1,120,000	km	\$2,717,568.00	16	1,179.50	\$18,872.00	31/12/2011				
Bogie, motor & trailer	1,120,000	km	\$15,743,692.80	4	27,332.80	\$109,331.20	31/12/2011				
Air compressor	840,000	km	\$2,143,915.39	1	11,166.23	\$11,166.23	31/12/2011				
Air boxes	1,120,000	km	\$31,104.00	2	108.00	\$216.00	31/12/2011				
Air dryer	840,000	km	\$545,283.84	1	2,840.02	\$2,840.02	31/12/2011				
Brake calliper	840,000	km	\$5,529,600.00	16	1,800.00	\$28,800.00	31/12/2011				
EBC5 brake rack	840,000	km	\$6,480,000.00	3	11,250.00	\$33,750.00	31/12/2011				
Brake system - valves, cocks, general	840,000	km	\$10,037,765.76	1	52,280.03	\$52,280.03	31/12/2011				
Auxiliary Systems - minor overhaul	840,000 km (following the O/H		\$384,000.00	1	2,000.00	\$2,000.00	AECOM Est 2013	Replace capacitors due to age and replacement auxiliary converter circuit breakers and discs - minor overhaul	\$ 384,000.00	BT/EDI will cover labour	
Communications/PIS	1 time (at the start)		\$9,600.00	2	100.00	\$200.00	Estimate	AM/FM System Upgrade	\$ 15,724.80	\$ 25,324.80 10hrs per unit	
Emergency Door Release (relocation)	1 time (at the start)		\$264,000.00	1	5,500.00	\$5,500.00	Interfleet 2010 +5%pa	Relocated to side of doors may be reqd post PTA discussion with DDA	\$ 83,865.60	\$ 347,865.60 32hrs per unit	
LED Saloon lighting	1 time (at the start)		\$430,080.00	64	140.00	\$8,960.00	\$50,000 one off cost for diffuser die mould, \$80 per diffuser - standard mkt rate for normal home diffuser	\$ 63,104.00	\$ 493,184.00 5 hrs per unit, PTA quote		
LED Cab dashboard lighting	1 time (at the start)		\$108,192.00	2	1,127.00	\$2,254.00	2013 ART quote	\$ 7,862.40	\$ 116,054.40 90minutes for 2 men per installation		
Smoke Detection - VESDA	1 time (at the start)		\$288,000.00	1	6,000.00	\$6,000.00	PTA 2013 quote	\$ 288,000.00	\$ 576,000.00 \$6000 per unit, 80 labour hours per unit		
Condition based replacement of equipment boxes	2 boxes per year condition based		\$560,000.00	1	10,000.00	\$10,000.00	PTA 2013 quote RR	Would not do fleetwide - very labour intensive	\$ 122,304.00	\$ 682,304.00 80 hours BT/EDI, 2 boxes replaced per year = 40 boxes over 28 yrs	
Anticlimbers - modify sole bar	1 time (at the start)		\$633,600.00	1	13,200.00	\$13,200.00	Interfleet 2010 +5%pa	\$ 62,899.20	\$ 696,499.20		
New GRP frontage	1 time (at the start)		\$4,898,880.00	2	48,600.00	\$102,060.00	2004+5%pa	plus \$15,000 for all pieces BT/EDI	\$ 460,800.00	\$ 5,359,680.00 BT/EDI will cover labour, 5 days, two people, two 8hr shifts, \$60pp - per end of unit	
New Cab HVAC system	1 time (at the start)		\$1,488,000.00	2	15,500.00	\$31,000.00	2013 Thermoking	includes 10% GST	\$ 655,920.00	\$ 2,143,920.00 155hrs per end	
Vaccum Circuit Breakers	1 time (at the start)		\$2,000,000.00	1	40,000.00	\$40,000.00	BT/EDI	48 plus 2 spare	\$ 7,862.40	\$ 2,007,862.40 3 manhours plus 1 hour for shunting	
Traction Controller	1 time (at the start)		\$2,328,000.00	2	24,250.00	\$48,500.00	Interfleet 2010+5%pa		\$ 2,328,000.00		
Traction motor (100% Re-wind)	1 time (at the start)		\$12,960,000.00	6	45,000.00	\$270,000.00	31/12/2011	100% of cost covered by PTA	\$ 12,960,000.00		
New Traction System (DC-Regen)	1 time (at the start)		\$11,240,976.00	2	117,093.50	\$234,187.00	11/04/2013 Alstom	Excludes labour for one off cost = \$112137 per unit, installation = \$77000 per unit	\$ 9,773,040.00	\$ 21,014,016.00	
New Brake and Air System	1 time (at the start)		\$8,106,400.00	1		\$ 8,106,400.00	Faiveley 2013 - excludes replacement of parts such as Transducers, and Power Supplies	Replace Obsolete Air Dryer with newer modern Graham White Air Dryer, Replace Compressor with modern Oil Free Compressor, Replace old Callipers with new slightly improved design to reduce impact of wear and tear, includes basic 4 year overhaul, and mandatory replacement of parts such as Transducers, and Power Supplies	\$ 8,106,400.00		
New HVAC System for saloon	1 time (at the start)		\$ 6,144,000.00	4	32000	\$ 128,000.00	Faiveley 2013 - excludes replacement of parts such as Transducers, and Power Supplies	Does not include conversion to energy green savings unit. Includes new HVAC and new controller. Includes replacement of motor fans	\$ 6,144,000.00		
New PIS/Communications System	1 time (at the start)			1				Would include new AM/FM upgrade	\$ -	Suntill awaiting costs	
Upgraded ATP cables and transmission racks	1 time (at the start)		\$600,000.00	1	12,500.00	\$12,500.00	PTA 2013 quote	transmission rack cards and cables - rejuvenation. System cards to be a fleet wide decision	\$ 29,184.00	\$ 629,184.00 8hrs per rail car at \$76/hr	
RAPID Software upgrade	1 time (at the start)		\$50,000.00	fleet wide	50,000.00	\$50,000.00	PTA 2013 quote		\$ 1,020.00	\$ 51,020.00 15 minutes for a technician to install upgraded software per unit at \$85 per hour	
New DCU Learning Door system	1 time (at the start)		\$2,688,000.00	8	7,000.00	\$56,000.00	Faiveley 2013 quote +50%	Replacement of pneumatics with electric cylinder and electronic DCU KB.2013 alternative quote - \$10000 per door	\$ 2,688,000.00		
Hearing Aid Loops/Augmentation	1 time (at the start)		\$860,000.00	1	20,000.00	\$20,000.00	Interfleet 2010 +5%pa	Dependent on DDA compliance re-addressed, currently does not meet DDA but pardoned due to being legacy rolling stock	\$ 187,824.00	\$ 1,047,824.00 2x40 hour weeks, 1 technician	
Replace electrical coupler heads	1 time (at the start)		\$2,534,400.00	2	44,000.00	\$88,000.00	Interfleet 2010 +5%pa		\$ 25,159.68	\$ 2,559,559.68 8hrs per coupler, assumes 60% of couplers will be replaced over the 30yrs	
New Train Management System	1 time (at the start)		\$8,606,400.00	1	179,300.00	\$179,300.00	Interfleet 2010 +5%pa		\$ 8,606,400.00		
		Total Material Cost	\$174,403,778.48								
		Material cost of upgrades only	\$67,182,528.00						Labour cost of upgrades only	\$ 12,071,680.48	\$ 186,475,458.96 Total Labour and Material Costs
			\$77,259,907.20						\$ 11,784,570.08	\$ 78,967,098.08 Total Labour and Material Costs for Upgrades only	
									\$ 13,552,255.59	\$ 90,812,162.79 Total Labour and Material Costs for Upgrades only (+15% contingency)	
										\$ 636,171,947.49 Total upgrade costs plus maintenance contract costs	

Option 3b - Major Upgrades with AC Re-gen

Avg km per year 140,000
End of life + 20 yrs 28

\$	228,358,473.00	until end of Phase 2 of current contract
\$	11,417,923.65	Plus 5% contingency as per AECOM standards
\$	239,776,396.65	
\$	87,247,220.00	Plus 5yrs on top of contract (equal to design life plus 10years). Based on costs of Phase 2 of current contract.
\$	17,449,444.00	Plus 20% on additional 5years to allow for higher risk associated with age of trains
\$	5,234,833.20	Plus 15% contingency as per AECOM standards
\$	109,931,497	
\$	130,870,830	Plus 10yrs on top of contract with 5yrs (equal to design life plus 20yrs). Based on costs of Phase 2 of current contract.
\$	39,261,249	Plus 30% on additional 10years to allow for higher risk associated with age of trains
\$	25,519,812	Plus 15% contingency as per AECOM standards
\$	195,651,891	
\$	545,359,784.70	Total Maintenance Contract Cost

O/H activities to be undertaken under Option 3

Task	Interval	Unit	End of life + 20 yrs	Qty per vehicle	Unit cost	Railcar cost	Quote base date	Special note	Labour Est.	Main. + Lab. for upgrade
MCB	1,400,000	km	\$2,152,137.60	1	22,418.10	\$22,418.10	31/12/2011			
Pantograph	1,120,000	km	\$1,361,376.00	1	9,454.00	\$9,454.00	31/12/2011			
HVAC - conversion	1,120,000	km	\$1,535,760.00	4	2,666.25	\$10,665.00	31/12/2011			
HVAC	1,120,000	km	\$5,737,507.20	4	9,960.95	\$39,843.80	31/12/2011			
Power/Brake controller	840,000	km	\$1,920,000.00	2	5,000.00	\$10,000.00	31/12/2011			
Driver's console	140,000	km	\$672,000.00	2	250.00	\$500.00	31/12/2011			
Traction control system	1,120,000	km	\$432,000.00	1	3,000.00	\$3,000.00	31/12/2011			
External passenger doors - heavy	1,120,000	km	\$3,309,465.60	8	2,872.80	\$22,982.40	31/12/2011	Door leaf not included, tracks and pistons included		
Gangway doors - heavy	1,120,000	km	\$552,960.00	2	1,920.00	\$3,840.00	31/12/2011	Bellow not included		
Cab doors	1,120,000	km	\$69,120.00	4	120.00	\$480.00	31/12/2011	Door leaf not included		
Driver's seat	1,400,000	km	\$710,400.00	2	3,700.00	\$7,400.00	31/12/2011			
Main transformer	1,680,000	km	\$1,311,264.00	1	13,659.00	\$13,659.00	31/12/2011			
Thyristor converter	140,000	km	\$142,093.32	1	105.72	\$105.72	31/12/2011			
Thyristor Converter - heavy	10yr	140,000 km	\$1,536,000.00	1	16,000.00	\$16,000.00	31/12/2012	Estimate based on life of capacitors and semiconductors		
Contact box	140,000	km	\$595,163.52	2	221.42	\$442.83	31/12/2011	does not include overhaul of internal components		
Auxiliary relay box	140,000	km	\$104,025.60	2	38.70	\$77.40	31/12/2011	does not include overhaul of internal components		
Brake resistor	1,120,000	km	\$1,719,921.60	2	5,971.95	\$11,943.90	31/12/2011			
PFC unit	140,000	km	\$1,028,445.60	1	765.21	\$765.21	31/12/2011			
PFC - Heavy	10yr	140,000 km	\$576,000.00	1	6,000.00	\$6,000.00	31/12/2012	Estimate based on life of capacitors (not filter cap)		
Auxiliary converter	1,400,000	km	\$11,059.20	1	115.20	\$115.20	31/12/2011			
Auxiliary Converter Heavy	10yr	1,400,000 km	\$480,000.00	1	5,000.00	\$5,000.00	31/12/2012	Estimate based on life of capacitors		
Automatic coupler	1,120,000	km	\$4,692,329.28	2	16,292.81	\$32,585.62	31/12/2011			
Semi-permanent coupler	1,120,000	km	\$1,108,264.32	2	3,848.14	\$7,696.28	31/12/2011			
Auxiliary transformer / reactor	840,000	km	\$59,788.80	1	311.40	\$311.40	31/12/2011			
Wheelsets	1,120,000	km	\$10,278,316.80	8	8,922.15	\$71,377.20	31/12/2011			
Traction motor (now AC)	840,000	km	\$21,600,000.00	6	25,000.00	\$150,000.00	31/12/2011	Assume O/H is same periodicity for AC and DC motors, performed three times as first time is replacement.		
Gearbox	1,120,000	km	\$1,421,798.40	6	1,645.60	\$9,873.60	31/12/2011			
Damper (vert & lat) - first	1,120,000	km	\$2,323,261.44	8	2,016.72	\$16,133.76	31/12/2011			
Brake disc, motor & trailer	1,120,000	km	\$2,717,568.00	16	1,179.50	\$18,872.00	31/12/2011			
Bogie, motor & trailer	1,120,000	km	\$15,743,692.80	4	27,332.80	\$109,331.20	31/12/2011			
Air compressor	840,000	km	\$2,143,915.39	1	11,166.23	\$11,166.23	31/12/2011			
Air boxes	1,120,000	km	\$31,104.00	2	108.00	\$216.00	31/12/2011			
Air dryer	840,000	km	\$545,283.84	1	2,840.02	\$2,840.02	31/12/2011			
Brake calliper	840,000	km	\$5,529,600.00	16	1,800.00	\$28,800.00	31/12/2011			
EBC5 brake rack	840,000	km	\$6,480,000.00	3	11,250.00	\$33,750.00	31/12/2011			
Brake system - valves, cocks, general	840,000	km	\$10,037,765.76	1	52,280.03	\$52,280.03	31/12/2011			
Auxiliary Systems - minor overhaul	840,000	km (following t	\$384,000.00	1	2,000.00	\$2,000.00	AECOM Est 2013	Replace capacitors due to age and Replacement of auxiliary converter circuit breakers and discs - minor overhaul	\$384,000	BT/EDI will cover labour
Communications/PIS	1	time (at the sta	\$9,600.00	2	100.00	\$200.00	Estimate	AM/FM System Upgrade	\$ 15,725	\$25,325 10hrs per unit
Emergency Door Release (relocation)	1	time (at the sta	\$264,000.00	1	5,500.00	\$5,500.00	Interfleet 2010 +5%pa	Relocated to side of doors may be reqd post PTA discussion with DDA	\$ 83,866	\$347,866 32hrs per unit
LED Saloon lighting	1	time (at the sta	\$430,080.00	64	140.00	\$8,960.00	\$50,000 one off cost for diffuser die mould, \$80 per diffuser - standard mkt rate for normal home diffusers are \$	\$63,104.00	\$493,184	5 hrs per unit, PTA quote
LED Cab dashboard lighting	1	time (at the sta	\$108,192.00	2	1,127.00	\$2,254.00	2013 ART quote	\$7,862.40	\$116,054	90minutes for 2 men per installation
Smoke Detection - VESDA	1	time (at the sta	\$288,000.00	1	6,000.00	\$6,000.00	PTA 2013 quote	\$ 288,000	\$576,000	\$6000 per unit, 80 labour hours per unit
Condition based replacement of equipment boxes	2	boxes per ye	\$560,000.00	1	10,000.00	\$10,000.00	PTA 2013 quote RR	Would not do fleetwide - very labour intensive	\$122,304.00	\$682,304 80 hours BT/EDI, 2 boxes replaced per year = 40 boxes over 28 years
Anticlimbers - modify sole bar	1	time (at the sta	\$633,600.00	1	13,200.00	\$13,200.00	Interfleet 2010 +5%pa	Check - \$10000 per unit? Or per door	\$62,899.20	\$696,499
New GRP Frontage	1	time (at the sta	\$4,898,880.00	2	48,600.00	\$102,060.00	2004+5%pa	plus \$15,000 for all pieces BT/EDI	\$ 460,800	\$5,359,680 BT/EDI will cover labour, 5 days, two people, two 8hr shifts, \$60pp - per end of unit
New Cab HVAC system	1	time (at the sta	\$1,488,000.00	2	15,500.00	\$31,000.00	2013 Thermoking	includes 10% GST	\$ 655,920	\$2,143,920 155hrs per end
Vaccum Circuit Breakers	1	time (at the sta	\$2,000,000.00	1	40,000.00	\$40,000.00	BT/EDI	48 plus 2 spare	\$7,862.40	\$2,007,862 3 manhours plus 1 hour for shunting
Traction Controller	1	time (at the sta	\$2,328,000.00	2	24,250.00	\$48,500.00				\$2,328,000
New Traction System (AC-Regen)	1	time (at the sta	\$64,286,688.00	2	669,653.00	\$1,339,306.00	17/04/2013	Excludes labour for one off cost = \$236320.74 per unit, installation = \$90000 per unit	\$ 15,103,296	\$ 79,389,984
New Brake and Air System	1	time (at the sta	8106400	1		\$ 8,106,400.00	Faiweley 2013 - excludes re	Replace Obsolete Air Dryer with newer modern Graham White Air Dryer, Replace Compressor with modern Oil Free Compressor, Replace old Callipers with new slightly improved design to reduce impact of wear and tear. Includes basic 4 year overhaul, and mandatory replacement of parts such as Transducers, and Power Supplies		\$8,106,400.00
New HVAC System for saloon	1	time (at the sta	\$ 6,144,000.00	4	32000	\$ 128,000.00		Does not include conversion to energy green savings unit. Includes new HVAC and new controller		\$6,144,000.00
New PIS/Communications System	1	time (at the start)		1			Faiweley 2013	Would include new AM/FM upgrade. Passenger safety upgrade to include CCTV, PA/Intercom system, if possible include passenger counting. Wireless offload of captured CCTV footage. Provide main Power Converter		\$0.00
Upgraded ATP cables and transmission racks	1	time (at the sta	\$600,000.00	1	12,500.00	\$12,500.00	PTA 2013 quote	transmission rack cards and cables - rejuvenation. System cards to be a fleet wide decision	29184	\$629,184.00 8hrs per rail car at \$76/hr
RAPID Software upgrade	1	time (at the sta	\$50,000.00	fleet wide	50,000.00	\$50,000.00	PTA 2013 quote		1020	\$51,020.00 15 minutes for a technician to install upgraded software per unit at \$85 per hour
New DCU Learning Door system	1	time (at the sta	\$2,688,000.00	8	7,000.00	\$56,000.00	Faiweley 2013 - quote - repl	KB 2013 quote Check - \$10000 per unit? Or per door		\$2,688,000.00
Hearing Aid Loops/Augmentation	1	time (at the sta	\$860,000.00	1	20,000.00	\$20,000.00	Interfleet 2010 +5%pa	Dependent on DDA compliance re-addressed, currently does not meet DDA but pardoned due to being legacy rolling stock	\$187,824.00	\$1,047,824.00 2x40 hour weeks, 1 technician
Replace electrical coupler heads	1	time (at the sta	\$2,534,400.00	2	44,000.00	\$88,000.00	Interfleet 2010 +5%pa		\$25,159.68	\$2,559,559.68 8hrs per coupler, assumes 60% of couplers will be replaced over the 30yrs
New Train Management System	1	time (at the sta	\$8,606,400.00	1	179,300.00	\$179,300.00	Interfleet 2010 +5%pa			\$8,606,400.00
		Total Material Cost	\$215,785,490.48							
		Material cost of upgrades only	\$107,268,240.00							
			123358476							
								Total Labour Cost	\$ 17,401,936.48	\$ 233,187,426.96 Total Labour and Material Costs
								Labour cost of upgrades only	\$ 17,114,826.08	\$ 124,383,066.08 Total Labour and Material Costs for Upgrades only
									\$ 19,682,049.99	\$ 143,040,525.99 Total Labour and Material Costs for Upgrades only (+15% contingency)
									\$	\$ 688,400,310.69 Total upgrade costs plus maintenance contract costs

Options Cost Analysis Summary as at 8th May 2013

	end of Phase 1 of current contract + 1.5 yrs End 2020 Option 1	End of life plus 5yrs - until end of Phase 2 of current contract End 2026 Option 2a	End of life plus 10yrs - current contract plus 5 yrs End 2031 Option 2b	End of life plus 20yrs (DC-Regen) - current contract plus 15 years End 2041 Option 3a	End of life plus 20yrs (AC-Regen) - current contract plus 15 years End 2041 Option 3b
Maintenance contract	\$ 141,344,769	\$ 239,776,397	\$ 349,707,894	\$ 545,359,785	\$ 545,359,785
Additional Materials (includes +15% contingency)		\$ 7,579,359	\$ 20,855,511	\$ 77,259,907	\$ 123,358,476
Additional Labour (includes +15% contingency)		\$ 592,642	\$ 1,983,362	\$ 13,552,256	\$ 19,682,050
Total	\$ 141,344,769	\$ 247,948,398	\$ 372,546,767	\$ 636,171,947	\$ 688,400,311
Current Maintenance Contract as is		Traction motor (100% Re-wind)	Anticlimbers - modify sole bar	New Traction System (DC-Regen)	New Traction System (AC-Regen)
		Auxiliary Systems - minor overhaul	New GRP frontage	New Brake and Air System	
		HVACS - replace fan motors	New Cab HVAC system	New HVAC System for saloon	
		Communications/PIS	Vaccum Circuit Breakers	New PIS/Communications System (Cost TBA)	
		Emergency Door Release (relocation)	Traction Controller	Upgraded ATP cables and transmission racks	
		LED Saloon lighting		RAPID Software upgrade	
		LED Cab dashboard lighting		New DCU Learning Door system	
		Smoke Detection - VESDA		Hearing Aid Loops/Augmentation	
		Condition based replacement of equipment boxes		Replace electrical coupler heads	
				New Train Management System	

Appendix F

Asset Inspection Checklist

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Assessment detail		
14	01	00
Primary Suspension		
Rubber sheath on primary		
14	06	00
Wheels		
14	06	01
Wheel Faults		
14	07	00
Axles		
Axle probe		
15	00	00
Coupling System		
15	08	00
Autocoupler Controls		
Car 36 auto coupler ceased?		
16	00	00
Underframe System		
Fixings on boxes have corrosion		
Some transformer mounts have stress fractures		
Rubber looms are sagging and need replacement		
17	00	00
Auxiliary System		
Semi-conductors failing at half life of car (ie 15 yrs)		
Battery box has reduced reliability		
Auxiliary converters have some corrosion leakage		
Capacitors failing at half life of car (ie 15 yrs)		
17	03	00
Saloon Lighting		
Saloon lighting changed periodically		
17	21	00
Programmable Logic System		
PLCs (controllers) nearing obsolescence		
18	00	00
Heating / Ventilation System		
18	10	00
Air Conditioning (saloon)		
18	10	01
Nearing electrical obsolescence and mechanical fatigue of compressors		
50% of fleet still uses unsuitable refrigerants R22		
18	11	00
Air Conditioning (Cab)		
Cab utilises HVAC air flow from saloon, considered often inadequate during summer		
19	00	00
Air Supply System		
19	04	00
Compressor		
Compressors experiencing oil carry over		
Air dryer		
24	00	00
Automatic Train Control System		
24	01	00
Pick-up Coils		
Replacement of coils		
24	34	00
ATP System		
Drivers cab panel		
Transmission		
25	00	00
Communication System		
Now nearing obsolescence		
wifi		
25	01	00
Cab to Cab Telephones		
25	02	00
Digitised Speech		
25	03	00
Train Radio Devices		
AM/FM Radio		
UHF/Train Radio		
Mobile Phone		
25	06	00
Closed Circuit Television (CCTV)		
CCTV analogue systems being installed		

Discreet Vehicle Inspections				
Findings	Date of Inspection	Inspected By	Above Normal Maintenance?	Vehicle No.
Need to be replaced	25/01/2013	MT	YES	
Hollow tread currently being experienced on most wheel sets	25/01/2013	MT	NO	Car 36
Electrical pins/boxes fail resulting in linkage not releasing.	25/01/2013	MT	YES	Car 36
Repainted on F-service on condition	25/01/2013	MT	YES	Car 36
Have been taken out to be re-welded	25/01/2013	MT	YES	Car 36
To be replaced	25/01/2013	MT	YES	Car 36
Replacement of semi-conductors (changed upon failure)	25/01/2013	MT	NO	Car 36
Replacement of battery box	25/01/2013	MT		Car 36
Replacement of converters	25/01/2013	MT		Car 36
Replacement of capacitors (first time changed)	25/01/2013	MT	YES	Car 36
Every 144 weeks (120V nominal)	25/01/2013	MT	NO	Car 36
Currently replacing with spares however will need to implement alternatives as a result of obsolescence	25/01/2013	MT		Car 36
HVAC system not yet overhauled but likely required to be done in the near future. Currently experiencing electrical system failures, corrosion of condensers, and aged piping. BT/EDI in collaboration with Faiveley (OEM) currently performing NDT on HVACs to determine business case for maintenance vs renewal	25/01/2013	MT	YES	Car 36
Being switch over from R22 to R134/410A. Also experiences refrigerant leaks.	25/01/2013	MT	YES	Car 36
Additional fan used to blow more air in from saloon to cab, however still significant heat experienced in summer	25/01/2013	MT	YES	Car 36
obsolescence issues and oil leaking into dessicators	25/01/2013	MT	YES	Car 36
PTA currently investigating train protection systems going forward	25/01/2013	MT	YES	Car 36
Went through o/h 10 yrs ago and fleet completed last year - outside of current BT/EDI scope. Relays are readily available and easy to remove, however other components may not be and therefore costly to remove	25/01/2013	MT	YES	Car 36
Shark fins on the roof for wifi downloading not very reliable	7/02/2013	MT	YES	Car 36
Obsolescence issues. Roof mounted antenna experiences corrosion issues.	7/02/2013	MT	YES	Car 36
Transceiver experience intermittent failure. Cable problems/degeneration due to constant manipulation.	7/02/2013	MT	YES	Car 36
4 per car	25/01/2013	MT	YES	Car 36

Tacit Knowledge Review					
Details	Extent of Fleet	Is it degrading?	Extra Maintenance?	Will it last 7-9 Years?	Further Requirements
Applies to most. Faults related to wheel skids that are caused by driver errors and weather.	MOST	YES	YES	NO	40% of wheels have been changed out with 60% remaining. Sole provider is GEMCO. Can do up to 12 years but are based on an 8 year periodicity. Currently being overhauled every 10 years to align with periodicity of bogie overhaul.
Vibration experienced due to other suspension systems.	SOME	UNKNOWN	NO	N/A	12 have been replaced in the past 12 months. Stock standard item. Unlikely to have obsolescence issues.
Auto couplers experience corrosion and significant wear with electrical interface issues.	ALL	YES	NO	NO	Every 4 weeks wiped down, every 12 weeks relubricated
Applies to all. Consumables sourced from the UK. \$8 per lamp. Inverters experience ground faults. When lights failed, they were previously causing power surges which would trip the main circuit breaker	YES	NO	NO	NO	Power system for the lighting has been modified (20 sets to go) to be separated from toher systems and operates on 50V DC at 200Hz
Applies to all. Regularly experience electrical faults that cant be traced (earthing faults). Fans have a three phase elctrical issue.	ALL	YES	NO	NO	Compressors likely to be O/Hauled in near future to extend life to 8-10yrs. O/H of compressors is \$12,000 per unit. 5 units for spares. Obsolescence not a significant issue, post next O/H may need to do mod/retrofit of parts due to obsolescence - eg compressor changed to rotary compressor
Applies to 50%					
Applies to all					
Main compressor experiences mixing of water condensation and oil - some compressors resolved this issue through conversion from 4 pole to 6 pole motors. Fleetwide replacement to commence soon	SOME	YES	YES	NO	Currently being replaced
Destroyed "sticky" buttons causing Transmission faults make up most of ATP system faults - signal problems with antenna, card and cables are the original fitted in 2006 and have not been replaced and subsequently experiencing aging issues (reactive maintenance).	SOME ALL	YES YES	YES YES	NO POSSIBLE	Currently being replaced - ATP cables need to be replaced - costly in the order of \$4000-6000 per car. Refurbish costs can range from \$50,000 to \$100,000 in total (material costs excluding labor). There are studies looking at the replacement of the trackside ATP equipment (to a moving block system) in the next couple of years for increasing capacity.
Redundancy item - obsolete					

Assessment detail		
		RAPID System, responsible for the CCTV, passenger announcement system and GPS signal system

Discreet Vehicle Inspections				
Findings	Date of Inspection	Inspected By	Above Normal Maintenance?	Vehicle No.

Tacit Knowledge Review					
Details	Extent of Fleet	Is it degrading?	Extra Maintenance?	Will it last 7-9 Years?	Further Requirements
Teething problems experienced including system freezes requiring reswetting, hard drive and display problems, and loss of GPS signal. Prior to RAPID VHS tapes were used.	ALL	NO	YES	YES	New technology likely to be implemented at end of life

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Appendix G

Vendor Quotes

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ALSTOM TRANSPORT NON-BINDING INDICATIVE PROPOSALS FOR UPGRADING THE TRACTION SYSTEM ON THE PERTH A-SERIES TRAINS INCORPORATING REGENERATIVE BRAKING

**ALSTOM REFERENCE BOID221531 REV 01
07 MARCH 2013**



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1 EXECUTIVE SUMMARY

We are pleased to provide a preliminary non-binding and budgetary proposal for upgrading the traction system of the Perth 'A-Series' trains which we understand to suffer from serious reliability problems, notably associated with thermal issues within the power modules integrated in the traction drive.

Our primary proposal re-utilises the existing DC traction motors by deploying our innovative DC Regeneration technological solution to achieve the PTA's stated objectives as far as reasonably possible (based on the relatively limited information that we hold to date). This solution is price-effective and unique to Alstom. Alternatively, we would be delighted to offer a full AC conversion whereby the existing DC traction motors are replaced with new AC machines housed within the same bogies. We would welcome an opportunity to discuss the relative merits of the two solutions and to develop the way forward alongside Aecom and personnel from the PTA.

In addition to the key driver of reliability improvement, we have also sought to address the following principal objectives identified to us:

- Removal of equipment obsolescence – *substantially achieved in both proposals;*
- Enabling re-regenerative braking and anticipated energy savings as % - *anticipated capability of up to 30% for both proposals;*
- Achievement of close to unity power factor – *substantially achieved in both proposals (DC Regen is expected to deliver >0.9 over much of its operation);*
- Improved traction electronics - fault handling and diagnostics interface – *achieved in both proposals. A new control system provides for all the traction-related functions including fault reporting and the option of remote communication for reviewing train status remotely at the depot office;*
- Preference to retain existing bogies – *achieved in both proposals;*
- Preference to retain existing transformer, if possible – *achieved in both proposals;*
- Is a solution with 4 (higher capacity) motors instead of 6 original motors would be feasible whilst maintaining the same performance? *At the present early and very indicative stage, we have retained a 6-motor solution in both options (DC Regen and full AC re-traction) in order to avoid potential bogie complexities although it is considered that the AC machines (220kW) will be capable of delivering a higher performance within the existing space envelope. But ... it is thought by the technical specialists that increased motoring performance would be acceptable but braking could unreasonably stress 4 motors, hence a further preference to retain the existing 6 motor configuration.*

Project Management

Alstom has a strong record worldwide in the effective management of major projects covering the fields of transport, power and electricity distribution. We apply a major focus on identifying appropriate project management skills and assigning project teams aligned to our major project requirements. Appropriately qualified personnel would be deployed both within Alstom's European business units and in Australia to ensure that the Perth traction upgrade is implemented efficiently and in alignment with customer needs.

Traction and Bogie Expertise

In terms of traction-related experience, our *Modernisation* sites in Preston (United Kingdom) and Ridderkerk (Netherlands) are well known as worldwide Centres of Excellence for traction technology, both having long histories in the traction field and both having adapted to modern and efficient energy-saving traction drive

schemes to meet the stringent demands of the current business and environmental climates. For the Perth A-Series project, this skill base is likely also to be supported by another Alstom traction unit in Charleroi, Belgium which is well experienced in dealing with traction markets worldwide. Notably, the Charleroi unit has electrical power capability to deliver a Combined Test of the traction drive train before train installation.

In addition, we would ensure that the motor to bogie interface for the new motors is fully validated and we may utilise our bogie centre of excellence at Neuhausen in Switzerland (formerly Fiat SIG) to assist in this activity.

With the capability outlined above, we can offer extensive world-class design, simulation and testing capabilities that are able to address all aspects of design, testing, validation and installing of new traction drives in an optimal manner and with minimal disruption.

Technology

As referenced above, our “DC Regen” solution is a product unique to Alstom that can be designed, tested, delivered and installed at less than half the price of an equivalent AC drive package. It uses a clever adaptation of existing circuitry to deliver regenerative braking and specifically retains the existing DC traction motors. Retention of the existing DC machines obviously demands that those machines are in good condition at the time of introduction of the new drive and we would therefore strongly recommend that a comprehensive heavy overhaul be undertaken and Alstom would welcome the opportunity to do this (but the costs of undertaking traction motor overhaul are not included within the budgetary figures declared within this indicative proposal).

The ONIX product offered for the AC solution has currently been ordered for more than 1,400 vehicles worldwide and is based on existing proven Alstom IGBT technology for which we have a well-established worldwide reference list of more than 5,000 ONIX inverters. Our proposed AC solution therefore utilises existing proven Alstom product.

Planning

Whilst we are uncertain of the precise programme requirements, we have constructed a simple plan that is conservative but achieves the timescales that are mentioned in the PTA proposal dated September 2010. Alstom will obviously seek to optimise this planning once more precise information is available on which to base the overall programme.

Whilst this is a top level plan and does not provide full detail in areas such as supply chain logistics and quality, it does identify the Design for Quality (DFQ) gate reviews that are fundamental to Alstom’s process. A more detailed plan will be developed after contract award and prior to the Specification Gate Review (SGR), showing key project deliverables.

Installation

We understand that installation is likely to take place at a workshop in the Perth area but is unlikely to utilise a running depot. As requested, we have made a very approximate assessment of the anticipated installation hours for both options on the assumption that all necessary workshop space, office accommodation, overhead cranes, all necessary electrical supplies, shunting, test train driving and parking/messing facilities for Alstom personnel and/or Alstom’s sub-contractor’s personnel will be provided to Alstom free of charge. The

assumptions are more fully detailed in our “Assumptions List” that is an integral part of this indicative proposal.

We can also offer comprehensive depot based expertise built on experience gained within Alstom and non-Alstom depot facilities, including modernisation projects such as TBTC implementation on London Underground tubestock, Pendolino and Coradia upgrade programmes in the UK, ERTMS implementation, and remote train monitoring installation on various fleets, notably on the Class 465/466 Networker trains operating in the South-East of England. All of these programmes were integrated into on-going operations without compromising service availability or fleet reliability.

Safety Case

For this project to be a success we fully appreciate that securing the relevant approvals and “Safety Case” will be a critical part of our obligations. In the event of being awarded a contract at a later stage, Alstom would propose to take responsibility for managing the Safety Case for the new drive (providing that all stake-holders agreed to support Alstom’s activities and make available personnel, documentation and test facilities, as required).

We have based our indicative costings on meeting a UK Safety Case but we would need to better understand the Australian regulatory regime and transportation obligations at the stage of compiling any definitive proposal.

Maintenance / Performance

We fully appreciate that by changing the traction system the resulting maintenance regime will also be impacted. Using our maintenance experience in optimising maintenance schedules, we propose to work closely with the Perth authorities to optimise the maintenance regime extending exam periodicities, thus increasing availability of the units and reducing maintenance costs, wherever possible.

In summary, based on our knowledge of the traction drive market, our wide experience in traction and bogies and our manufacturing and installation capabilities, we can provide Western Australia with a partner on whom they can rely – a partner who has the strength, breadth and depth to manage and deliver this project.

2 TERMS OF REFERENCE

This proposal refers to the Perth ‘A-Series’ Traction Upgrade project which involves the “*re-tractioning*” of the existing 48 x 2-car EMUs with a solution that provides the capability to regenerate whilst simultaneously increasing the levels of fleet availability and reliability.

3 SCOPE OF SUPPLY

The proposed scope of supply on which we have based this indicative proposal covers a turnkey package inclusive of the areas of activity described below:

- **Project Management**
 - Overall project management in Europe (Preston, UK or Ridderkerk, Netherlands) and in Australia
 - Project planning

- Management of the installation works
- Cost control
- **Engineering design**
 - Design
 - Bogie mechanical adaptation
 - Electrical loadings
 - New system integration
 - Integration of traction control and brake blending (assuming that the Brake Control Unit is the Master; there are implications relating to the SIL – Safety Integrity Level – requirements that require this caveat).
 - Safety analysis
 - Engineering requirement specifications for works & equipment
 - Modification instructions
 - Routine test requirements
 - Validation of design
 - Engineering change control
- **Equipment Supply**
 - Manufacturing and procurement of all material to programme
- **Combined Test**
 - Integrated testing of equipment prior to first installation - motor, brake, and thermal emissions would be carried out at an Alstom facility, currently anticipated to be in Alstom Charleroi, Belgium.
- **Installation**
 - Removal of existing equipment and installation of new equipment onto the units
 - Testing and commissioning of supplied equipment
- **Approvals (*Safety Case*)**
 - Approvals documentation
 - Validation and Certification

4 PROJECT MANAGEMENT

Projects in Alstom Transport are managed through an extensive and mandatory procedure prescribed by the Alstom Transport Project Management Manual.

The Project Management Manual (PMM) requires that a detailed Project Management Plan is established, which lists all the project objectives and the way in which they are achieved, including a detailed planning of activities with clear milestones.

The PMM also addresses in detail the project organisation with clearly defined roles for the Project Manager, Project Technical Manager and the various Work Package owners. The PMM will form the basis for the Project Execution Plan which will comply with the PTA's requirements concerning professional project control.

Monthly reviews are usually held locally and periodic reviews are held at Alstom Transport Sector level to ensure that the project is kept in line with the requirements and agreed objectives.

5 ENGINEERING DESIGN

The Alstom design philosophy is controlled using the V-cycle design process. This is a step by step design process (from specification through to first built product/equipment to final acceptance by the customer) where every step must be successfully closed with a Design Review Gate before the next step can be started.

This process will be implemented by the main traction engineering team which will be based in either Preston or Ridderkerk, depending upon which drive package is selected. It will take place under the responsibility of a Project Technical Manager who will manage a team of senior traction engineers based in Preston or Ridderkerk who will be responsible for the overall system integration. This includes full specification of the traction system and all its components and the functional design of 'train-to-converter' interface and of the mechanical brake control. Working closely alongside our colleagues in Australia (both within and outside Alstom), one of our European units will take charge of the Safety Case for the new traction equipment and for securing a fully validated electrical and mechanical integration of the new equipment in the existing trains.

6 EQUIPMENT SUPPLY & SUPPLY CHAIN MANAGEMENT

Alstom's facilities have approvals to international standards and have internal rigorous processes and procedures to ensure quality. Our technological solutions are always fully validated before being applied on new projects and as such the selected solution will have already undergone extensive homologation testing. Our DC solution has been extensively tested at Alstom's facility in Stafford in the UK and will be subject to further testing in the coming year while the AC proposal uses current standard technology with an established supply chain in place that has been extensively used in the global marketplace.

7 COMBINED TEST

We currently anticipate that a full combined test will be undertaken at one of our European units, probably at our plant in Charleroi, Belgium. The cost of undertaking such a comprehensive test has been included in the budgetary figures declared within this proposal.

8 APPROVALS & VALIDATION

A comprehensive approach to validation and certification would be adopted and we will use the services of an ISA (Independent Safety Assessor) or equivalent to review critical technical documentation.

The process to be adopted would be a formal Hazard Analysis review followed by close-out of the hazards identified. Clearly, the replacement of the traction cases will necessitate mechanical validation of the cases and their mountings as well as the electrical consequences of the changes.

The Alstom V-cycle gate review process will be employed and design approvals will be obtained within an agreed initial period from date of contract award.

9 PROGRAMME

Whilst we do not yet have a clear view of the programme requirements but we have based our preliminary proposals on the following assumptions:

- | | | |
|---|---|-----------------|
| • Project commencement (NTP) | = | June 2015 |
| • 1st Modified train - installation completed | = | NTP + 18 months |
| • 48th Modified train - acceptance | = | NTP + 58 months |

Fleet installation is based on completion of two complete EMUs per month.

Note that our indicative pricing is current and does not reflect any firming to take into account actual programme durations at this very preliminary stage.

10 INDICATIVE AND BUDGETARY PRICE SCHEDULE

Please refer to separate Indicative Price Matrix.

11 BASIS OF PROPOSALS

Our proposals are:

- Wholly indicative within a tolerance band of +/- 20%;

- Based on a contract quantity of 48 x 2-Car Perth 'A-Series' EMUs to be modified ;
- Based on Alstom's standard Terms and Conditions and the assumptions listed within the separate "Assumptions List" which forms an integral part of the proposals.

Perth 'A-Series' Re-traction Package
BOid221531/TLS18544

List of Assumptions

<u>Item</u>	<u>Assumption</u>
	(A) Specific Pricing Assumptions on which the non-binding indicative prices are based:
A1	This “proposal” is strictly indicative and non-binding at an accuracy of +/- 20%. The “proposal” is not sufficiently rigorous to form the basis of a definitive contract and offers guidance only.
A2	No financing fees have been included. No bonds or other forms of guarantee are included in the indicative figures. No importation fees, charges, taxes or other financial surcharges of whatsoever nature are included.
A3	Cash-flow must be neutral or better for Alstom and payment terms will have to be agreed under any definitive contract to ensure that Alstom does not incur any financing costs. A mobilisation payment of 15%, prototype delivery payment of 10% and a series of subsequent monthly/milestone payments will be required, the details of which are to be agreed at definitive ITT/offer stage.
A4	Indicative prices are strictly current, exclude firming or any other form of escalation provision and are supplied in source currencies on an ex-works basis. Alstom has no liability for any change in the respective exchange rates and the resulting impact upon the indicative prices when determined in the end user currency, AUD.
A5	A simple parts repair or replacement warranty of 2 years is included on the basis of all specified maintenance activities being performed in a timely manner – i.e. consistent with specified maintenance time or period intervals, as appropriate. Irrespective of the train acceptance position, the warranty period shall extend to a maximum of 2.5 years (30 months) from equipment delivery to the nominated conversion facility. Repaired or replaced parts shall be under warranty for the residual warranty term – i.e. no new warranty period shall commence.
A6	Any costs incurred as a result of interpretation or changes in legislation or government guidelines or variation in any applicable standards imposed by the industry, Aecom, Western Australia PTA or any other government or other agency will be subject to an additional charge under an agreed variation process within any future definitive contract.
A7	It is assumed that the modification programme will be undertaken exclusively at one nominated location. Alstom has neither costed nor made provision in its indicative figures for undertaking any work at a second location.
A8	In the absence of a preliminary upgrade programme, Alstom requires that the programme shall be sufficient to support a realistic and efficient equipment build, delivery and installation programme. Trains to be modified are to be made available by the customer for the modification works at a regular beat rate to ensure a consistent and broadly constant work-load that avoids waiting time.
A9	Alstom Transport’s standard Terms & Conditions shall apply to the exclusion of any others.
A10	A “Combined Test” of the equipment will be undertaken at an Alstom plant in Europe (currently anticipated to be in Charleroi, Belgium).
A11	In the absence of detailed “Safety Case” requirements, the indicative costing has been derived based on the requirements being broadly the same as those required for a similar project undertaken in the United Kingdom.
A12	No manuals, parts catalogues, maintenance tools or as-made drawings are included as the requirement for these items is not yet defined.
A13	Updating of the existing train wiring diagrams is excluded and assumed to be the responsibility of Western Australia PTA.
A14	Overhaul or other remedial work on the DC traction motors is excluded for indicative costing purposes but Alstom would be interested to undertake such work once the requirement is better understood and we have had an opportunity to assess the average motor condition. All DC motors should be overhauled as part of the conversion process.
A15	The non-binding indicative prices exclude provision of a new IGBT Auxiliary Converter but Alstom would be interested to supply and install such a new Auxiliary Converter as additional scope, once the precise converter rating requirement is fully understood.

(B) Assumptions relating to conversion Site/Location:	
B1	Sufficient workshop and workshop space shall be made available at the nominated facility (expected to be within the Perth metropolitan area), including the provision of necessary (but yet to be defined) office accommodation to run the programme at a rate yet to be defined and agreed. Alstom shall have no liability for workshop charges or rentals.
B2	It is assumed that suitable staff welfare/changing/washroom/personal storage facilities will be made available at the nominated depot free of charge for workshop personnel.
B3	All normal workshop utility services (gas, electricity and water) are to be supplied to Alstom free of charge and it is assumed that such provision will include phone lines for the needs of the Alstom team, and other facilities such as toilets, car parking spaces and other essential services.
B4	The customer shall be responsible for the timely provision of train driving personnel to meet all reasonable requirements of Alstom or its sub-contractors for the purposes of marshalling, shunting, testing, commissioning and handing over of the trains. The obligation on the customer in respect of train testing shall extend to the provision of drivers, as required (but with reasonable notice), at any nominated and agreed test track in the event that the testing site is different to the conversion depot.
B5	It is assumed that the customer will make arrangements at its cost for the following to be undertaken by depot personnel at the nominated depot without the need for intervention by Alstom and/or its subcontractors: <ul style="list-style-type: none"> • Vehicle Marshalling. • Disconnecting Bogies and Mounting on Stands. • All vehicle lifting and lowering operations. • All heavy material movements requiring the use of a fork-lift truck – e.g. the loading and unloading of road vehicles and the moving of materials to train side. • Making safe the Vehicle prior to Modification Works (Dumping air, power supply, etc.). • Any car height adjustment after re-installation in accordance with approved VMI documentation. • Removal and re-installation of any sub-assemblies, parts, components or the like that may be deemed to require repair or replacement under the warranty terms.
B6	Alstom has not allowed for any special tooling or equipment to undertake the works but expects that all tooling and test facilities that might reasonably be anticipated for works of this nature to be made available on demand free of charge.
B7	Testing equipment at the nominated depot shall be provided by the customer in a timely manner at no charge to Alstom. All such testing equipment shall be in compliance with current electricity supply regulations. Such equipment is to include appropriate line voltage (25kV AC) and lower voltage supplies yet to be defined during preliminary project works.
B8	Certain equipment may be specified by Alstom (items to be specified from the existing DC drive package) for the purposes of conducting a Combined Test and/or the Train Testing of the equipment package and any/all such equipment shall be provided on a free-of-charge to Alstom by way of extended loan by the customer.
B9	Customer shall make necessary arrangements for the removal of any scrap and waste, as identified by Alstom, after completion of each train conversion.

(C) Assumptions relating to Vehicles:	
C1	All prices and other information assume that the vehicles prior to the traction upgrade will be supplied in an operational and sound condition and that Alstom shall have no responsibility under the conversion contract to remedy existing defects, corrosion or any other malfunctions or issues of general deterioration, whether structural or otherwise (issues of this nature could, of course, be addressed under separate additional works arrangements in any future definitive contract).
C2	Additional Arising Work (e.g. vehicle corrosion issues) will impact upon price and programme and Alstom shall be automatically entitled to a reasonable extension of time in any such circumstances under any subsequent definitive contract.
C3	Equipment and cases are deemed to be interchangeable within the car types – i.e. that a case of a particular type will fit every car of that type. No painting or welding work is included. If this is not the actual situation, then there may be an added complexity and Alstom would reserve the right to amend any formal offer as a consequence.
C4	It is assumed that existing cases and cars are wired consistently and, wherever this is found not to be the case, that any necessary remedy shall be undertaken at customer's expense. Alstom will be prepared to support/undertake any such works, providing that such works can be undertaken without impacting upon the project programme in any critical manner and always assuming that time and cost adjustments are to be agreed through an agreed variation process.
C5	It is assumed that redundant cables need not necessarily be removed but that they should be professionally and safely terminated and left on the vehicles/case, as appropriate. If this is not an acceptable scenario, then any agreed remedy shall be effected at customer's expense and subject to such extra time as the circumstances may reasonably require.
C6	A prototype vehicle installation and extended prototype line trial is excluded for indicative costing purposes but Alstom would be very willing to undertake such a trial after discussing the details, duration and scope of the trial (in the event that our non-binding indicative proposal is of interest).



Technical Proposal

Public Transport Authority of Western Australia
Perth A-Series EMU
DC to AC modernization

AUSTRALIA
TECHNICAL DESCRIPTION

Customer: Public Transport Authority of Western Australia
Version: 00.

Date: 2013 March 05

CONTROL SHEET

Version	Issue date	Amendments	Author
00	5-03-2013	First version	Salvien PORCU

	Name	Position	Date	Signature
Written by:	Salvien PORCU	Tender Engineer	05-03-2013	
Verified by:	Gaspard DUPAIN	Technical Consultant	05-03-2013	
Approved by:	Vincent VAN-EUJ	Manager Engineering	05-03-2013	

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1. INTRODUCTION

This document describes the electrical equipment which is offered concerning the DC to AC modernization of the Perth A-series Emu's.

The electrical equipment offered consists of two identical traction chains. Each chain consists of one *4 Quadrant Converter (4QC)* with an *inductor*, a *100 Hz filter*, a *precharge circuit*, an *inverter* with a *rheostatic chopper* and *brake resistor* and three *AC-motors*. This configuration based on IGBT technology makes it possible to regenerating electrical energy back to the line during braking.

The modules used are based on the ONIX™ propulsion technology. The ONIX™ traction module is the result of very large experience acquired by ALSTOM during recent years in design, manufacturing and operation of IGBT's traction drives for railways application. More than 5000 ONIX™ inverters have been sold all over the world.

ONIX™ propulsion incorporates two main elements: the ONIX™ converter using IGBT power modules and the TCU microprocessor control. These two components are designed specifically to work together to achieve a drive with maximum efficiency using the properties of each building block to its fullest potential. The advantages of the ONIX™ propulsion system for the car-builder include:

- A system that is fully tried and tested on railway networks throughout the world, assuring a shorter and more successful installation and commissioning period, and giving the advantage of ALSTOM's world leading experience in IGBT technology.
- A traction system that is supported by a full combined traction converter ALSTOM test facility which permits us to simulate the operation of the propulsion system on the customer's track, before the equipment is mounted on the train, thus further increasing efficiency at commissioning.
- A propulsion system designed with Life Cycle Costs in mind, requiring minimum maintenance, improve reliability and availability of rolling stocks and designed for ease of access by the maintainer's personnel.
- A technology, which provides optimized low energy consumption and running costs.
- A high performance slip/slide control system to take full advantage of the available adhesion.
- Excellent experience in ensuring signaling compatibility through integrated system design.
- A sophisticated data logging system, which provides the operator with full maintenance information including fault recording, and self-test facilities.

So broadly the configuration is designed in such a way that the modernised vehicle meets today's demanding requirements with respect to reliability, maintenance and energy consumption.

2. GENERAL DATA

2.1 Vehicle configuration

The Perth A-series EMU's of the Public Transport Authority of Western Australia (PTA) consists of an A-car and a B-car. The A-car is equipped with two driven bogies (4 motors) and the B-car with a driven bogie and a trailer bogie (2 motors) as can be seen in Figure 2.1.

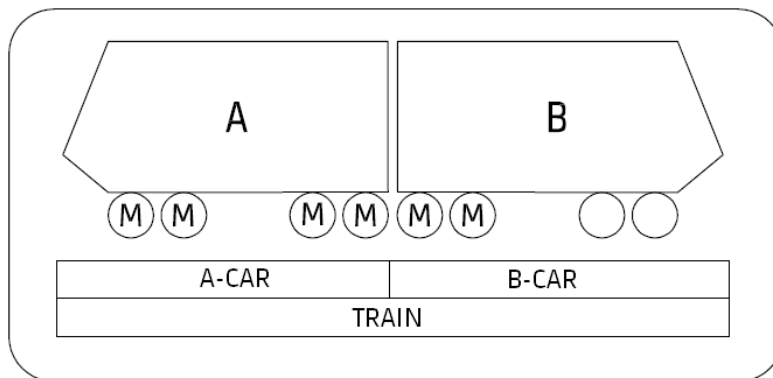


Figure 2.1 : PTA A-Series train configuration

2.2 Propulsion System

The existing system consists of:

- **A collection system (pantograph) at 25 kV AC.**
- **A main transformer with traction and auxiliary secondaries:**

The main transformer is an oil cooled transformer with a 25kV primary winding and four secondary windings. The first two windings have each a voltage of 1003 V with a rating of 607 kVA and are currently used for the traction armature supply. The third winding is 849 V, rated at 187 kVA for the auxiliary supply and the fourth two times 135V rated at 53 kVA for excitation.
- **Two series connected phase controlled rectifiers (main converters).**

phase controlled bridge rectifiers with thyristors and diodes.
- **Smoothing reactors in each motor group DC feed.**
- **Six separately excited DC traction motors in three series parallel circuits.**

2.3 Technical assumptions in line with the proposed system

The following conditions apply:

It is assumed that the train set electrical system is equipped with a VCB directly behind the pantograph. This VCB will be considered as an existing item that will not be examined changed or touched in any way.

The performance after modernisation is equal or better to the performance before the modernisation.

2.4 General description of proposed configuration

In Figure 2.2 the proposed architecture diagram is depicted for the propulsion system after the secondary transformer windings. Each 1003 V AC 50 Hz secondary transformer winding [1] are identical and provides power via the 4QC inductor [2] and precharge circuit [3] to the 4QC [4].

The 4QC will provide a DC link voltage of 1800 V, which will be filtered by the 100 Hz filter [5], to the inverter [11] to drive three AC-motors. Also the 4QC will take care to provide a maximum powerfactor of 1 making the line better utilisable. Although it is possible to regenerate all the braking energy back to the line, the brake resistor [10] will dissipate the energy via the rheostatic chopper[8] if the line is not receptive.

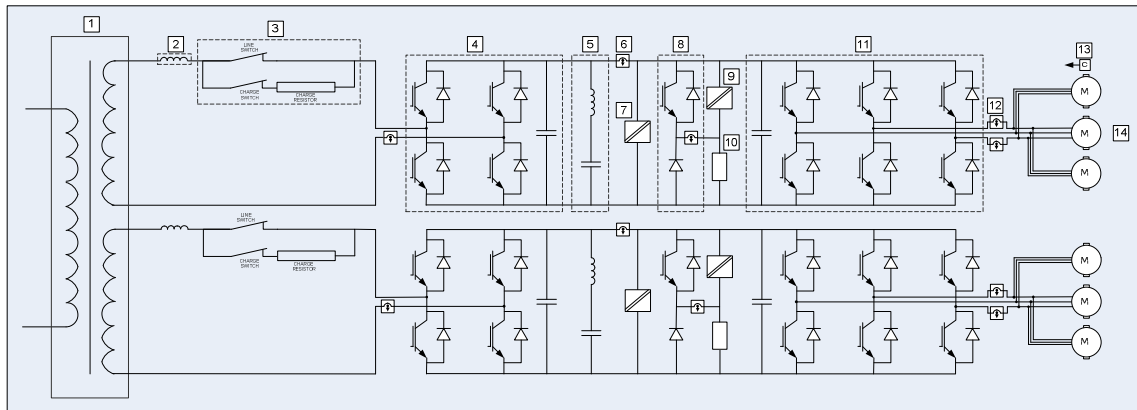


Figure 2.2: Propulsion System Architecture

The following components/functions can be recognized in the propulsion system architecture:

- 25 kV tranformator [1]
- 4QC inductor [2]
- Precharge circuit [3]
- 4 Quadrant Converter (4QC) [4]
- 100 Hz filter [5]
- DC link line current measurement [6]
- Line voltage measurement [7]
- Rheostatic chopper [8]
- Rheostatic chopper voltage measurement [9]
- Brake resistor [10]
- Inverter [11]
- Motor current measurement [12]
- Speed sensors [13]
- AC-traction motors [14]

In Figure 2.3 the existing under frame layout of the A-series EMU's is shown, where the in blue colored equipments are replaced, the yellow ones will stay, the red ones removed the rest may be retained, for the in this document proposed DC to AC modernization.

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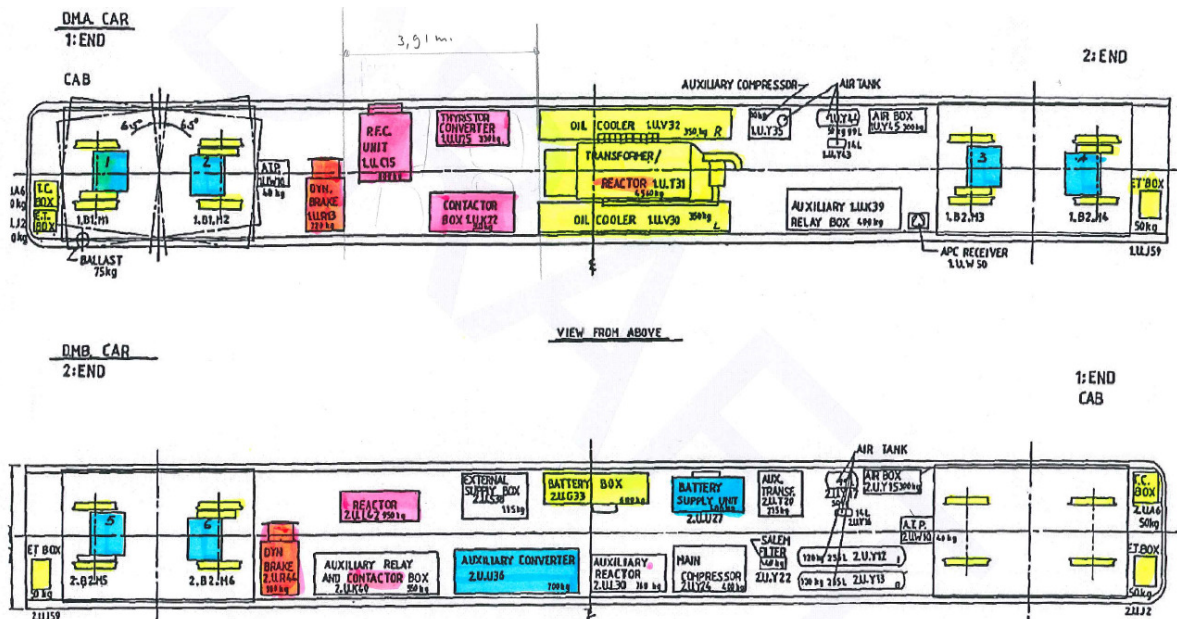


Figure 2.3 : Underframe layout

Each new AC driveline will consist of three main cubicles: 4QC cubicle; filter cubicle; and an inverter cubicle. Each EMU will be equipped with two drive lines.

The definitive placement of the cubicles will be based on further information of the existing space envelope of the current equipment and under floor, which are not yet available.

What is currently foreseen :

The 4QC's will be placed in the A-car close to the transformer. Both, the A-car and B-car , will be equipped with a filter cubicle and an inverter cubicle.

2.5 Equipment retention

In table 1, the equipment retention is shown for the proposed DC to AC modernization.

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Table 1 :Equipment retention

Equipment				
Existing	Retained	Removed	Optional renew	New
Pantograph	Pantograph			
Main Circuit Breaker	Main Circuit Breaker			
Main Transformer	Main Transformer			
Main Converter		Main Converter		
Main Reactor		Main Reactor		
Power Factor Correction Unit		Power Factor Correction Unit		Ajustable: $\cos \phi \approx 1$ due to controlled 4QC
Traction Motors (DC)				Traction Motors (AC)
Auxiliary Converter			Auxiliary Converter	
Battery Charger			Battery Charger	
Traction Computer System				TCU
Brake Resistor				Brake Resistor
Pneumatic brake	Pneumatic brake			
Braking and Wheel Slide Protection System		Braking and Wheel Slide Protection System		Braking and Wheel Slide Protection System
Signaling systems				Signaling systems to be determined

3. CONTROL STRATEGY

The power module provides a variable voltage and variable frequency (VVVF) supply for the 2 traction motors (see Figure 3.1). The inverter consists of 6 power switches (A1, A2, B1, B2, C1 and C2) using Insulated Gate Bipolar Transistors (IGBTs).

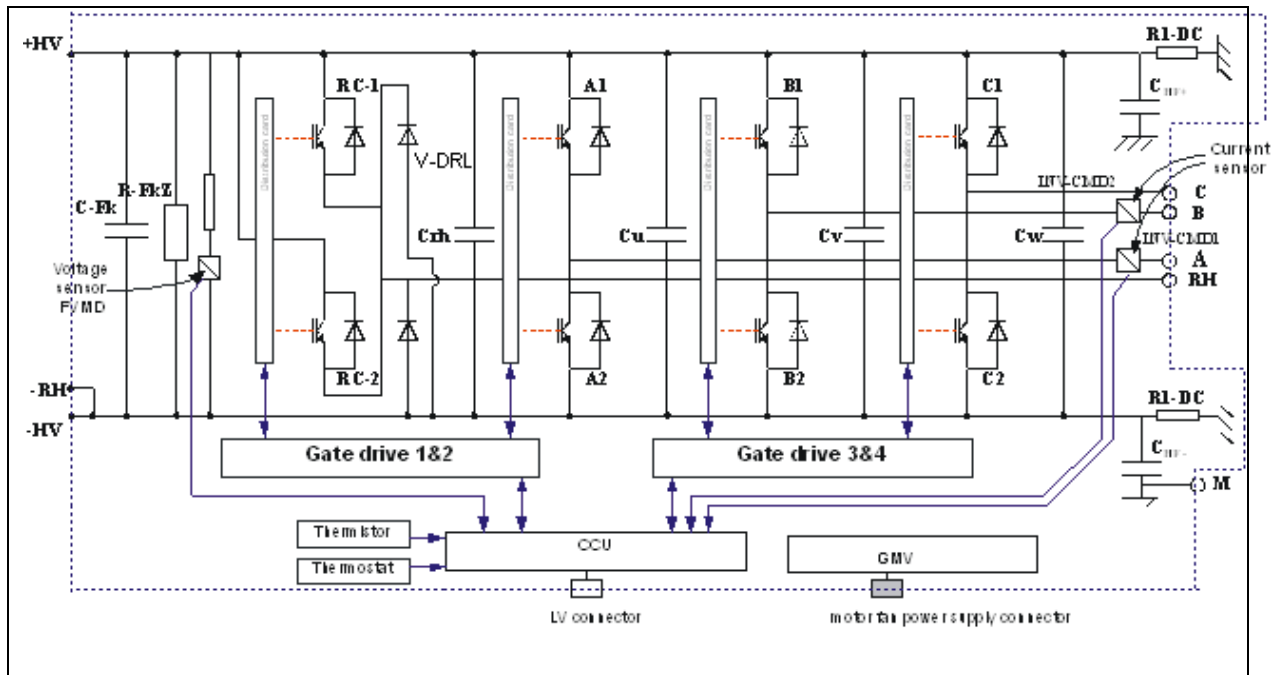


Figure 3.1: Power module

The output of the inverter is monitored by two current monitoring devices (INV-CMD1 and 2). In addition the DC link voltage is measured (FVMD) and all CMDs and VMDs are of the active type and provide galvanic isolation of the control electronics from the power circuit.

By switching the IGBTs, +HV or 0V is applied to the terminals of the star-connected motors, in order to obtain an alternate waveform. (see Figure 3.2) A delay is always maintained between the switching of two IGBTs belonging to the same phase, in order to avoid short-circuiting the input filter capacitor. When the IGBT is switched off, the internal free-wheel diode allows maintaining current flow.

Pulse Width Modulation (PWM) is used to control the inverter. PWM allows to vary the amplitude and the frequency of the fundamental voltage applied to the motors.

ALSTOM uses a vector control strategy, with special patented features, designed to reduce response times, to optimize the precision of the torque regulation and to improve low speed operation.

Vector control gives a very quick flux and torque response (<1 second for an unfluxed motor) with optimum control of the current in the motor. By adjusting the inverter output voltage according to the electromotive force of the motor, vector control enables effort to be re-established following a short shut-down of the inverter, without having to wait for the flux in the motor turning back to zero.

Torque control with an established flux is carried out by a regulator with a wide pass band, independently of the speed of rotation of the motor. The torque regulator includes a current regulation loop, reducing the

possibilities of over-currents that can occur with conventional control techniques when there are fast variations of the supply voltage.

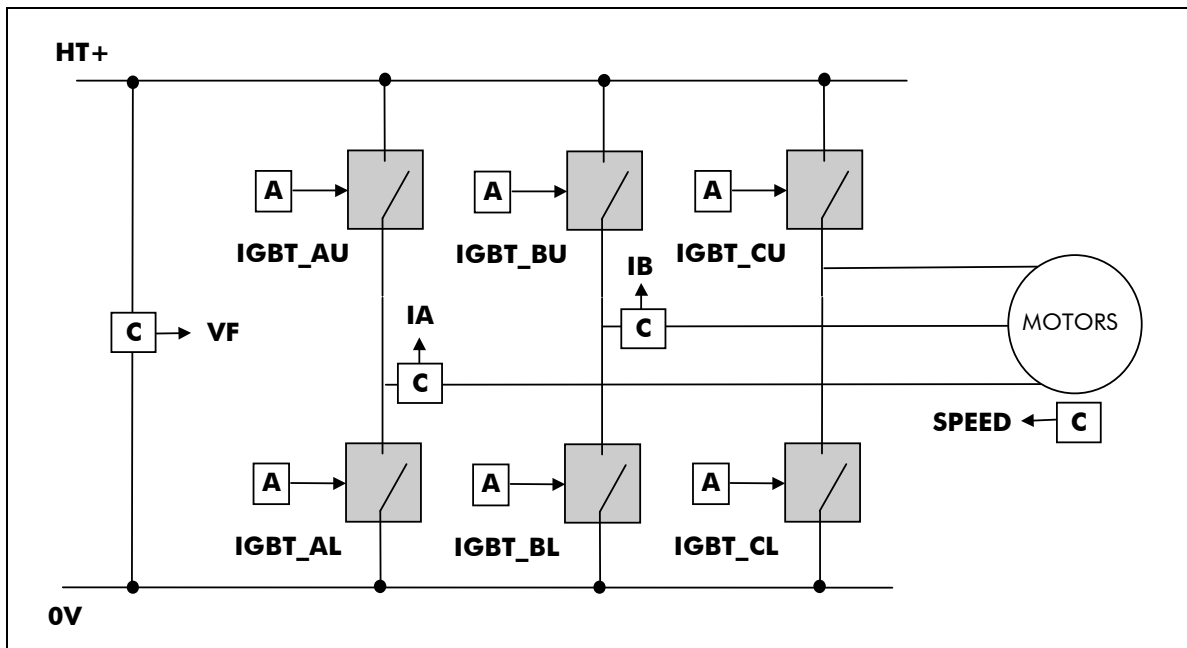


Figure 3.2: Motor supply

3.1 Measurement Methods

The ALSTOM vector control is based on measurements that are external to the motor. It does not require measurements within the motor. These are:

- no motor stator or rotor temperature measurement¹;
- no flux measurement inside the motor.

The current measurements used for control and monitoring are performed at the inverter output.

Strategy for motors connected in parallel is based on:

- a common current measurement on the inverter output, instead of individual motor measurements;
- speed measurement for each motor;
- total effort regulation which is independent of the wheel diameter variation, within specified tolerances;
- motor design operation parameters.

¹ There may be a temperature sensor (PT100) for the stator temperature but it is not needed for the control.

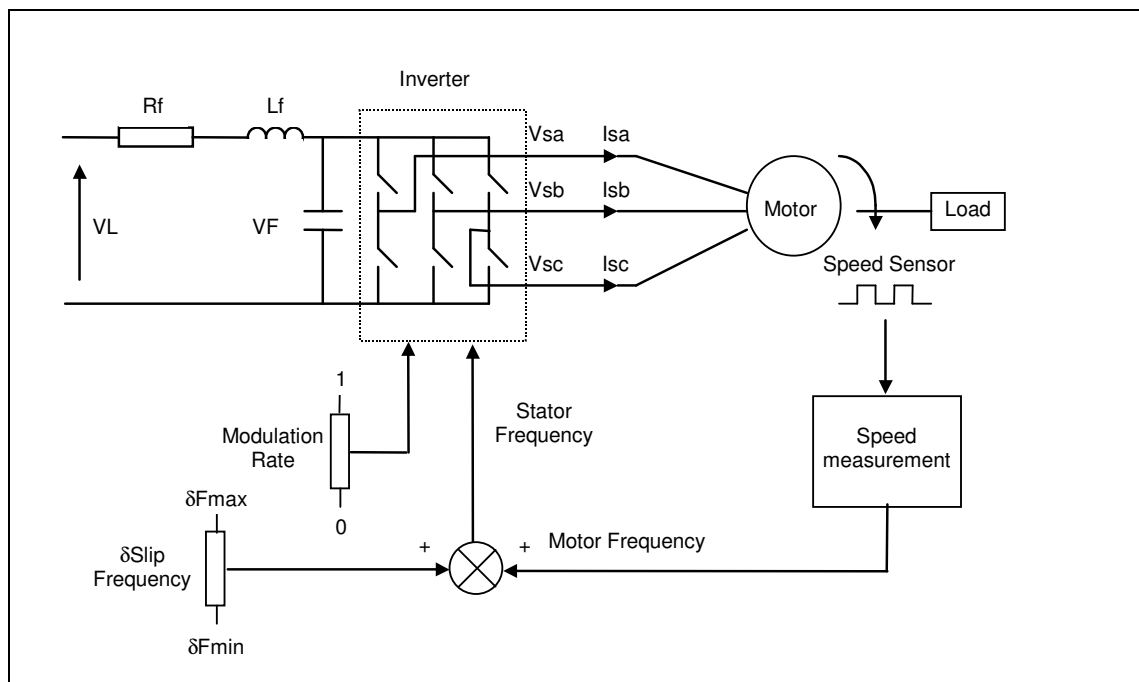


Figure 3.3: Vector control diagram

The traction effort demand is processed by the supervisor. A correction is made according to the vehicle weight in order to control the acceleration. The variations of the traction effort demand are limited by the supervisor in order to limit the jerk; this feature ensures a smooth operation of the vehicle.

3.2 Slip/slide Protection

The supervisor includes a slip/slide detection function. This is achieved by measuring wheel acceleration and/or the difference between each wheel speed and a reference speed for the vehicle.

In the event of wheel slip, the traction effort is reduced. Then, the effort is ramped back in two stages. The first stage is at a fast rate to approximately 70% of the traction effort demand (known as the knee-point) that was present at the start of the slip condition. The second stage is at a much lower rate back to the initial demand. If a second wheel slip occurs during the re-application of effort, the effort is reduced again but, on the next re-application of effort, the point at which the ramp rate changes (i.e. the knee-point) is much lower. In this way the system modulates the effort demand to make the best use of the available adhesion.

The above process is also used if wheel slide conditions appears during braking.

The proposed system has been used by ALSTOM for many years over a wide range of applications including Trams, Metros and Locomotives.

The principle is presented in Figure 3.4.

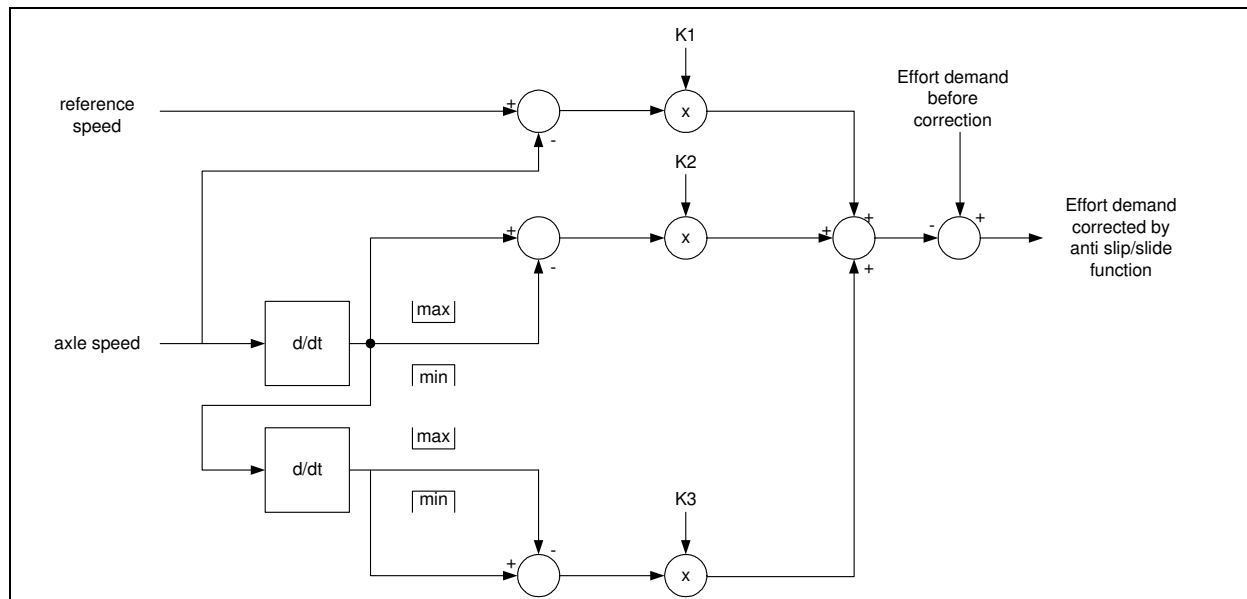


Figure 3.4: Slip/slide protection

3.3 Wheel slide

When a wheel slide is detected, the electric brake will be reduced by the TCU on all axles of the motor car regardless of the brake effort demand from the BCU. The electric brake effort demand will be reduced by the TCU until the wheel slide has corrected, and the electric brake effort will be restored in two stages. See Figure 3.5 hereunder.

During the time from the wheel slide being detected and the corrective action completed the TCU will set the LO_WSP output high. This will inform the BCU that a wheel slide correction is taking place and that the friction brake effort should not be increased. Note that if a second wheel slide occurs before the first wheel slide recovery has completed, this output will remain high until this slide has been corrected and the recovery completed.

At the same time the TCU will freeze the electric brake effort achieved value (AO_BEA) sent to the BCU, whilst wheel slide correction is taking place. The effort achieved value will be that present at the time the slide was first detected. Once the wheel slide recovery action is complete the electric brake effort achieved signal will revert to the actual achieved value.

Once the wheel slide recovery is complete LO_WSP will be set low. If brake is no longer demanded during the recovery period, then LO_WSP would be set low.

Under very low adhesion conditions it is possible that there may always be an axle sliding, although it may not always be the same axle. This would result in a permanent wheel slide recovery action by the TCU. Thus the BCU must monitor the wheel slide signal from the TCU. If the BCU detects that LO_WSP is continuously high for longer than TIM_MAX_WSP, then the BCU must inhibit electric brake by setting LI_DISED high.

The BCU must be responsible for determining the correct action in the event of an extended wheel slide indication from the TCU.

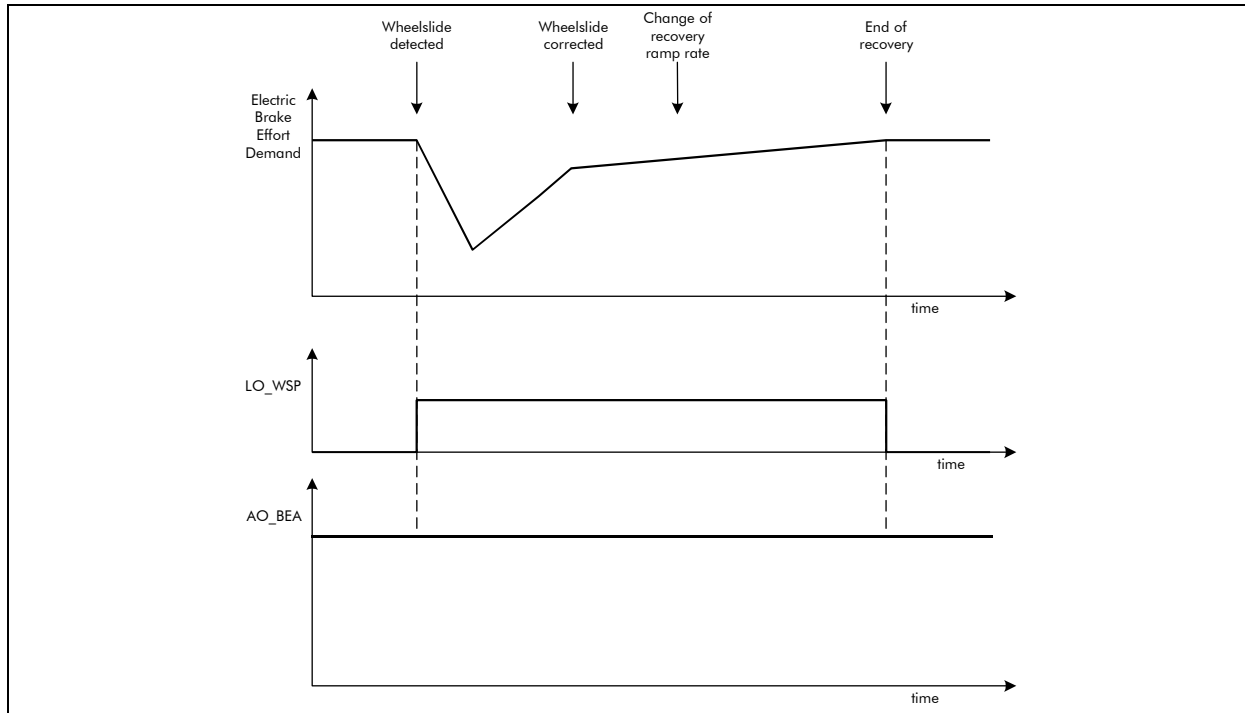


Figure 3.5: Wheel slide

3.4 Braking

3.4.1 Electrical braking

The electrical braking is regenerative, and it is balanced by pneumatic braking. It is provided a short term resistor with following functions:

- overvoltage protection, in order to protect the filter capacitor and the inverter devices from line voltage transient;
- to ensure the deceleration performances during the blending period between regenerative and pneumatic braking.
- to dissipate a part of energy to achieve the electric brake performance.

This crowbar chopper uses IGBT identical to the ones of the inverter. A diode (V-DRL) is connected in parallel with the IGBT of braking resistor (R-BZ) to provide a free-wheel path for any inductive current in the braking resistor.

The CCU regulates the DC link voltage by varying the on-time of the braking chopper. The reference for the DC link voltage regulation is defined by the supervisor:

- in function of the operating mode (traction, braking, coasting);

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- in order to prevent positive line current during the braking (to avoid dissipating energy from the line into the braking resistor);
- in order to not exceed the maximal line current;
- in order to reduce progressively the regenerative braking when the line voltage gets higher.

3.4.2 Brake scheme description

As an example the interface between the TCU and BCU is presented in Figure 3.6.

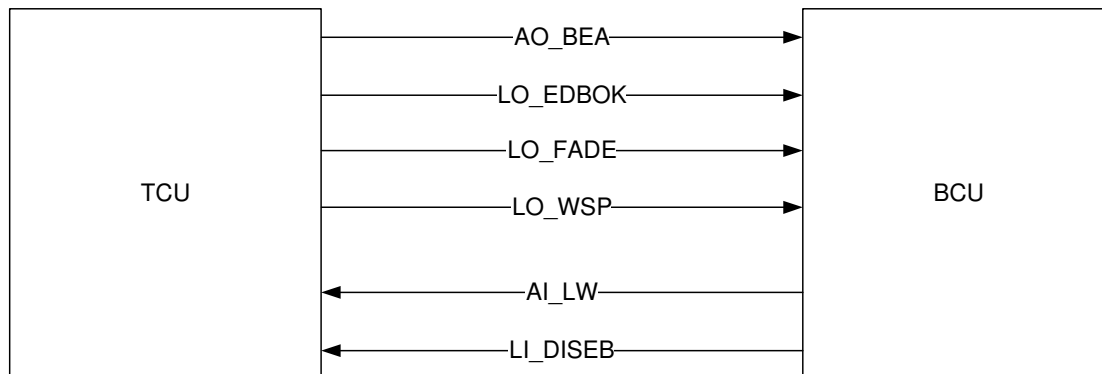


Figure 3.6: Interfaces between TCU and BCU (example)

Table 2: Signals from TCU to BCU

Signal	Description
AO_BEA	Brake effort achieved
LO_EDBOK	Indicator of electrical brake availability
LO_FADE	Indicator of FADE sequence
LO_WSP	Indicator of wheel slide detected by TCU

Table 3: Signals from BCU to TCU

Signal	Description
AI_LW	Load weight signal
LI_DISEB	Electrical brake disabling signal

3.4.3 Brake blending

Following a brake demand, an effort level signal is sent out from the controller to the BCU. The BCU will send a Brake Command to the TCU. The ED brake will then operate up to the Brake Demand. The TCU will indicate the level of ED brake effort achieved to the BCU (AO_BEA).

Any additional brake effort required to meet the brake effort demanded shall be calculated by the BCU and supplied by the pneumatic brakes.

3.4.4 Load compensation

The electrical brake effort will be increased by the TCU to account for the extra load. If the load signal fails at the transmitter, both the TCU and BCU will assume maximum service speed load.

3.4.5 Emergency braking

During Emergency braking, only pneumatic brakes will be used and therefore the TCU has no effect on braking. Wheel slide during Emergency braking will be controlled solely by the BCU, using the information from the Pneumatic System speed probes.

The electrical brake shall be inhibited by hardware and software during Emergency braking.

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CONTROL SHEET

Version	Issue date	Amendments	Author
A	6 th March 2013	First Version	Jonathan GREENING Martin LUMLEY

	Name	Position	Date	Signature
Written by:	Jonathan GREENING	Solutions Engineer	05-03-2013	
	Martin LUMLEY	Performance Engineer	05-03-2013	
Approved by:	Sean RING	Engineering Manager	05-03-2013	

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1 INTRODUCTION

Using latest Insulated Gate Bipolar Transistor (IGBT) technology, Alstom have developed a fully controlled rectifier bridge that allows dc motor traction equipment supplied from a 25kVac supply to be modified to allow for efficient regeneration during braking and give an overall better power factor. This is proposed as a possible lower priced alternative for Perth Series A trains. The major benefits of this solution are:

- Offers regenerative capability up to 30% with reduction in energy costs
- Operates with much improved power factor > 0.9 over much of its operation
- Minimises costs by retaining the existing transformer, bogies and dc motors.
- Designed for ease of installation with direct bolt-off, bolt-on replacement of traction converter.
- Maximisation of use of existing equipment, but commissioning the modification creates an ideal opportunity to review obsolescence and unreliability issues and address those at the same time. The new converter itself uses modern IGBTs that will have 'Form and Function' replacements for years to come.
- Minimal change on the maintenance cycle if reliability issues are addressed at the time of modification.
- A new control system provides for all the traction related functions including fault reporting and the option of remote communication for reviewing train status at the depot office.

2 HOW IT WORKS

The historical phase angle controlled bridge fires the rectifying thyristors progressively into the applied ac half cycle waveform (see fig 1). During low times of conduction, the applied voltage and current are significantly out of phase giving rise to very poor power factor. Even when the bridge is full on, the power factor is typically no better than 0.8 unless some additional correction is applied.

If the thyristors are replaced by IGBTs, the current can be turned on and off symmetrically with respect to the voltage waveform and give much improved power factor. Also if the free-wheel diodes are replaced with more IGBTs, the bridge may be used in reverse to regenerate power back into the supply during braking (see fig 2).

When the current is switched in this way, a means of managing the energy stored in the leakage inductance of the transformer secondary is needed. The secondary is fitted with an energy recovery circuit that captures the energy and either feeds it into the motor or back into the supply.

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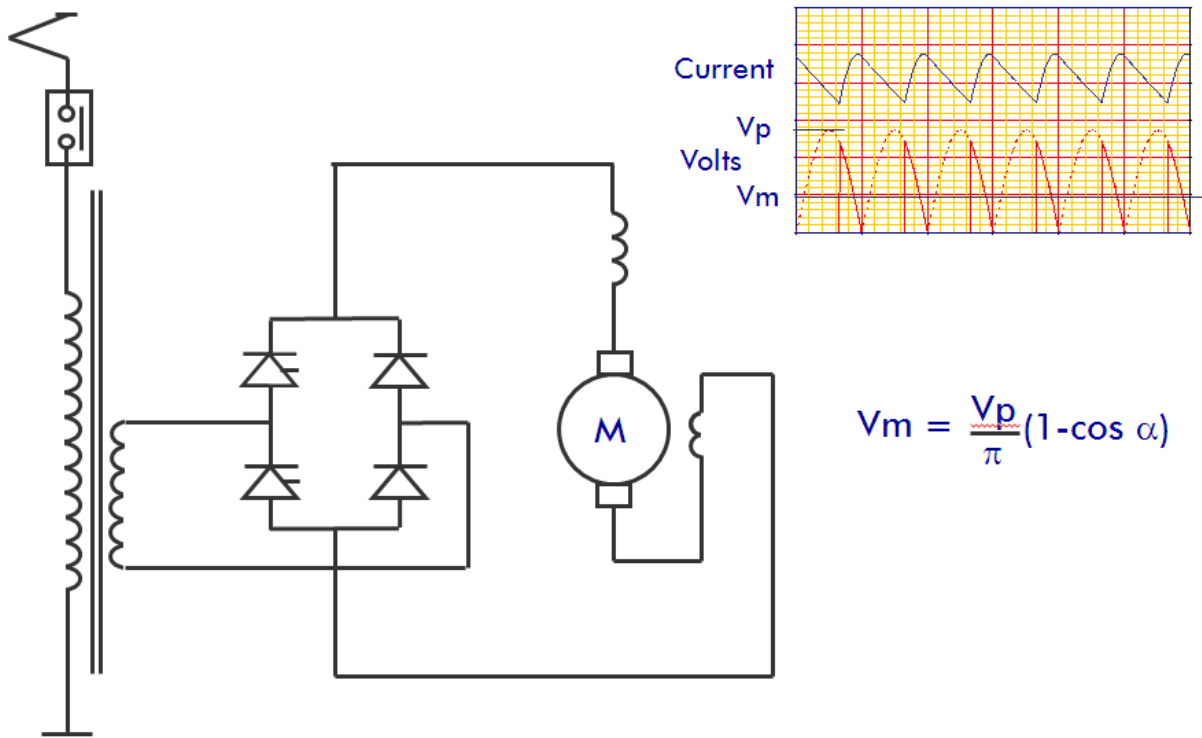


Fig 1 – Traditional Phase Controlled Bridge Rectifier

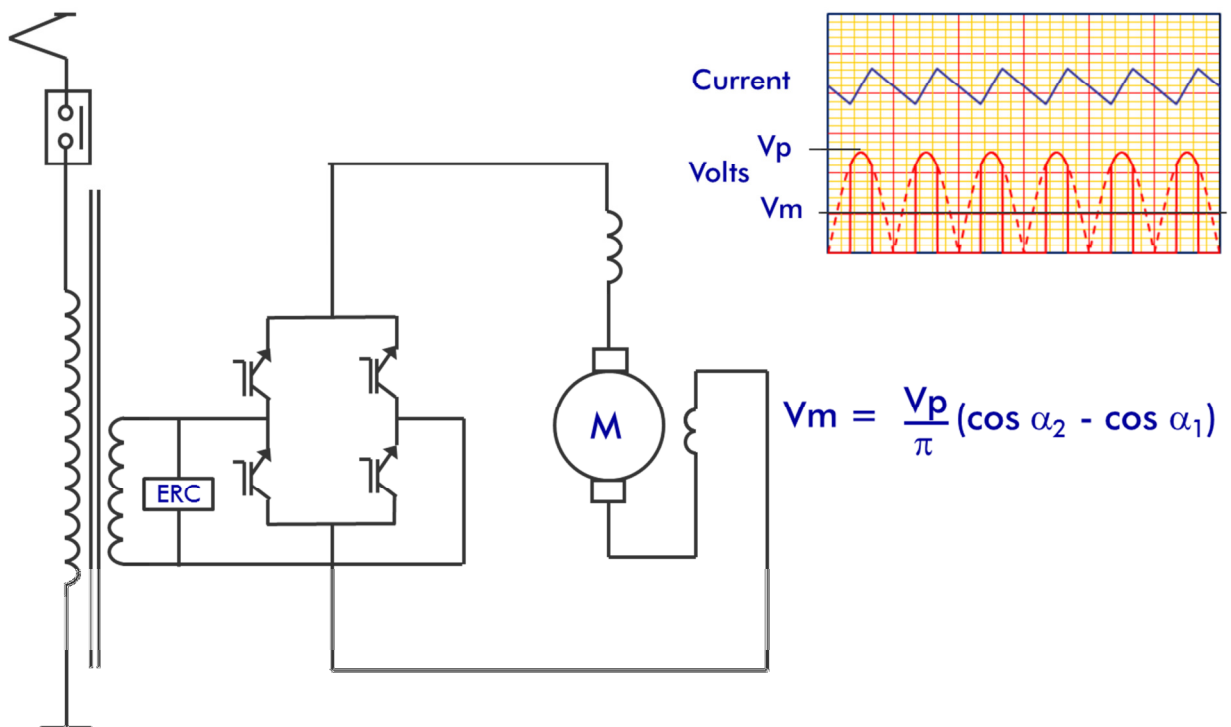


Fig 2 – Phase Angle Controller with IGBTs

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3 PROPOSED PERTH A SERIES POWER SCHEME

Refer to fig 3. The two existing series converter bridges will be replaced by two series IGBT bridges to give improved power factor and regenerative capability. In order to facilitate the required motor voltage reversal on the transition of motoring to braking, extra field thyristors are added to avoid having to use mechanical forward and reverse switching. Existing switches will be retained for isolation purposes. New transducers will be added for motor armature and field current and secondary voltage measurement. The rheostatic brake resistor on the DMA will be modified to allow it to be used as the short term soft crowbar. Its revised duty will allow the removal of the fan and the rheostatic resistor on the DMB may be removed altogether. Since the new scheme does not require separate power factor correction, the PFC unit is no longer required. In all others respects, the power scheme will remain the same and existing components will be re-used unless there is a known maintenance and reliability issue, in which case Alstom will research proposals for corrective alternatives.

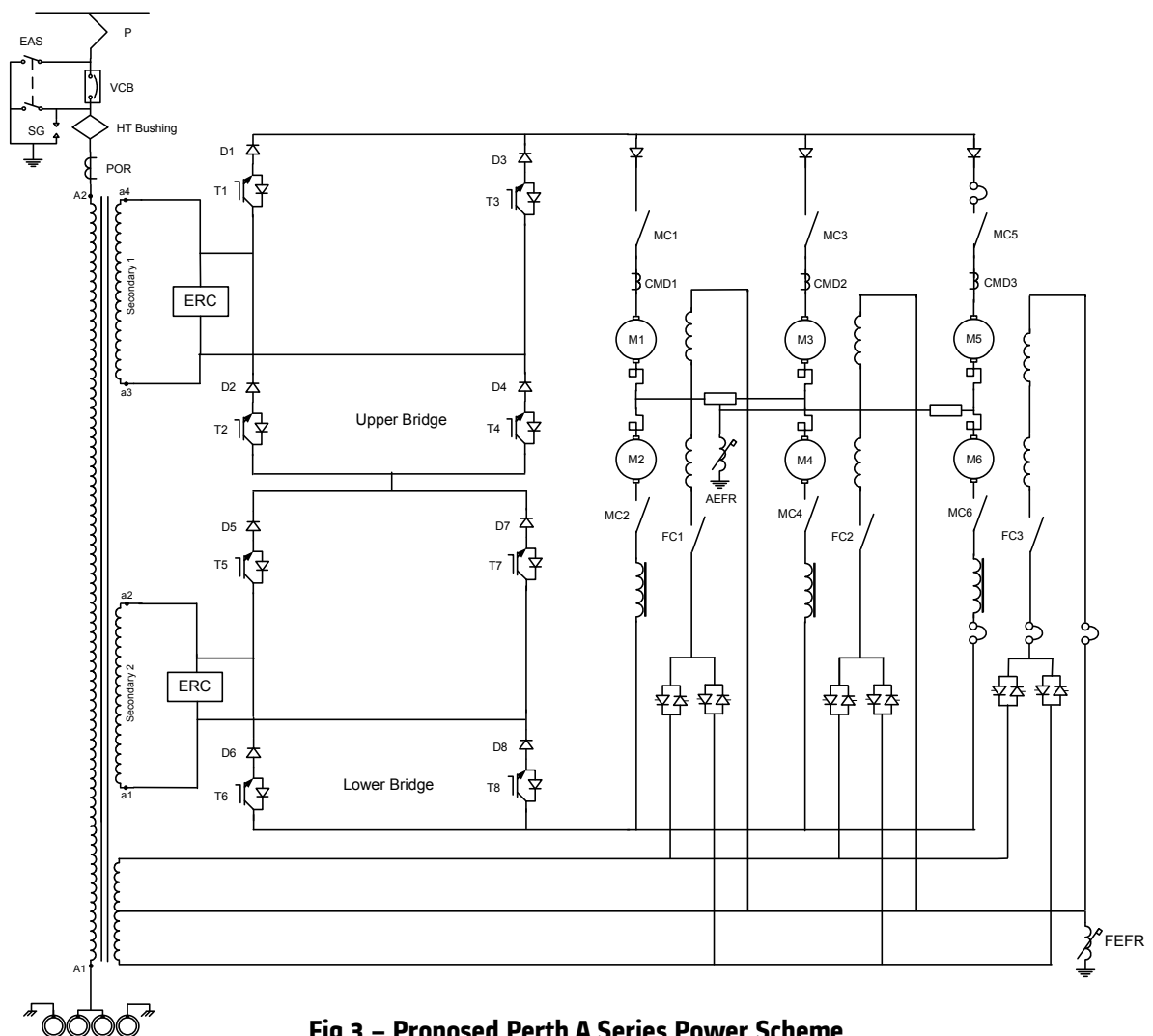


Fig 3 – Proposed Perth A Series Power Scheme

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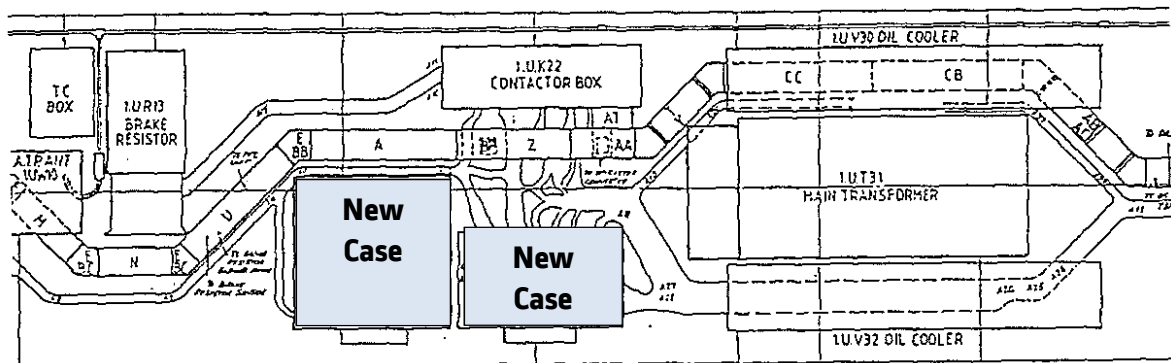
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In order to provide sufficient natural cooling, one new IGBT converter bridge will be fitted in place of the existing traction converter and the other in the place of the PFC unit; see fig 4. Alstom will endeavour to re-use the existing cases, but this will be subject to detailed analysis and for the time being a new single case to replace the converter and PFC unit has been planned.

**Fig 4 – Replacement Cases****5 ELECTRONIC CONTROL**

A new traction electronic control will replace the existing electronic cards and perform all the traction related functions. The electronics will have full fault handling and recording capability and remote communications can easily be added as an option if required. A brake effort achieved will be available to feed to whatever existing external system manages the air brake blending.

The new converter will have more control signals than at present, so it will be necessary to add some wiring up to the control electronics. It is expected that a single, easy-to-fit conduit, will be used for this purpose.

6 PERFORMANCE CALCULATIONS**6.1 Results**

The graphs in the end section plot train speed, speed limit, traction power (solid blue lines), regenerative braking power (dashed red lines) and time against distance.

Curve no. 2013017 shows Perth to Armadale.

Curve no. 2013018 shows Perth to Thornlie.

Curve no. 2013019 shows Perth to Midland.

Curve no. 2013020 shows Perth to Fremantle .

Curve no. 2013021 shows Whitfords to Cockburn.

Regenerative braking recovers, on average, 30% of motoring energy.

The expected average power factor is over 0.9 for both motoring and braking.

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6.2 Basic Assumptions

Existing limits on traction motor current and voltage are respected

Armature current - 525A maximum (motoring) 0 to 28 km/h

Armature current - 580A maximum (braking) 90 to 108 km/h

Field current - 170A maximum 0 to 80 km/h then reducing as square of speed

Armature voltage - 720V maximum (motoring) = 1440V rectifier output

Armature voltage - 750V maximum (braking) = 1500V rectifier input

The same values of tractive effort and motor current against speed are used as the existing equipment. This ensures identical traction and braking performance and ensures that the duty on the traction motors is unchanged.

Curve no. 2013010 shows the motoring characteristic.

Curve no. 2013011 shows the regenerative braking characteristic.

Calculations assume 21kV AC at the pantograph when motoring and 22kV when braking.

2-car unit mass: 90 tonnes tare + 26 tonnes passenger load + 4.9 tonnes rotational inertia.

Average wheel diameter (half worn) 800 mm.

Train resistance formula:

$TR = 1.782 + 0.01624 \times V + 0.0004725 \times V \times V$ kilonewtons (V is train speed in km/h)

Starting effort 99kN for 0.82 m/s² initial acceleration

Maximum electric brake effort 116kN with 1.12m/s² average deceleration

All-out running with 30s dwell time at each stop and 116 tonnes laden weight throughout.

6.3 Route Data

We have no gradient or speed limit information for the Clarkson and Mandurah lines, so have assumed level track throughout and have set speed limits arbitrarily to achieve running times consistent with the timetable.

We have archival information (from 1987) for the other routes and have simply adjusted station names and locations in accordance with section 4.2 of the PTA document.

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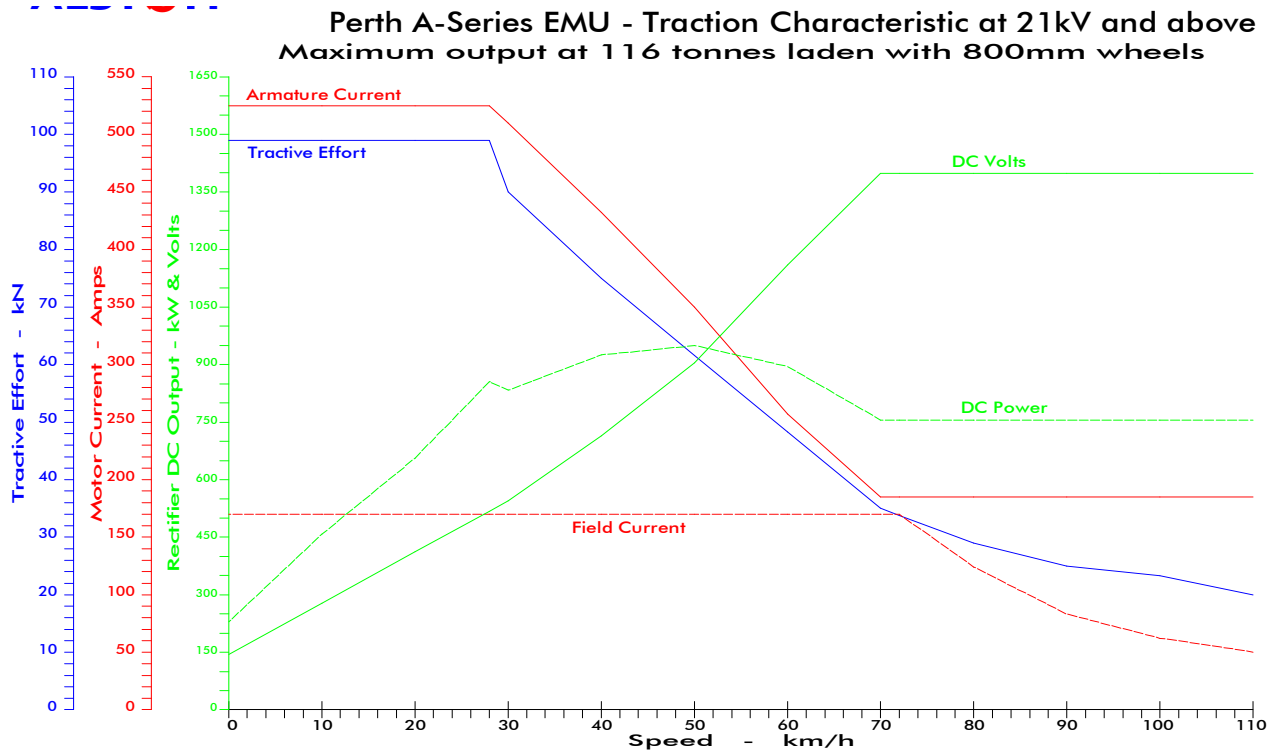
Curve no. 2013012 shows the route profile of the Armadale line.

Curve no. 2013013 shows the route profile of the Thornlie line.

Curve no. 2013014 shows the route profile of the Midland line.

Curve no. 2013015 shows the route profile of the Fremantle line.

Curve no. 2013016 shows the assumed route profile from Whitfords to Cockburn.



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Curve no. 2013010

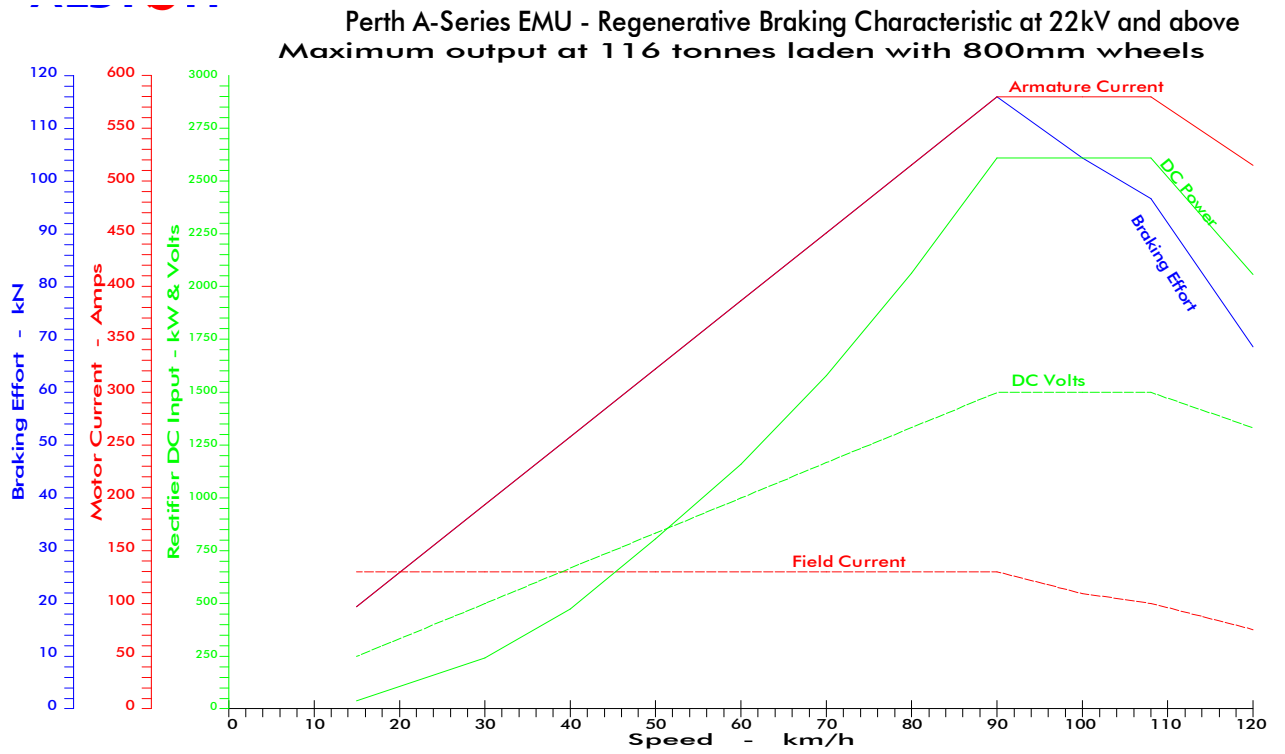
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Curve no. 2013011

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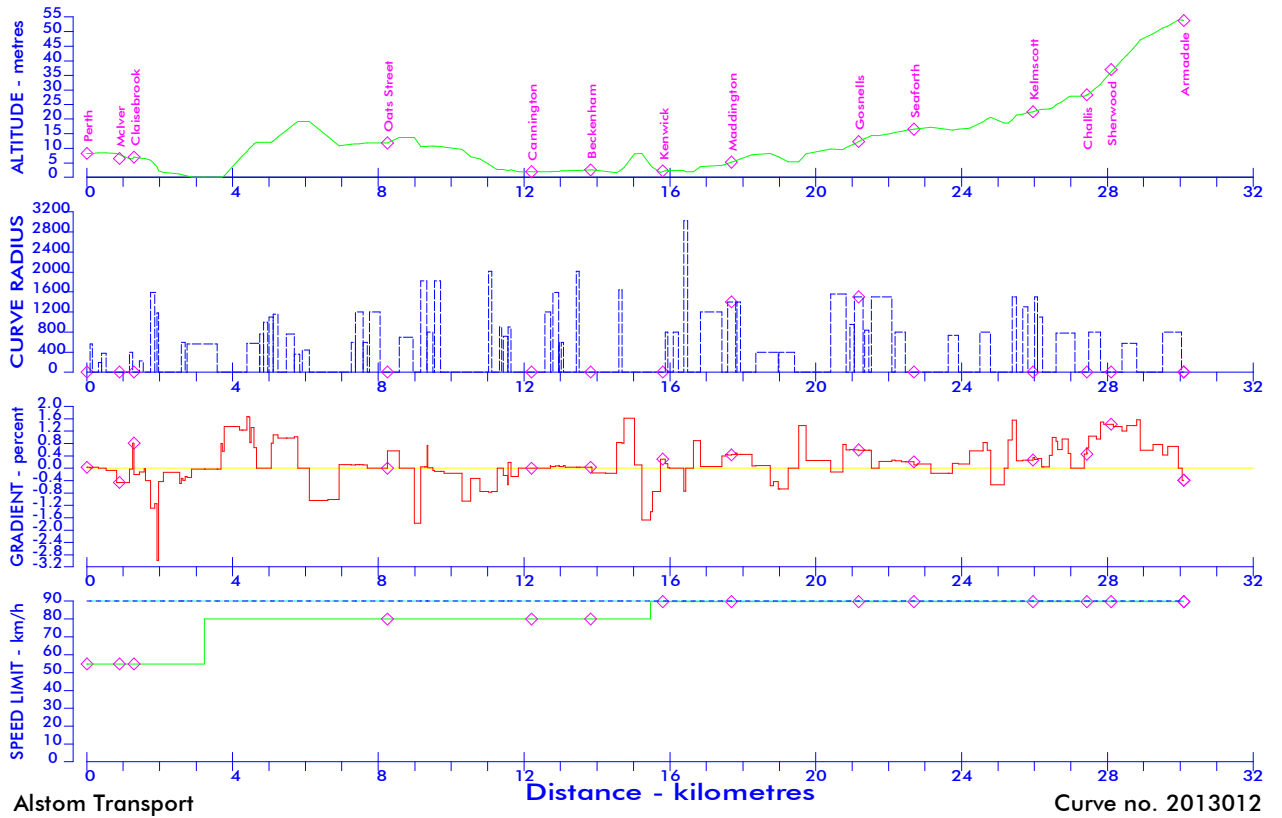
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Perth A-Series EMU - Route Profile - Armadale line



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Curve no. 2013012

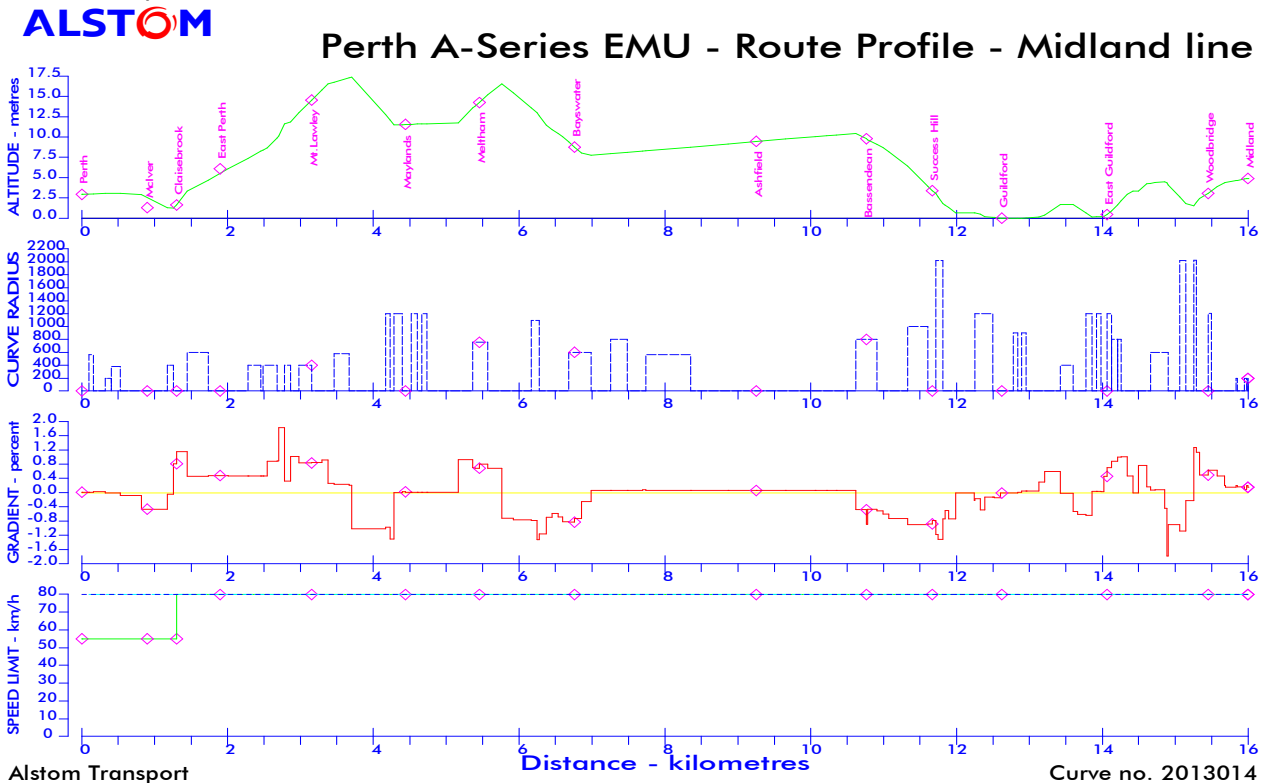
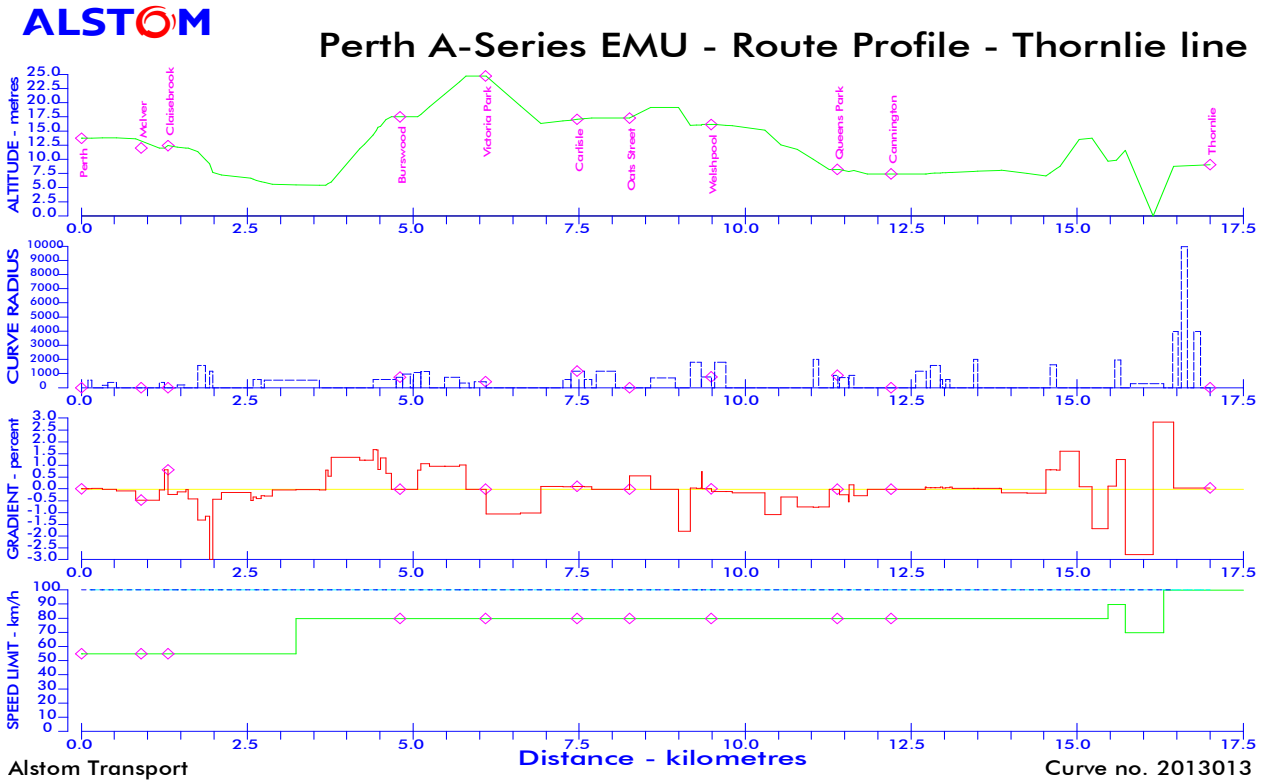
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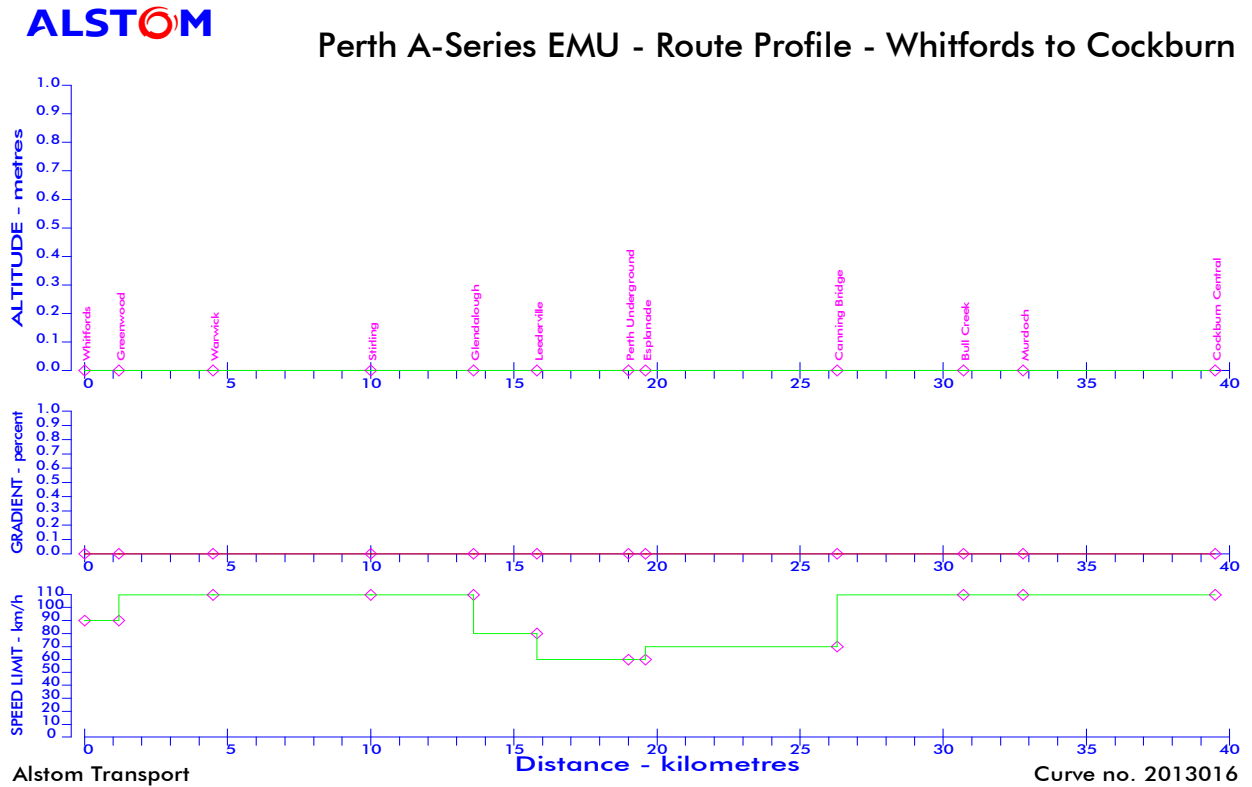
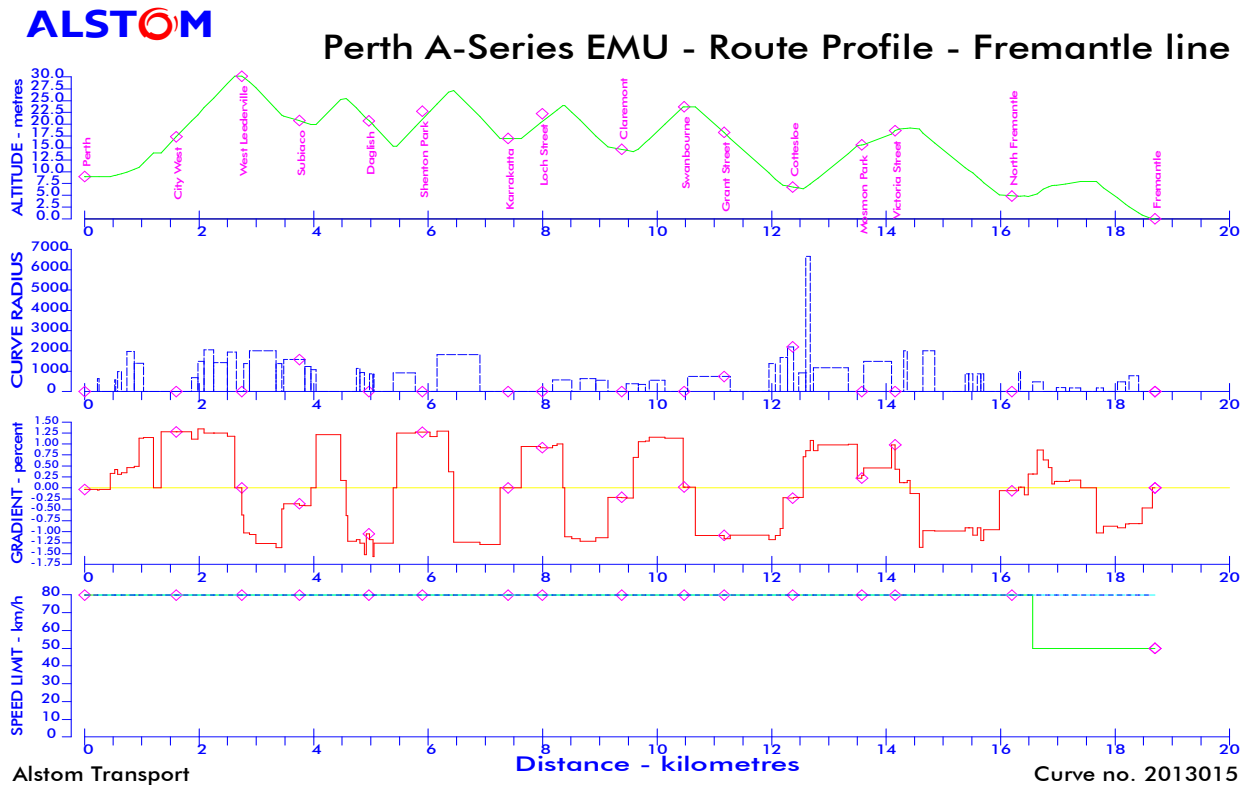
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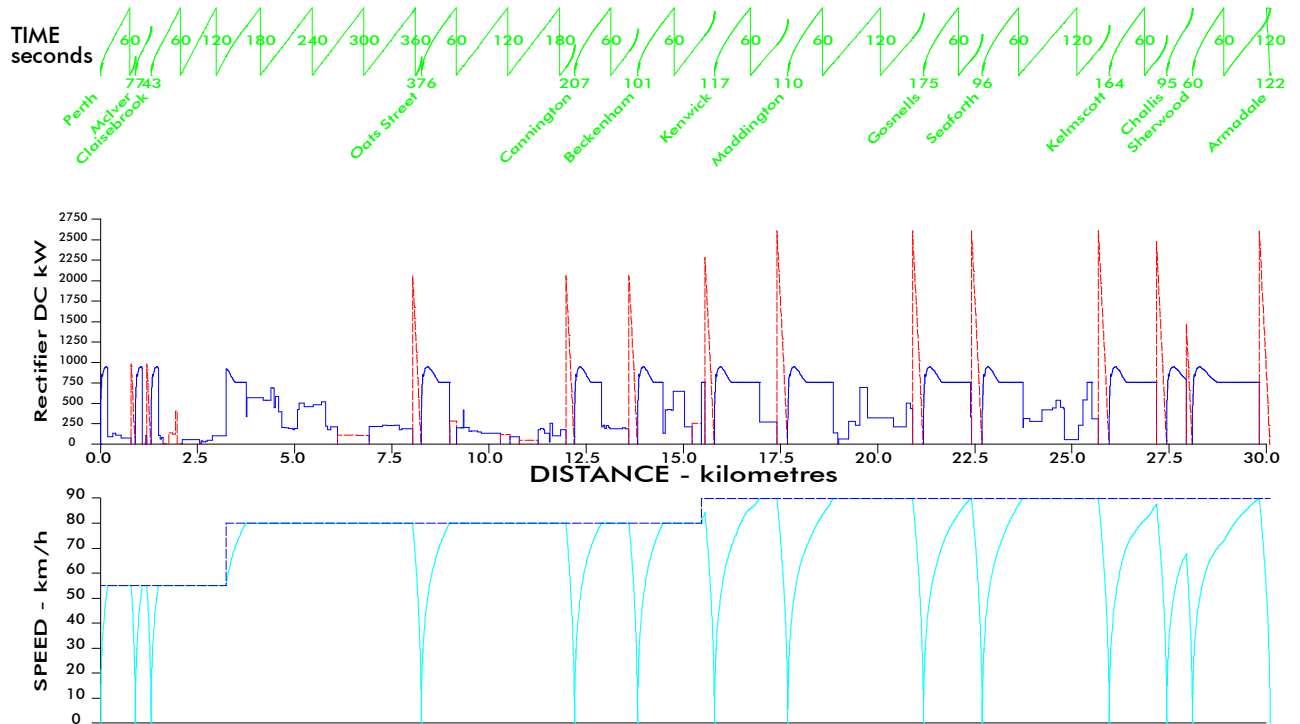
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Perth A-Series EMU - all-out run on Armadale line



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Curve no. 2013017

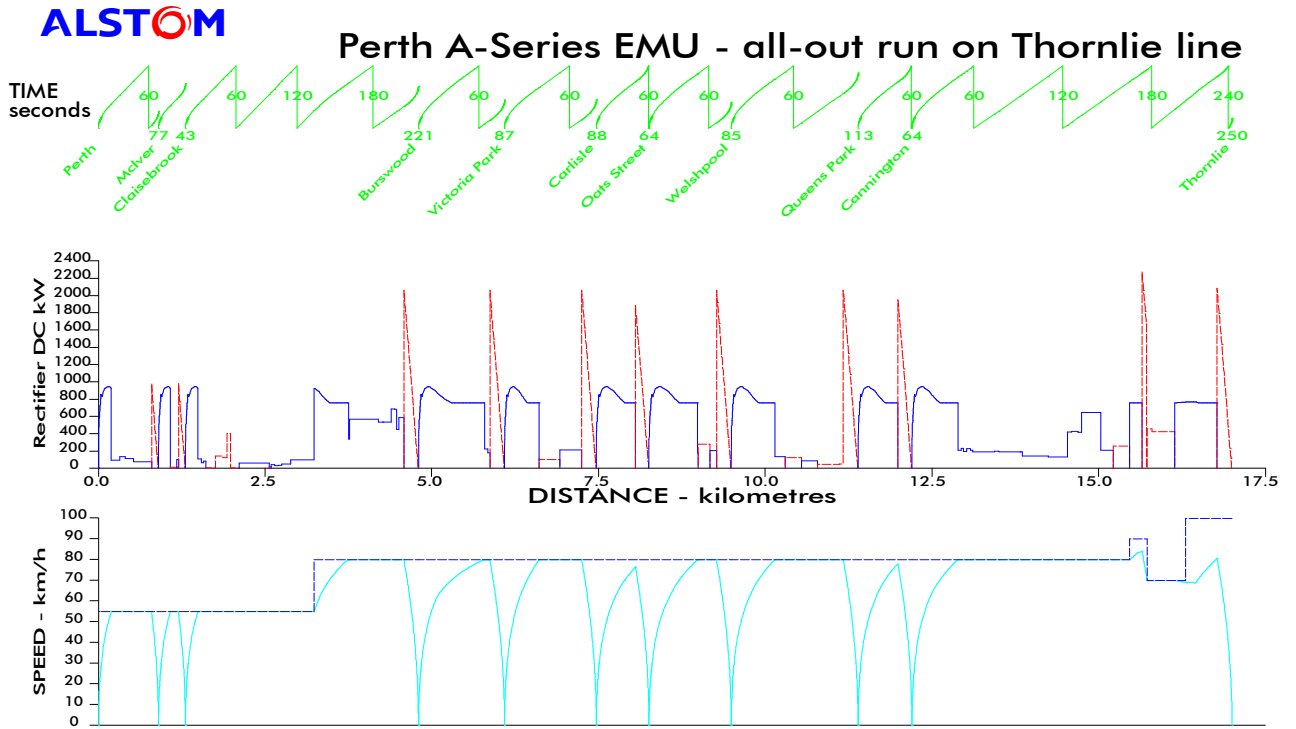
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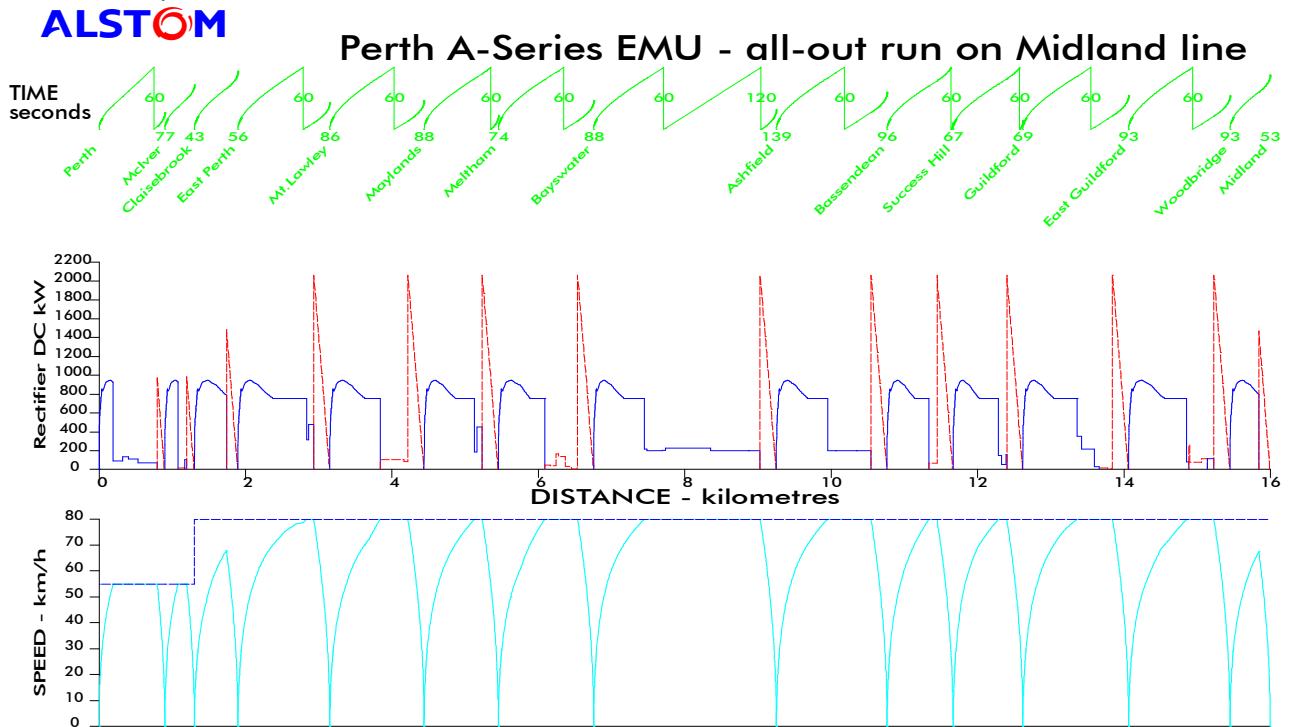
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Curve no. 2013018



Alstom Transport

Curve no. 2013019

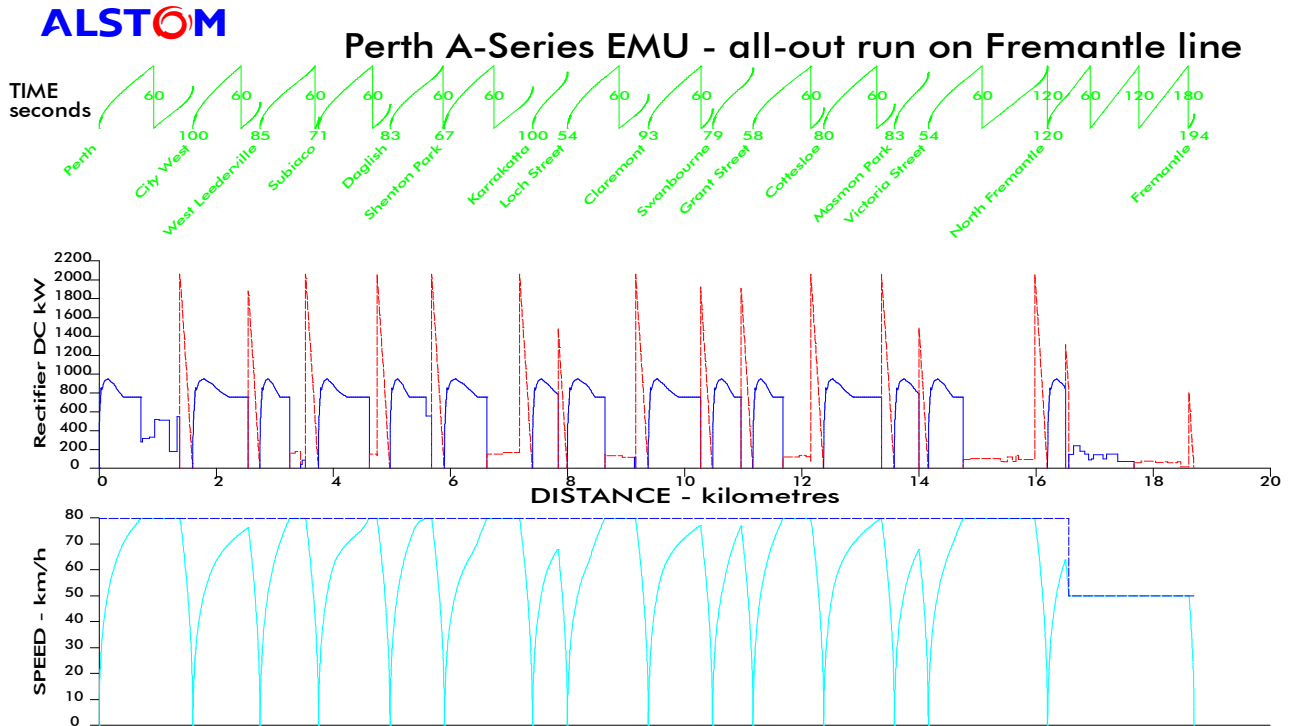
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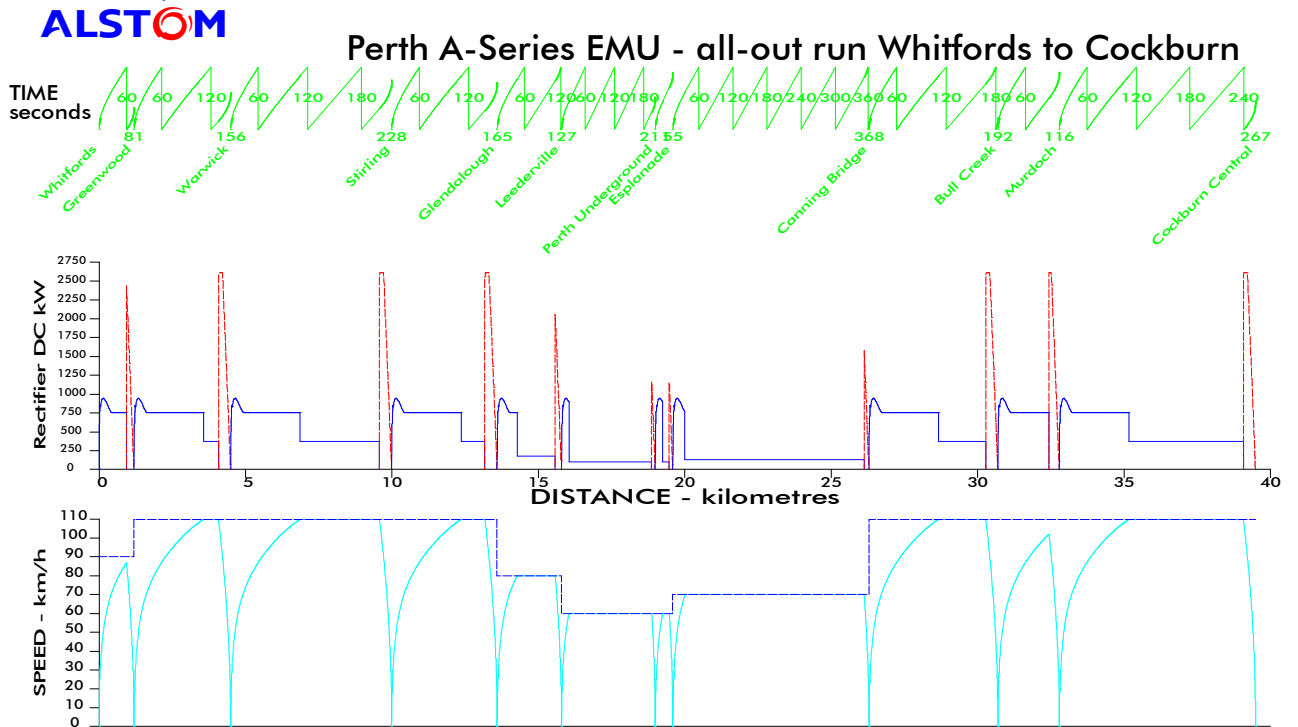
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Curve no. 2013020



Alstom Transport

Curve no. 2013021

Faivelely PTA "A" Series Upgrade Proposal

System	Proposed Upgrade	Approx. Le Install time	Cost (Budg	Responsible	Comments
Brake	Replace existiting WSP system	10 months	\$1,300k	Neil W & Munaf M	See Munaf's Comments 1.2 and 1.2.1
	Replace existiting WSP and Brake control system on current brake rack.	12 months	\$5,100k	Neil W & Munaf M	See Munaf's Comments
	Replace air dryer	5 months	\$400k	Neil W & Munaf M	Replace Obsolete Air Dryer with newer modern Graham White Air Dryer
	Replace main air compressor with Oil free compressor	9 months	\$2,400k	Neil W & Munaf M	Replace Compressor with modern Oil Free Compressor
	Replace calipers	9 months	\$2,700k	Neil W & Munaf M	Replace old Calipers with new slightly improved design to reduce impact of wear and tear
	Replace whole brake rack. (this may be an option as PTA may extend the life by 20 Years)	N/A	N/A	Neil W & Munaf M	Not Recommended. Cost will outweigh benefits. Suggest that oter improvements listed could be just as effective
	Basic upgrade of existing Brake Rack (Major Overhaul)	6 months	\$2,600k	Neil W & Munaf M	Includes basic 4 year overhaul, and mandatory replacement of parts such as Transducers, and Power Supplies
Doors	Replace existing pneumatic equipment with electric cylinder and electronic DCU	9 months	\$4.5K per c	Shawn M	Our estimate only to be confirmed when final installation and design confirmed. Non recurring costs (Engineering) not included. Normally for this type of project around \$300?
HVAC	Upgrade HVAC controller to give better control (software)	5 months	\$2K per un	Shawn M	Includes wiring modifications and new controller
	Upgrade HVAC to give energy savings "Green HVAC"	2 days		Shawn M	Quite complex and a lot of extra time needed.
	Replace existing HVAC with new	12 months	\$30K per u	Shawn M	NRC (Engineering) to be confirmed.
Electronics	Passenger safety upgrade to include CCTV, PA/Intercom system, if possible include passenger counting.			Shannon W & Neil W	
	Wireless offload of captured CCTV footage			Shannon W & Neil W	
	Provide main Power Converter (Input voltage 25kV Output 415v 3 phase 100kW to be confirmed)			Shannon W & Neil W	



IRAIL

A U S T R A L I A

8th March 2013

AECOM
Level 5, 3 Forrest Place,
Perth, WA 6000

ATT Michelle Tan

QUOTE #08042013AECOM

Dear Michelle

DRIVERS CABIN AIRCONDITIONING

Further to our email correspondence, we have pleasure in submitting budget prices for the supply of drivers cab air-conditioning in 2015.

NEW EQUIPMENT PRICING ONLY

Model	Quantity	Budget Price
RAC 60	200	AUD \$15,000 +10% GST

Features

- High Ambient operation. 48 DegC
- High Cooling capacity 5.3 KW nominal. 5.9 KW max.
- High heating capacity 5 KW.
- High Airflow 850m3/h
- Fresh air 60m3/h
- Refrigerant R407C

Availability

Approximately 16 weeks from confirmation of Purchase order

4-6 Burns Road, Altona VIC 3018, Australia / PO Box 22, Altona North VIC 3025, Australia D +61 3 868-7111 F +61 3 8689-7112 / AU00306





Validity

This quotation remains valid for 60 days from today's date.

Payment terms-

30 Days

Important-

1. All prices are quoted in \$AUD
2. All prices are exclusive of GST
3. Price excludes installation of unit

Concerning Metro trains, Victoria, we have supplied some 950 passenger units, which have been in service for over 10 years. During this time we have maintained the equipment as per specification, which has resulted in ultra high reliability. Some units are now close to 12 years of age, which we are about to embark on an overhaul program design and constructed in conjunction with Metro. Happy to discuss this in detail as and when necessary.

I hope this submission meets your approval and we look forward to further discussion and meeting in the near future.

Best Regards,

A handwritten signature in blue ink that reads 'M. Phillips'.

Yours sincerely

Michael Phillips

Business Development Manager

Email- Michael@thermo-king.com.au

Mobile 0400 643 534

ATTACHED FILE. RAC 40/60-RAC-60-AUS Spec.

RAC 40 / 60 - RAC-60-AUS



Dimensions & Weight

Length	[mm]	1188	[inch]	46.8
Width	[mm]	831	[inch]	32.7
Height	[mm]	416	[inch]	16.4
Weight	[kg]	115	[lb]	254

Design Parameters

Cooling Capacity @ TK Std Conditions	[kW]	5.4	[Btu/h]	18442
Cooling Capacity @ Design Conditions	[kW]	5.9	[Btu/h]	20150
TK Std Conditions	[°C]	35 / 26.7 / 15.6 *	[°F]	95 / 80 / 60 *
Design Conditions	[°C]	46 / 46.1 / 15.6 *	[°F]	114.8 / 115 / 60 *
Total Airflow	[m ³ /h]	850	[cfm]	500
Fresh Airflow [m ³ /h]	[m ³ /h]	60	[cfm]	35
Refrigerant		R407C		
Heating Capacity	[kW]	5kW 3x400V AC		

* ambient dry bulb temperature / evaporator inlet dry bulb temperature / evaporator inlet dew point temperature

Electrical Data

Power Supply	3x400V AC
Frequency	50Hz
Control Voltage	24V DC
Train Communication System	ClimaAIRE

Material

Frame	Aluminium
Covers	Aluminium

High Ambient Performance

Max Temp - Full Cooling	[°C]	48	[°F]	118
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Further configurations and technical information upon request



UGL
ABN: 58 000 003 136
15 Wood Street
Bassendean WA 6054
Australia
Phone: +61 8 9442 5800
Fax: +61 8 9442 5801

www.uglimited.com

Ref: Am: EV: Rbs: BN13038/101540

12 April 2013

Ms.M.Tan
Graduate Rail Engineer
AECOM
Level 5, 3 Forrest Place, Perth
GPO Box B59
PERTH WA 6849

Email to: Michelle.Tan@aecom.com

Dear Michelle,

BUDGET SCHEDULE OF RATES FOR EMU A RAILCAR REFURBISH.

Further to your recent email UGL Bassendean offers the following for your information and consideration for budgetary purposes.

HOURLY RATES FOR LABOUR.

The rates offered assume that all work will be carried out at our Bassendean Site.

CLASSIFICATION	HOURLY RATES EXCLUDING GST.
Engineer Support	\$150.00*
Supervising Personnel	\$128.00
Locomotive Technicians, Trades and Semi-Skilled Staff	\$122.00

* Please note UGL Rail can offer engineering support from Newcastle NSW.

We offer our current all-inclusive charge out rate that is all inclusive Monday to Friday that includes penalty hours, not including public holidays.

UGL Standard Conditions of Sale for Goods & / or Services apply, a copy is enclosed.

We hope that this meets with your approval and should you require further information contact Enzo Viti on 08 6310 7852 or on 0417 047 966 or at enzo.viti@uglimited.com.

Yours sincerely
UGL

Enzo Viti
OPERATIONS MANAGER, BASSENDEAN

CONDITIONS OF SALE FOR GOODS AND/OR SERVICES

1. Application
 - 1.1 A tender by UGL RAIL SERVICES Pty Ltd (UGL) with these Conditions of Sale ("these Conditions") shall be subject to these Conditions. Any contract ("contract") between UGL and a party ("the Purchaser") upon these Conditions shall be governed by these Conditions and by any other terms and conditions agreed in writing between the Purchaser and UGL.
 - 1.2 UGL may vary or withdraw its tender at any time prior to acceptance. Subject thereto, unless otherwise stated by UGL the tender shall remain valid for 30 days from the date thereof.
 - 1.3 Any tender which quotes a budget, preliminary or estimate price is subject to variation in any respect and shall not be considered an offer capable of acceptance until confirmed in writing by UGL. Any preliminary specifications, illustrations, drawings, data, dimensions and weights submitted by UGL with a tender are illustrative and approximate only and do not form part of the contract unless expressly confirmed and incorporated herein.
 - 1.4 In these Conditions "tender" means a tender, submission, proposal, offer (including counter-offer) or quotation in connection with goods and services the subject of the contract.
 2. Specification
 - 2.1 Goods and/or services shall be supplied in accordance with these Conditions and the specification set out in the contract, and the Purchaser is responsible for satisfying itself as to the suitability of such goods and/or services for the Purchaser's application. In these Conditions "goods" means the goods under the contract and "services" means the services under the contract (as the case may be).
 - 2.2 UGL shall not be bound by any representation concerning the scope of supply, performance or characteristics of goods or services unless expressly incorporated in the contract.
 3. UGL's General Obligations
 - 3.1 UGL shall supply the goods and/or services in accordance with the requirements of the contract and will use all reasonable endeavours to deliver the Goods and/or Services on or before the agreed date for delivery ("Delivery Date") which may be extended from time to time as provided for in the contract. UGL will ensure that the goods conform to the specification set out in the contract, as well as any applicable standards and codes. UGL will perform the services with reasonable care and skill.
 4. Purchaser's General Obligations
 - 4.1 The Purchaser shall pay UGL the price for the goods and/or services, as the same may be adjusted from time to time as provided for in the contract (the "contract price"), in accordance with the contract.
 - 4.2 The Purchaser shall, in a timely manner and so as to avoid any delay to UGL, provide all information, approvals, permits, authorisations, licences, customs clearances, instructions, materials, civil works, reports, drawings, geotechnical and survey information, access and other things which may be required in relation to the performance of UGL's obligations and which is not expressly stated to be UGL's responsibility. The Purchaser shall provide to UGL any approval or comment with respect to drawings submitted by UGL to the Purchaser within seven (7) days from the date of the submission by UGL of such drawings unless some other time is provided for in the contract.
 - 4.3 UGL considers the information, documents and other particulars made available to UGL by the Purchaser are not sufficient to enable UGL to provide the services in accordance with the contract and the provision of which is not reasonably to be considered within the responsibility of UGL under the contract. UGL may advise the Purchaser who shall then provide such further assistance, information or other particulars as necessary in the circumstances or as requested by UGL as the case may be.
 5. Price
 - 5.1 Except as otherwise provided elsewhere in the contract:
 - (a) invoices for goods and services shall be submitted by UGL on a monthly basis;
 - (b) invoices shall be due and payable within thirty (30) days of the date of invoice;
 - (c) the prices quoted include the cost of delivery as at the date of UGL's tender;
 - (d) any increase in the cost to UGL for the provision of the goods or services as a result of a variation in exchange rates or change in law between the date of UGL's tender and the date of delivery shall be borne by the Purchaser and the contract price shall be adjusted accordingly. In these Conditions "change in law" means when any legislation, regulation, by-law, ordinance, standard, award or order comes into effect or is changed, including but not limited to any new tax, duty or other impost or change in the rate of any tax, duty or other impost.
 - 5.2 The Purchaser shall pay interest to UGL on any moneys outstanding on and from the date thirty one (31) days after the date of receipt of the relevant invoice by the Purchaser (the "interest date"), such interest to be calculated from the interest date until such outstanding moneys are paid. The interest rate shall be the maximum per annum commercial overdraft rate determined by the Commonwealth Bank of Australia on the interest date plus 3%, accruing daily.
 - 5.3 The parties hereby expressly agree that any payment obligations pursuant to the contract which are presently denominated in a national currency of a member state of the European Community or in "ECU" shall be automatically converted to an equivalent obligation in the proposed single European currency unit (the "euro") on the date on which the euro becomes the sole legal currency of such member state. The rate of conversion shall be the irrevocably fixed conversion rate to be adopted by the Council of the European Communities. The contract shall not be amended or terminated as a result of the conversion referred to in the foregoing sentence, and shall remain in full force and effect.
- ### Goods and Services Tax
- 6.1 The price and all other amounts referred to in the Contract are exclusive of GST.
 - 6.2 If GST is payable in respect of any supply made under or in connection with the contract, the recipient of the supply must reimburse the supplier for the amount of that GST. PROVIDED THAT the supplier must first issue a tax invoice for the supply to the recipient of the supply.
 - 6.3 If the amount payable for any supply made under or in connection with the contract is calculated by reference to any cost or expense incurred by the supplier, the amount payable is to be calculated using the GST-exclusive amount of that cost or expense.
 - 6.4 If there is an adjustment event in relation to a supply made under or in connection with the contract:
 - (a) the supplier must refund to the recipient of the supply the amount by which any GST reimbursed pursuant to clause 6.2 exceeds the adjusted GST; or
 - (b) the recipient of the supply must pay the supplier the amount by which the adjusted GST exceeds the GST reimbursed pursuant to clause 6.2.
- For the purpose of calculating the GST to be reimbursed to the supplier pursuant to clause 6.2, the amount payable for the supply or any part thereof which is expressed or calculated in a currency other than Australian dollars shall be converted into Australian dollars:
- (a) using the method required to be used by the *A New Tax System (Goods and Services Tax) Act 1999* (Cth) or any relevant regulation, ruling or determination under that Act; or
 - (b) if no method is specified by that Act or any such regulation, ruling or determination, using the relevant mid-market exchange rate quoted by Westpac Banking Corporation for the date on which the supplier issues an invoice or receives payment for the supply, whichever is earlier.
- In this clause 6, "GST" means goods and services tax levied pursuant to the *A New Tax System (Goods and Services Tax) Act 1999* (Cth) and the expressions "supply", "tax invoice", "input tax credit" and "adjustment event" have the same meanings as in that Act.
- ### Delivery, Transfer of Title and Risk
- For delivery within Australia:
- (a) except as otherwise provided elsewhere in the contract the Purchaser shall be responsible for off-loading the goods when delivered on board the transportation vehicle to the nominated address. All risks of loss or damage to the goods shall transfer to the Purchaser on such delivery;
 - (b) title (legal and beneficial ownership) in the goods shall not pass to the Purchaser until UGL has been paid the contract price for them in full.
- For exports to a country other than Australia:
- (a) except as otherwise specifically provided elsewhere in the contract UGL shall deliver the goods FOB at the port of dispatch, and the Purchaser shall obtain any necessary import clearances;
 - (b) title (legal and beneficial ownership) in the goods and (as provided in INCOTERMS 1990) all risks of loss or damage to them shall pass to the Purchaser upon loading on board the transportation vehicle at the port or depot or other point of export unless otherwise provided in the contract.
- Until the passing of title in the goods delivered to the Purchaser:
- (a) the Purchaser shall hold the goods as bailee to the same extent as if he were a bailee for reward and shall clearly identify the goods as belonging to UGL;
 - (b) the Purchaser may not modify, sell or otherwise remove, dispose or grant to a third party any interest in the goods and shall store and maintain the goods in good condition and allow UGL unrestricted access to them for the purposes of inspection, protection or removal, and for the purpose of such removal, the Purchaser hereby grants UGL an irrevocable licence to enter the premises where the goods are and sever them from any other property to which they may be attached.
- If the Purchaser does not take delivery of goods at the nominated address or otherwise at the time for delivery as provided in the contract UGL shall be entitled on behalf of the Purchaser to put the goods into storage at the Purchaser's expense. UGL shall be deemed to have delivered such goods to the Purchaser on storage and shall be entitled to payment on presentation of the warehouse receipt in place of any bill of lading or similar document otherwise required under the contract. Risk shall pass to the Purchaser on storage, but title shall only pass in accordance with the provisions of this clause 7.
- For goods or services to be supplied outside of Australia the contract price does not include any duty, customs, fees or other impost on the goods or services or on the equipment, property or activities of UGL, its subcontractors or any of their respective employees in relation to the contract levied outside Australia or any tax on or withholding from any payment to UGL or on the contract levied outside Australia and the same shall be for the account of the Purchaser.
- (a) Subject to clause 7.6 (b) where loss of or damage to the goods (excluding loss or damage caused by or in any way connected with off-loading of the goods) occurs during transport or delivery of the goods by or on behalf of UGL to the nominated address UGL shall at its option repair or replace the goods lost or damaged, but shall not otherwise be liable for or in respect of such loss or damage or any delay consequent thereon.
 - (b) Unless a claim for the loss or damage referred to in clause 7.6 (a) is made in writing and received by UGL within 7 days of delivery, or within the time necessary to comply with any sub-contractor's conditions of carriage, whichever is the lesser, UGL shall not be liable for or in respect of such loss or damage.
- ### Warranty
- UGL warrants that the goods supplied shall, under proper use, be free from defects in materials and workmanship and conform to the specification in the contract. In this clause 8 "proper use" means installation, commissioning, operation and maintenance in accordance with UGL's advice and good engineering practice, and "defect" means any defect (including any omission) in materials or workmanship and any non-conformity with the specification.
- UGL's obligation under this warranty shall be limited to making good by repair or replacement, at UGL's option, of any goods in which any defect appears and is notified by the Purchaser to UGL before the expiry of a period ending 12 months after first putting such goods into use or 18 months after dispatch from UGL's premises, whichever is earlier. In respect of goods which have been repaired or replaced hereunder, UGL's obligation shall in any event expire 24 months after first delivery of the original goods. Items which are replaced during the warranty period shall become the property of UGL.
- UGL's obligation under this warranty shall not extend to any failure caused by fair wear and tear, designs, specifications and items which are outside UGL's scope of supply, accidents, misuse, neglect, lack of proper use, or repairs or modifications to the goods which have been made without UGL's approval. UGL's obligation is subject to UGL being given prompt notice by the Purchaser of the appearance of the defect and a reasonable opportunity to investigate it.
- UGL's liability and the Purchaser's remedies in respect of defects in the goods and any loss or damage resulting therefrom are solely and exclusively as stated in this clause 8, and UGL shall have no liability for any defect, omission or damage unless notified by the Purchaser to UGL prior to expiry of the applicable warranty period described above.
- The undertakings and obligations of UGL under this clause 8 are in place of and exclude to the fullest extent permitted by law all other warranties and conditions, whether oral, written, statutory, express or implied. Subject to clause 14.3, implied warranties or conditions as to fitness for purpose and merchantability shall not apply.
- ### Completion
- UGL shall supply the goods and services hereunder within the time required by the contract. UGL shall be entitled to a reasonable extension of time for the performance of its obligations hereunder where any of the following causes delay to UGL:
- (a) variation in the scope of supply under clause 10;
 - (b) obstructions or conditions which could not have been reasonably foreseen by UGL;
 - (c) change in law;
 - (d) any act or omission of the Purchaser or any contractor, consultant, representative or agent thereof, including but not limited to failure to confirm a start date and failure to provide access;

- (e) Force Majeure under clause 15;
- (f) delays of municipal, government or statutory authorities.
- 9.2 The Purchaser shall pay UGL the reasonable costs incurred by UGL (including off site and on site overheads) as a result of obstruction and/or delay caused by the matters referred to in clause 9.1(a),(b),(c),(d) or (f).
- 9.3 In the event the Purchaser fails to make payment when due UGL may suspend performance of the contract until such time as payment is made and UGL shall be entitled to a corresponding extension of time for performance.
10. Variations
- 10.1 Unless otherwise agreed any variation to the goods or services to be supplied hereunder shall be valued in accordance with UGL's schedule of rates for variations (a copy of which may be inspected at the office of UGL and a copy of which shall be issued to the Purchaser on request) existing at the time the goods or services are the subject of the variation are supplied (or if none, variations shall be valued at a reasonable rate and any rates usually charged by UGL for similar work shall be deemed to be reasonable).
- 10.2 Where any of the matters referred to in clause 9.1(b), (c) or (d) reasonably require a change in the goods or services to be supplied or the conditions in which UGL is to perform its obligations hereunder, then UGL shall be entitled to vary the goods or services in such manner as UGL reasonably considers necessary and the value of such variation valued in accordance with clause 10.1 shall be added to or deducted from the contract price as the case may be.
11. Drawings and Documentation
- 11.1 All designs, drawings and other technical information relating to the goods or services, including any software provided by UGL under the contract ("technical information"), and the intellectual property rights therein shall be and remain the property of UGL. Any drawings and documentation for goods supplied hereunder shall be standard issue technical literature.
- 11.2 Any descriptive or shipping specifications, illustrations, drawings, data, dimensions and weights contained in UGL's catalogues, price lists or publicity material or submitted with UGL's tender are illustrative and approximate only and do not form part of the contract unless certified by UGL in writing, in which event they shall be subject to generally recognised tolerances.
- 11.3 Technical information shall be kept confidential by the Purchaser, its employees, agents or subcontractors, shall not be copied, modified or disclosed by any of them and shall not be used by them otherwise than for the purposes of the operation and maintenance of the goods. In the event that the Purchaser does not accept UGL's tender it shall return to UGL all technical information supplied by UGL together with any copies made.
- 11.4 UGL grants to the Purchaser the non-exclusive and non-transferable right to use the technical information, including software, provided by UGL for the life of the goods supplied under the contract for the purposes of their operation and maintenance in the place and manner anticipated at the time of UGL's tender and for no other purpose.
12. Intellectual Property Rights
- 12.1 UGL shall indemnify the Purchaser against all damages and costs awarded against the Purchaser for infringement of any intellectual property right granted or registered at the date of contract in the country of destination of the goods specified in the contract (or, if none be specified, in Australia) and resulting from the use or sale of the goods but this indemnity shall not apply to any infringement which is due to the association or combination of the goods with any other article, apparatus or device or to any goods or parts thereof made to designs supplied by the Purchaser.
- 12.2 This indemnity is conditional on the Purchaser giving UGL prompt written notice of any claim for infringement and permitting UGL (at UGL's expense) to conduct on the Purchaser's behalf and in the name of the Purchaser any litigation or negotiations in respect thereof. The foregoing states UGL's entire liability for intellectual property right infringement.
13. Tests on Completion
- 13.1 UGL shall at its own expense carry out any tests required by the contract together with any tests required by any government or regulatory authorities, or absent such requirements, UGL may carry out its standard tests on the goods. Any additional tests required by the Purchaser shall be at the Purchaser's expense.
- 13.2 UGL shall give not less than seven (7) days notice of its intention to carry out any test that the Purchaser is entitled to attend and, unless otherwise agreed, such test may then be conducted by UGL at the nominated time and the Purchaser will be deemed to have been present and to have accepted the reported test results. The Purchaser shall give UGL such access as UGL reasonably requires to carry out such tests.
- 13.3 Where the goods or part thereof fail to pass the tests on completion UGL will be given reasonable opportunity to carry out that work which it considers necessary to achieve the required performance, and to reperform the tests.
14. Limitation of Liability
- 14.1 Notwithstanding any other provision of the contract, the liability of UGL to the Purchaser, whether arising under or in connection with the contract or the performance or non-performance thereof or anything incidental thereto, and whether by way of indemnity, by statute (to the extent that it is possible to exclude such liability), in tort (for negligence or otherwise), or on any other basis in law or equity is hereby limited and excluded as follows:
- (a) anticipated saving, or for any delay (other than liquidated damages expressly provided for and limited in the contract), financing costs or increase in operating costs or any other financial or economic loss or for any special, indirect or consequential loss or damage;
- (b) the total aggregate liability of UGL to the Purchaser is limited to 5% of the contract price.
- 14.2 UGL will not be liable for any loss, damage or other liability (whether in contract, tort [including negligence] or otherwise) and whether directly or indirectly arising from the Goods and/or Services not being delivered by the Delivery Date for any reason. The Trade Practices Act, 1974, implies warranties, terms and conditions in consumer contracts which cannot be excluded or modified except as permitted under that Act. In the event UGL may be in breach of any such warranty, term or condition as is implied in this contract, the liability of UGL shall be limited:
- (a) in respect of goods, at UGL's option, to the repair or replacement of the goods or the cost of repairing or replacing the goods;
- (b) in respect of services, at UGL's option, to the reperformance of the services or the cost of reperforming the services.
- 14.4 For the purpose of this clause 14, UGL contracts also on behalf of and as agent for any and all subcontractors and suppliers of UGL in connection with the contract which are bodies corporate related to UGL (as defined in the Corporations Law). The cumulative liability of UGL and all such subcontractors and suppliers to the Purchaser shall not, in aggregate, exceed the liability of UGL to the Purchaser under this clause 14.
- 14.5 The Purchaser shall ensure that the liability of UGL to the end user(s) or owner(s) or beneficiary(ies) of the goods or services the subject of the contract is limited and excluded in accordance with this clause 14. The Purchaser indemnifies UGL against claims of any kind by such end user(s) or owner(s) or beneficiary(ies) to the extent that UGL would not be liable therefor to the Purchaser under the contract if the claim had been made by the Purchaser.

15. Force Majeure
- 15.1 If performed by a party of any obligation under the contract (other than an obligation of the Purchaser to make payment) is prevented, restricted or delayed by Force Majeure then that party shall be excused from and shall not be liable for failure in performance to the extent of that prevention, restriction or delay and the time for performance shall be extended accordingly, subject to the terms of clause 15.2.
- 15.2 If performance is delayed for more than four (4) months by Force Majeure and the parties have not agreed upon a revised basis for continuing the work at the end of the delay, then either party may after that period and while the cause of the non-performance still exists terminate the contract by not less than 30 days' notice in writing to the other party.
- 15.3 In these Conditions "Force Majeure" means act of God, act or omission of government, war, blockade, embargo, hostilities, fire, earthquake, flood, explosion, accident at sea, exceptionally inclement weather, except where restricted to employees of UGL, industrial condition, sabotage or commotion, or by any cause (whether similar or not to any of the above events) beyond the reasonable control of the party whose performance is affected.
16. Termination
- 16.1 Without limiting any other rights it may have, a party (the "notifying party") may give a written notice stating its intention to terminate the contract pursuant to this clause 16 to the other party (the "defaulting party") in the event that the defaulting party:
- abandons or repudiates the contract;
 - commits a continuing and substantial breach of the contract;
 - suspends performance of the contract for a significant time, or fails to pay monies due under the contract, without reasonable cause;
 - purports to assign the whole of the contract without the other party's consent; or
 - appears likely to become subject to an Insolvency Event described in clause 17.
- 16.2 Unless the defaulting party takes all practicable steps available to it to remedy or overcome the event complained of within twenty one (21) days after receipt of such notice, the notifying party may thereafter, by notice in writing, terminate the contract forthwith.
- 16.3 Termination of the contract pursuant to these provisions shall be without prejudice to the rights of either party accruing up to the date of termination.
- 16.4 If the contract is terminated for any reason whatsoever, then, without prejudice to the rights of either party accruing up to the date of termination, UGL will be entitled to payment for: goods delivered and services performed to the date of termination; the cost of goods and services reasonably ordered but not delivered (the property in which shall become the Purchaser's upon payment of all monies then payable to UGL) or of cancelling such orders where possible; costs reasonably incurred by UGL in expectation of completing the contract. Except where the Purchaser terminates due to a breach of contract or Insolvency Event on the part of UGL, the Purchaser shall in addition pay or return to UGL all retention money and security and pay UGL the cost of demobilising UGL's site establishment.
17. Bankruptcy
- 17.1 If either party becomes bankrupt or insolvent or makes any agreement with its creditors compounding debts or, if, being an incorporated entity, any proceedings are begun in respect of it applying for the appointment of a liquidator, administrator, receiver or similar official for it or all or any substantial part of its assets or seeking an order of relief against it as debtor or under any law relating to insolvency, readjustment of debt, reorganisation, administration or liquidation (each such event or process referred to in these Conditions as an "Insolvency Event"), the other party may at any time by written notice terminate the contract forthwith.
18. Entire Contract
- 18.1 Except as otherwise expressly provided in this contract, and subject to clause 14, UGL excludes all statements, representations, warranties, conditions, promises, undertakings, covenants and other provisions, express or implied (and whether implied by law including Act of Parliament or otherwise) relating to UGL's tender, the goods or the services or their delivery or supply, being provisions that might otherwise form part of the contract or be collateral to or form part of any agreement that is collateral to the contract.
19. Severance
- 19.1 If any provision or part of any provision of these Conditions is unenforceable, such unenforceability shall not affect any other part of such provision or any other provision of these Conditions.
20. Waiver
- 20.1 Any waiver by UGL of strict compliance with these Conditions shall not be deemed a waiver unless it is in writing and signed by an authorised officer of UGL.
21. Proper Law
- 21.1 The contract shall be governed by the law of the Australian State in which UGL submitted the tender and the parties agree to submit to the jurisdiction of the courts of that State and any courts having appellate jurisdiction from them.
22. Assignment and Transfer
- 22.1 Neither UGL nor the Purchaser shall assign or transfer the whole of the contract or any interest therein or in any monies payable hereunder without the written consent of the other party.
- 22.2 Nothing contained in this clause 22 shall prevent UGL from subcontracting any part of the work under the contract as UGL deems appropriate.
23. Interpretation
- 23.1 Clause headings shall not form part of, and shall not be used in the interpretation of, the Contract.
- 23.2 Words in the singular include the plural and words in the plural include the singular, according to the requirements of the context.
- 23.3 Words importing a gender include every gender.
- 23.4 Delivery acronyms such as FCA, FOB, CIF used in UGL's tender or contract shall be interpreted in accordance with INCOTERMS 1990 edition.



Perth 'A' Series Trains

Presentation for Aecom
February 2013



Vossloh Group

Focus on rail technology

The Vossloh Group operates in the world's rail technology markets. The Group has structured its activities into two divisions: Rail Infrastructure (~65% group turnover) and Transportation (~35%).

Vossloh AG

Rail Infrastructure

The Rail Infrastructure division provides products and services and has three business units:

Vossloh Fastening Systems

Vossloh Cogifer

Vossloh Rail Services (since 2010)

Transportation

The Transportation division provides locomotives, LRVs, components and maintenance services and has three business units:

Vossloh Locomotives

Vossloh Rail Vehicles

Vossloh Kiepe

Vossloh Kiepe

International Representation

Vossloh Kiepe GmbH Düsseldorf						
Electrical Systems Components Service						
Vossloh Kiepe Main Line Tech. GmbH Germany	Vossloh Kiepe GesmbH Austria	APS electronic AG Switzerland	Vossloh Kiepe S.r.l. Italy	Vossloh Kiepe UK Limited UK	Vossloh Kiepe Corp. Canada	Vossloh Kiepe Inc. USA
Electr. Systems Components for Main Line Vehicles	Heating Air Cond. Ventilation Systems System Mngt. Representation	Sales Service Components	Sales Service	Sales Service Engineering	Sales Service	Sales Service Production
International Representations						

Vossloh Kiepe UK Limited

Position in Market

- ▶ Vossloh Kiepe UK Limited (formerly Transys Projects Limited) specialises in turnkey project management of engineering solutions, installation of technology enhancements, equipment upgrade and replacement, modernisation and renovation of railway rolling stock
- ▶ Extensive engineering intellectual knowledge of both new and legacy rolling stock
- ▶ Activities include vehicle overhaul, modernisation and enhancement at the customers' depots or leased workshops, deploying a managed workforce
- ▶ Strong reputation for quality and professionalism
- ▶ Customer base includes train operating companies, rolling stock owners, London Underground, Transport for London and Network Rail
- ▶ Work with vehicle manufacturers and equipment suppliers to support integration and development of electrical and mechanical equipment for use on rail vehicles
- ▶ Brings new capabilities into the Vossloh group and new market offerings for the UK company

Vossloh Kiepe UK Limited

History and Capability

- ▶ Established 1989
- ▶ Based in Birmingham
- ▶ Acquired by Vossloh Kiepe GmbH on 1st June 2012
- ▶ Changed name to Vossloh Kiepe UK on 1st October 2012
- ▶ Permanent staff: 44
- ▶ Sub-contract to consumable purchasing capabilities
- ▶ Own stores and logistics facilities
- ▶ Ability to provide fully kitted materials for fleet installations
- ▶ RISAS accredited
- ▶ ISO9001
- ▶ Link-up approved



Vossloh Kiepe UK Limited

Engineering Skills



- ▶ Structural engineering and weight management
- ▶ Underframe equipment
- ▶ Couplers and drawgear
- ▶ Passenger and crew doors
- ▶ Interior and exterior upgrades
- ▶ Air conditioning
- ▶ Bogies and wheelsets
- ▶ Electric traction upgrades
- ▶ Diesel engines and transmissions
- ▶ Air systems including brakes
- ▶ Electrical supply systems
- ▶ Control, communications and radio systems
- ▶ Fire performance management

Vossloh Kiepe UK Limited

Turnkey Engineering and Installation



Passenger environment improvements

- ▶ Reliability improvements
- ▶ Train management system upgrades
- ▶ Traction upgrades
- ▶ CCTV, passenger information and WiFi
- ▶ Energy and fuel saving improvements
- ▶ Sanding systems
- ▶ Refurbishment and refresh
- ▶ Modifications

Vossloh Kiepe UK Limited

Perth 'A' Series Upgrade

- ▶ Bodyshell fatigue life
- ▶ Bogie fatigue life
- ▶ HVAC replacement
- ▶ Body modification: two door to three door
- ▶ Brake system
- ▶ Saloon door upgrade
- ▶ Passenger information system
- ▶ Communications system
- ▶ Traction Upgrade

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Bodyshell Fatigue Life

- ▶ Class 323 Bodyshell in Aluminium designed by our staff with support from outside agencies to our requirement specification
- ▶ Fatigue studies on the KCRC Mid Life refurbishment for provision of additional doorways
- ▶ VKB have managed full FEA (provided by subcontract supplier) on previous projects
- ▶ Proposed activities have included validation of structural changes related to both air conditioning and traction equipment
- ▶ In-house capabilities include non-FEA structural engineering calculations
- ▶ Noted that 'A' Series structure is stainless steel: likely to be spot-welded rather than stitch- or continuous-welded
- ▶ Creating a third door aperture in the bodyshell would affect the situation (see below): comparative calculations can be undertaken in-house so both scenarios can be understood

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Bogie Fatigue Life

- ▶ VKB has good understanding of bogie engineering based on significant experience of engineering and installation of bogie-structures and bogie mounted equipment:
 - ▶ Axle box mounted sander brackets have extreme load cases
 - ▶ The company designed and managed the manufacture of the Glasgow underground bogie
 - ▶ Original involvement in new rolling stock supply included the review of bogie FEA results
 - ▶ We have undertaken feasibility studies on the integration of AC traction motors into existing bogie frames

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HVAC Replacement

- ▶ Extensive experience in installation and replacement of cab cooling systems
- ▶ Installation of saloon air conditioning into previously unfitted rolling stock formed part of previous tenders
- ▶ May impact on body structure if new equipment is not a direct replacement
- ▶ Air Conditioning feasibility studies, including installation of HVAC roof modules
- ▶ Vossloh Kiepe HVAC equipment solutions on Class 380 EMU

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Body Modification: Two Door to Three Door

- ▶ Immediate thoughts on 'A' Series:
 - ▶ Principal issue could be the increased maximum loading resulting from the increase in standing space in the new door area
 - ▶ Location of air conditioning equipment immediately above doors may limit scope for strengthening
 - ▶ There appears to be little space underneath the existing doors for a strengthening 'flitch'
 - ▶ The use of pocketed doors inherently means there is a gap in the door pillar which may limit scope for strengthening
 - ▶ 'Lozenging' effect will be most severe at the existing door locations (assuming they remain with an additional door in the centre of the vehicle)
 - ▶ As a possible alternative, VKB could provide assistance with changes to the internal layout to improve passenger flow without additional doors
- ▶ Noted that passengers said to have suffered nausea when vehicles first introduced:
 - ▶ May indicate that body's natural frequency is on lower borderline (approx. 8Hz) and so cutting new holes in the bodyshell could re-introduce the problem

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Brake System

- ▶ VKB currently undertaking feasibility studies on traction upgrades including new braking
- ▶ Currently introducing new brake control and WSP system which will be cross blended across all vehicles in the unit.
- ▶ Designers of regenerative braking solution for Class 323 EMU, Class 321 EMU and Class 455
- ▶ Prepared and developed technical requirements specifications for braking systems
- ▶ Undertaken a large range of Brake system control modifications on UK Fleets
- ▶ Integrated braking control with sanding systems

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Saloon Door Upgrade

- ▶ VKB has undertaken numerous projects to improve door control systems
- ▶ Previous work with suppliers providing upgrades with VKB undertaking installation
- ▶ Now bidding for scheduled overhaul work that includes complete door system overhaul, so engaging with skilled sub suppliers for this scope

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Passenger Information System

- ▶ VKB has both replaced PIS and installed new systems into older rolling stock that was never previously fitted
- ▶ Scope included full installation design

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Communications System

- ▶ VKB has engineered, designed and installed improvements to communications systems including:
 - ▶ Wi-fi transmission from train to shore
 - ▶ GSM (mobile phone technology) transmission from train to shore
 - ▶ GSM-R radio installation design and fleet installation
 - ▶ Integration of PIS, CCTV, remote condition monitoring, passenger counting, etc. into train systems
 - ▶ integration with Bombardier train management system for CCTV

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- ▶ The Case for Traction Upgrade
 - ▶ Elimination of potential obsolescence
 - ▶ Improvement in availability
 - ▶ Reduced Maintenance and operational costs
 - ▶ Energy reduction

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By comparing the 'A' Series fleet of EMU's against a UK fleet of EMU's of a similar age and with a similar traction system it has been broadly possible to calculate existing running costs and predict possible savings.

All figures are in AU\$, using the exchange rate of 1.00GBP = 1.53 AUD

Existing System

Consists of 6 DC traction motors in 3 groups of 2 motors. 2 motors per bogie in the AEA car & 2 motors on 1 bogie in the AEB car. 288 motors in service use.

Bogies are narrow gauge (3ft 6in – 1,067mm)

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1. Uses friction brake only, no regenerative or brake blending capability. Therefore high pad and disc wear and costs
2. High energy costs due to no regenerative capability
3. Traction system now over 20 years old, therefore obsolescence will become an issue in the future.
4. DC motors less efficient and reliable than AC equivalent.
5. DC motors require a commutator replacement during lifespan.
6. Major overhaul interval limited by motor life (500k miles)
7. Traction convertor and auxiliary supply reliability.

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Major Overhaul (C4) Costs (assuming 450K between C4) – AU\$320 Million

Disc replacement Costs – AU\$4.5 Million

Tyre turning Costs – AU\$2.5 Million

Pad replacement Costs – AU\$5.3 Million

Energy Costs – AU\$215 Million (*Assumes 3% rise in annual energy inflation*)

Motor reliability Costs – AU\$65.7 Million

Commutator replacement Costs – AU\$24.7 Million

Wheelset replacement Costs – AU\$13.5 Million

Motor Brush Costs – AU\$9.3 Million

Obsolescence – AU\$8 Million

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Predicted total costs if not upgraded – **>AU\$670 Million**

As can be seen from the previous slide, energy costs make up the bulk of the existing running costs to 2032, approximately 68% of the total.

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Benefits

1. 3 phase asynchronous motor. Increased reliability with a Mean Time Between Casualty of 750k miles.
2. Reduced maintenance costs due to squirrel-cage, brushless design
3. Elimination of commutator replacement costs
4. Regenerative and brake blending capabilities leading to lower energy costs and reduced disc and pad replacement costs
5. Reduced tyre turning and wheelset replacement costs
6. Increased interval between major (C4) overhauls. C4 can be extended by 40%, therefore major savings on overhaul costs for remaining life of fleet.
7. Elimination of obsolescence in traction/ brake system

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Predicted costs of maintaining/ running fleet to 2032, if the traction system is upgraded, are as follows:

Major Overhaul (C4) Costs (assuming 650K between C4) – AU\$240 Million

Disc replacement Costs – AU\$2 Million

Tyre turning Costs – AU\$0.9 Million

Pad replacement Costs – AU\$2.9 Million

Energy Costs – AU\$170 Million (assumes 20% regenerative capability)

Motor reliability Costs – AU\$6.5 Million

Commutator replacement Costs – AU\$0

Wheelset replacement Costs – AU\$7 Million

Motor Brush Costs – AU\$0

Obsolescence – AU\$0

Total Costs post upgrade – AU\$430 Million

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Over the projected life of the fleet, to 2032, the potential savings if the traction system is replaced with an AC system are:

AU\$240 Million

Appendix H

FEA Report

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Fatigue Analysis
of the
A-series Railcar

Report Prepared for;

AECOM
3 Forrest Place,
Perth,
WA. 6000.
GPO Box B59

Report Number: C3263-003
Issue: B
Issued Date: 02/05/2013
Author: R Horsley
Checker: C Woolley

Change Control

Issue Status	Author	Details of Change	Date
A	RPH	First Issue	28/04/13
B	RPH	Incorporation of AECOM's comments	02/05/13

Executive Summary

This document reports the finite element analysis carried out by Design and Analysis Ltd (DAL) on the A-series fleet of railcars that are operated by the Transperth Trains division of the Public Transport Authority (PTA) of Western Australia. The A-series electric multiple unit (EMU) trains were the first electric passenger trains to operate in Western Australia and have been in service on the Perth suburban rail network since 1991. Each train consists of two cars named DMA and DMB. The DMA car is the heavier of the two cars being fitted with a pantograph, two powered bogies and the main transformer located on the underframe. The DMB car has one powered bogie and lighter underframe equipment.

This analysis is intended to assess the proposed fleet life extension beyond the original 30 year service life.

The analysis covers the fatigue assessment of the carbody main structure only with no assessment of the bogie, couplers or underframe equipment. The DMA car has been chosen to form the basis of the analysis as it is the heavier of the two vehicles and will therefore see the highest loads.

The loads applied to the vehicle are from load case document [Ref. 1].

The fatigue assessment has been conducted in accordance with Eurocode 3 [Ref. 2].

Throughout the carbody structure, six areas of the carbody framework and two areas of spot welds have been identified to have fatigue lives less than 30 years under the load cases applied. These areas are:

Carbody Framework:

1. All door aperture bottom corners.
2. Cab back wall door apertures bottom corners.
3. Waistrails on both sides forward of cab end passenger doors.
4. Window stiffeners on both sides above cab end bolster.
5. All door aperture top corners.
6. Bodyside columns on both sides above the cab end bolster.

Spot Welds:

1. All door aperture top corners.
2. End of roof stiffeners rear of HVAC well at the cab end.

The fatigue lives predicted in the areas listed above are less than the current service life for the vehicles. A detailed discussion on why this could be is included in section 9.

The following actions are recommended to progress the life assessment of the A-series railcars.

1. The proposed work outlined as Phase 2 in the project plan is embodied. This will allow the high stress areas of the carbody identified during this analysis to be strain gauged so that more accurate life predictions based on actual vehicle loadings can be made. The findings of this work will also allow adjustment of the FEA based load cases if the on-track loadings are significantly different to those estimated.
2. The areas of the vehicle where this report has identified a life lower than the 30 year design life should be tested for the presence of cracking by thoroughly cleaning the welds and conducting non-destructive testing (such as dye-penetrant testing). This includes the spot welds.

3. It is recommended that a thorough dimensional investigation using a weld gauge is carried out for the critical welds identified in this report. This should identify if and where the carbody manufacture differs from design and may enable the Class 36 welds to be re-categorised.

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1 Introduction

This document reports the finite element analysis carried out by Design and Analysis Ltd (DAL) on the A-series fleet of railcars that are operated by the Transperth Trains division of the Public Transport Authority (PTA) of Western Australia. The A-series electric multiple unit (EMU) trains were the first electric passenger trains to operate in Western Australia and have been in service on the Perth suburban rail network since 1991. Each train consists of two cars named DMA and DMB. The DMA car is the heavier of the two cars being fitted with a pantograph, two powered bogies and the main transformer located on the underframe. The DMB car has one powered bogie and lighter underframe equipment.

This analysis is intended to assess the proposed fleet life extension beyond the original 30 year service life.

The analysis covers the fatigue assessment of the carbody main structure only with no assessment of the bogie, couplers or underframe equipment. The DMA car has been chosen to form the basis of the analysis as it is the heavier of the two vehicles and will therefore see the highest loads.

The loads applied to the vehicle are from load case document [Ref. 1].

The fatigue assessment has been conducted in accordance with Eurocode 3 [Ref. 2].

2 Objective

The objective of this analysis is to assess the fatigue life of the A-series railcars.

3 Notation

Table 1 below defines the nomenclature used in the report.

Symbol	Description
E	Young's modulus
ν	Poisson's ratio
ρ	Density
R_e	Yield stress
R_m	Ultimate stress
σ	Stress
σ_C	Fatigue Class (at 2×10^6 cycles)
σ_D	Variable Amplitude Knee Point (at 5×10^6 cycles)
σ_L	Variable Amplitude Cut-off Limit (at 100×10^6 cycles)
RF	Reserve factor
g	Gravitation constant
x	longitudinal coordinate
y	transverse coordinate
z	vertical coordinate
N	Newton
mm	millimetre
kg	kilogram
T	Tonne
s	Second
MPa	Megapascal (Equivalent to N/mm^2)

Table 1 - Notations

4 Design Data

The finite element model generated for this analysis was based on original vehicle manufacturing drawings supplied by AECOM.

4.1 Analysis Program Used

The Altair Hyperworks suite version 11 has been used for this analysis, specifically:
 Hypermesh for pre-processing
 Hyperview for post-processing
 Optistruct for solving

4.2 Coordinate System

x longitudinally, along the vehicle
 y transversely, across the vehicle
 z vertically

4.3 Units

The units used in the analysis are: Newtons (N), millimetres (mm), tonnes (T) and seconds (s).

4.4 Materials

The materials used for the analysis are listed in the table below. Standard steel properties were used for the bolts and beams.

#	Material	E [MPa]	ν [-]	ρ [T/mm ³]	R _e [MPa]	R _m [MPa]
1	Stainless Steel 301 (BS EN 10088 1.4301)	200,000	0.3	7.9e-9	230	540
2	Cast Steel AS2074 LIA (BS EN 10293:2005 1.1165)	210,000	0.3	7.8e-9	275	480
3	Plywood	8,000	0.3	6.8e-10	-	-

Table 2 - Material Properties

The vehicle structure has been given Stainless Steel 301 material properties. Cast components, such as the coupler mounting and centre pivot have been given Cast Steel properties. The floor has been modelled as Plywood.

5 Finite Element Model

5.1 Mesh

The FEA model is constructed predominantly with quadrilateral 2D linear shell elements with a global mesh size of 25mm. In highly stressed areas the mesh size has been refined to 7.5mm to increase accuracy. See Figure 1, Figure 2 and Figure 3.

Components such as the coupler casting, centre pivot and ARB mounts have been meshed with 3D solid elements to reflect the more complex nature of the geometry. See Figure 4.

The mass and centre of gravity of the model has been adjusted to reflect the true mass of the carbody by adding point mass elements along the solebar and cantrail. See Figure 5.

The carbody model is supported by a kinematic bogie representation to allow the carbody to deflect accurately under the applied loads. See Figure 6.

The passenger floor has been modelled as Plywood and is included in the model to allow passenger loading to be distributed accurately and for stiffness and mass purposes. See Figure 7.

The seat frames are modelled using 1D bar elements and are attached to the bodyside structure at the appropriate locations. See Figure 8.

The corrugated roof, bodyside and floor panelling are attached to the structure using 1D bar elements representing the spot welds. The bar elements have an equivalent cross section to the weld diameter. Spot weld locations are seen in Figure 9.

The underfloor equipment has been modelled with 0D point mass elements which are attached to the under frame using RBE3 (rigid elements with no stiffness representation). See Figure 10.

The finite element model contains 1,028,801 elements and 1,002,359 nodes.

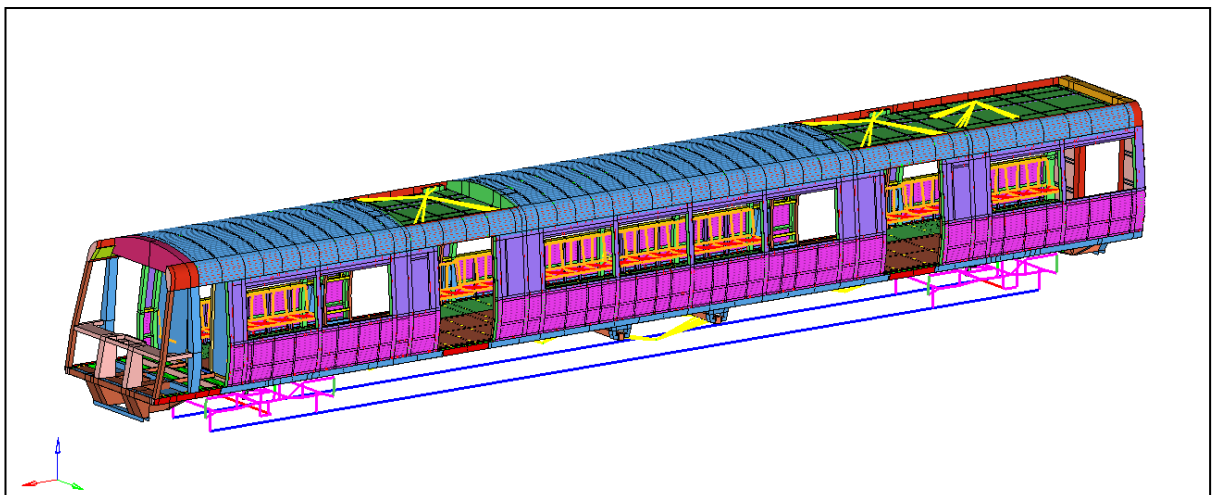


Figure 1 - Overall plot of the Finite Element Model

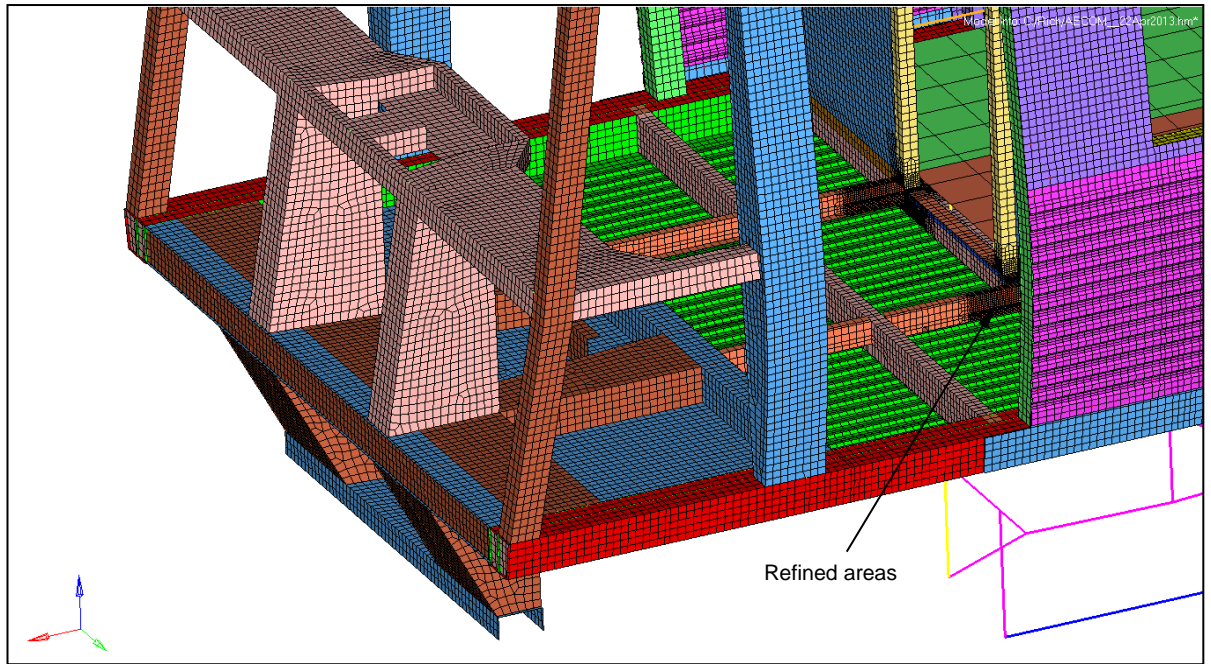


Figure 2 - General Mesh Definition

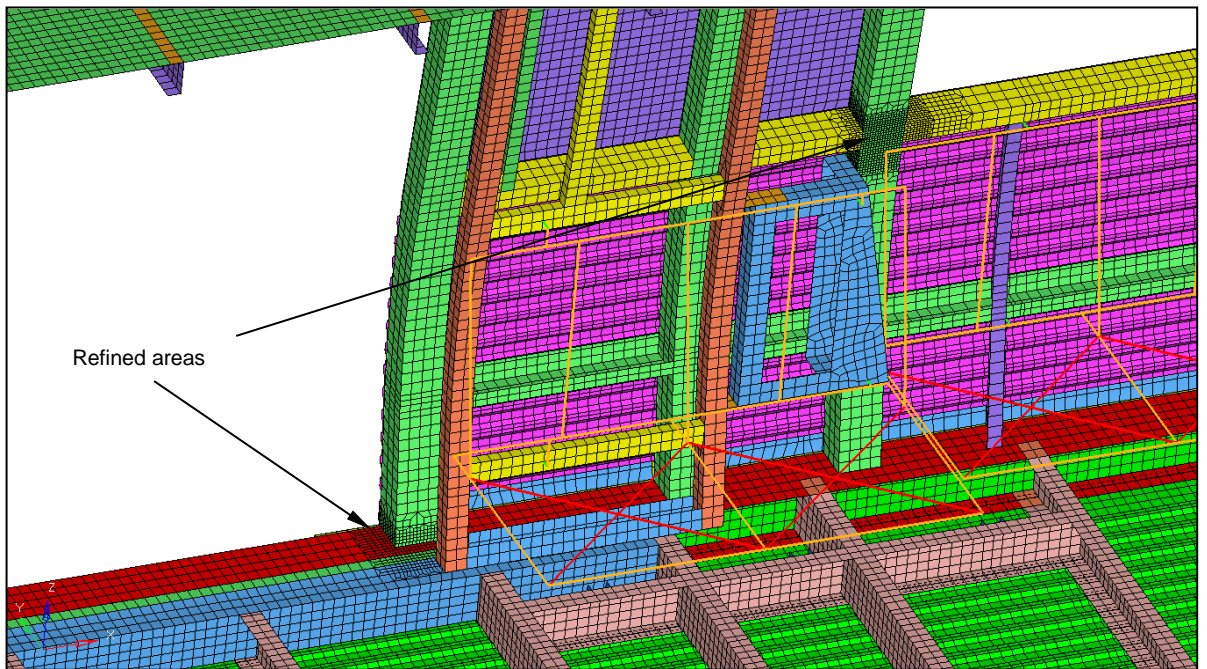


Figure 3 - Refined Mesh Definition

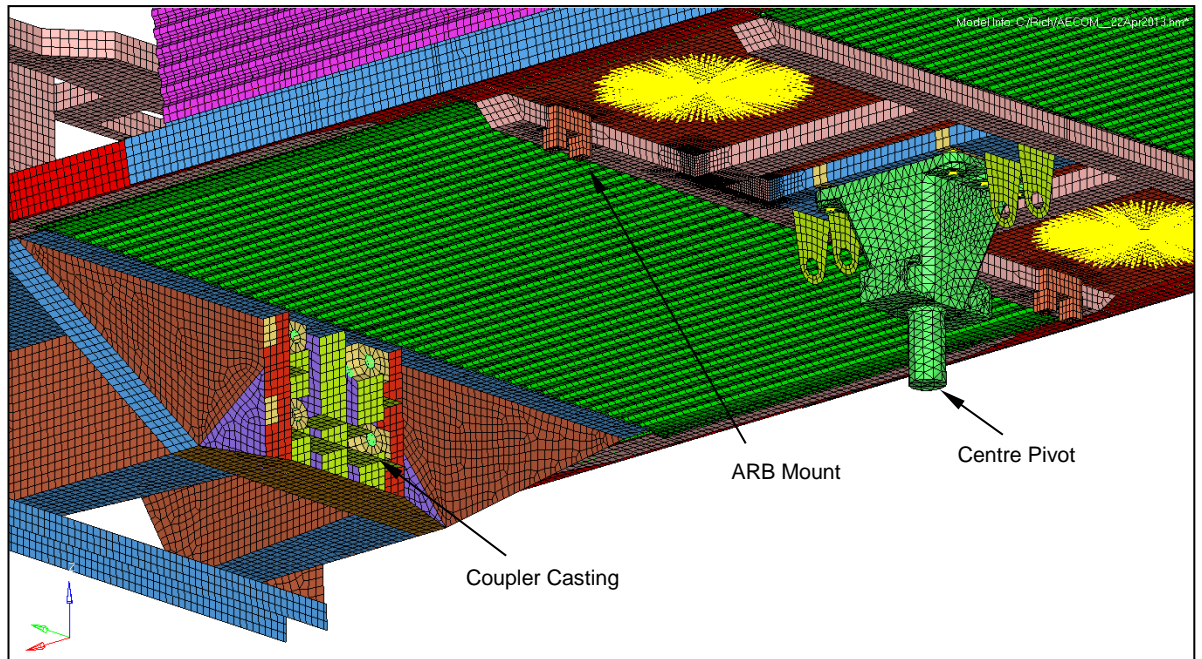


Figure 4 - 3D Solid Element Modelling

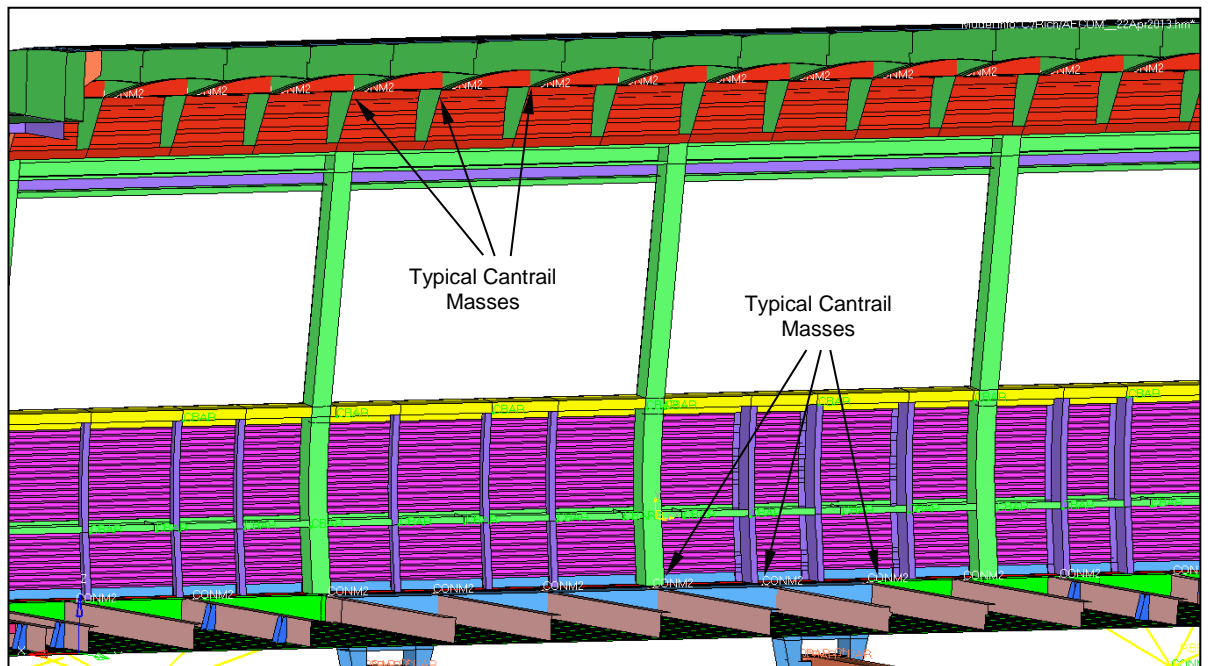


Figure 5 - Cantrail and Solebar Masses

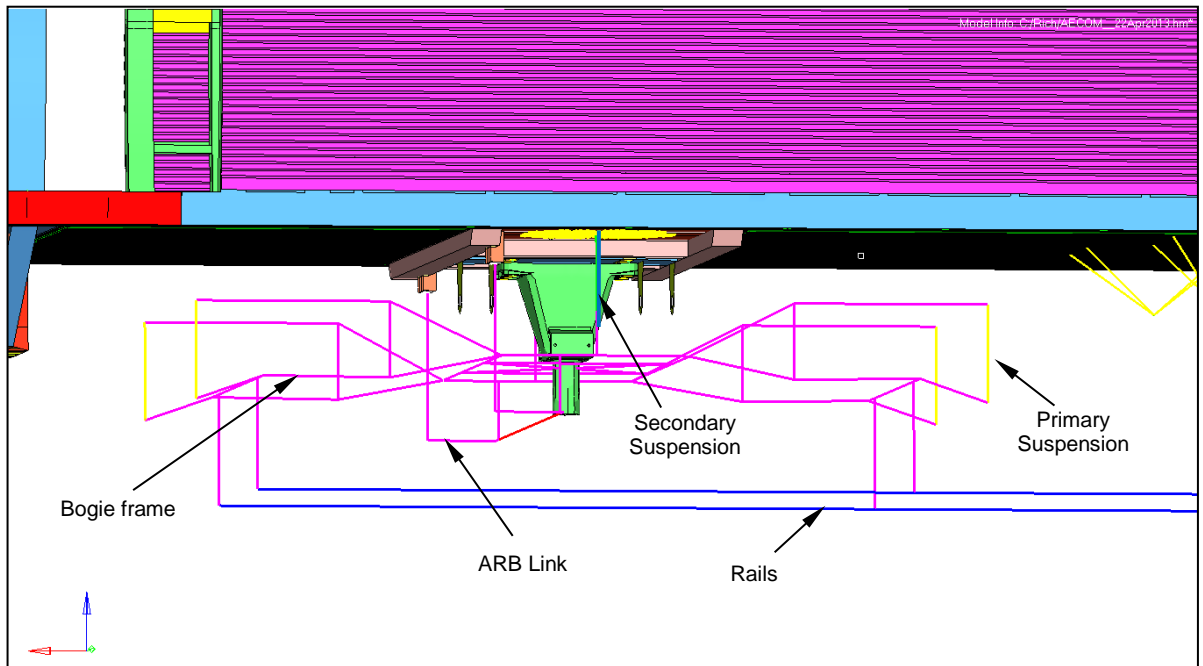


Figure 6 - Kinematic Bogie Representation

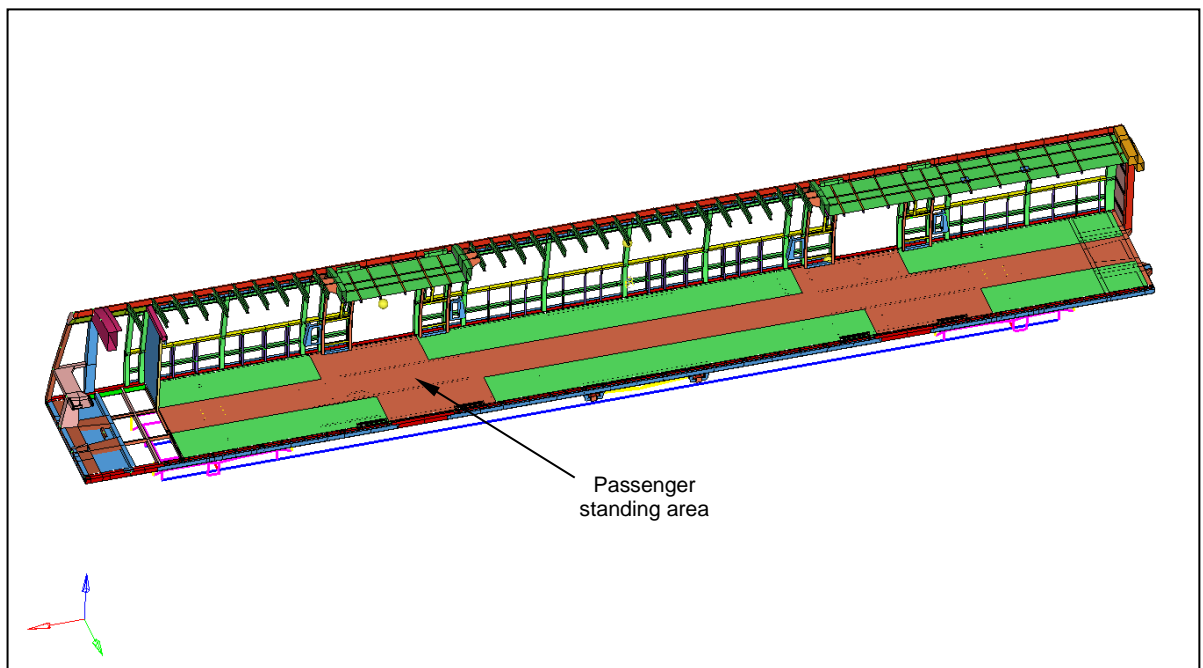


Figure 7 - Passenger Floor Representation

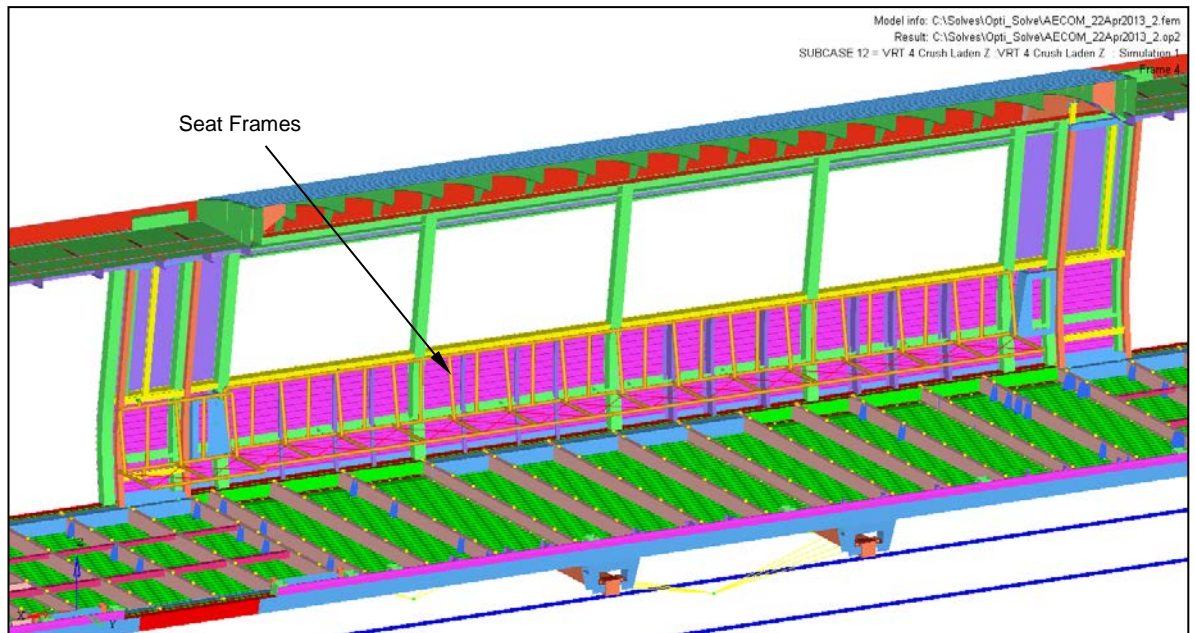


Figure 8 - Passenger Seat Frame Representation

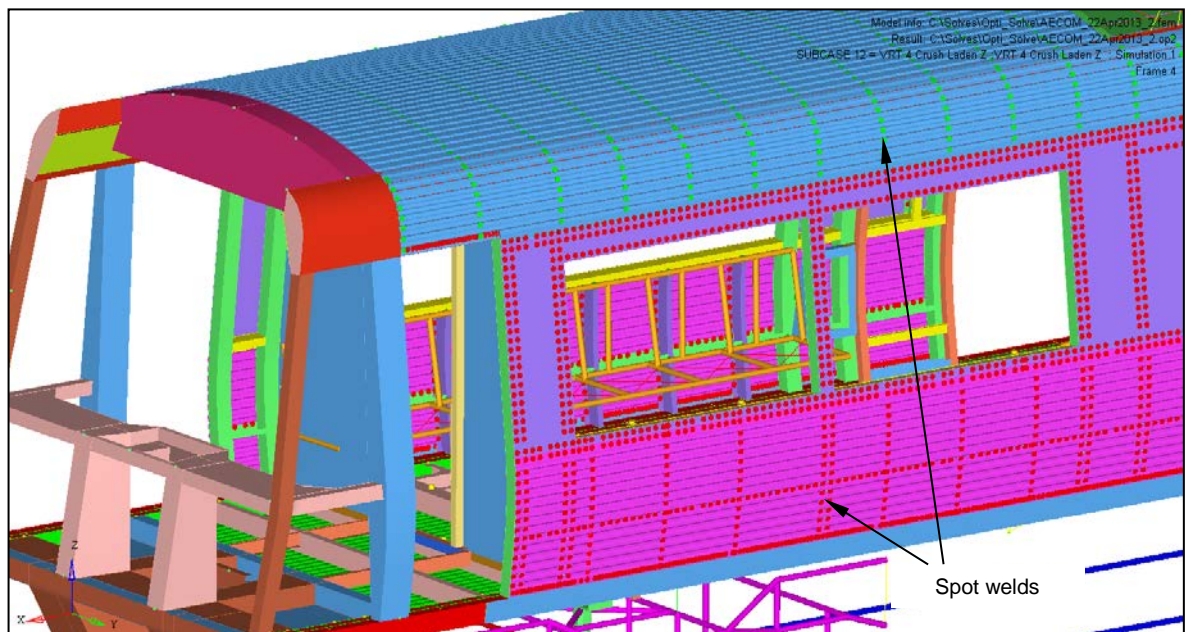


Figure 9 - Corrugated Panels and Bodyside Panels Showing Spot Welds.

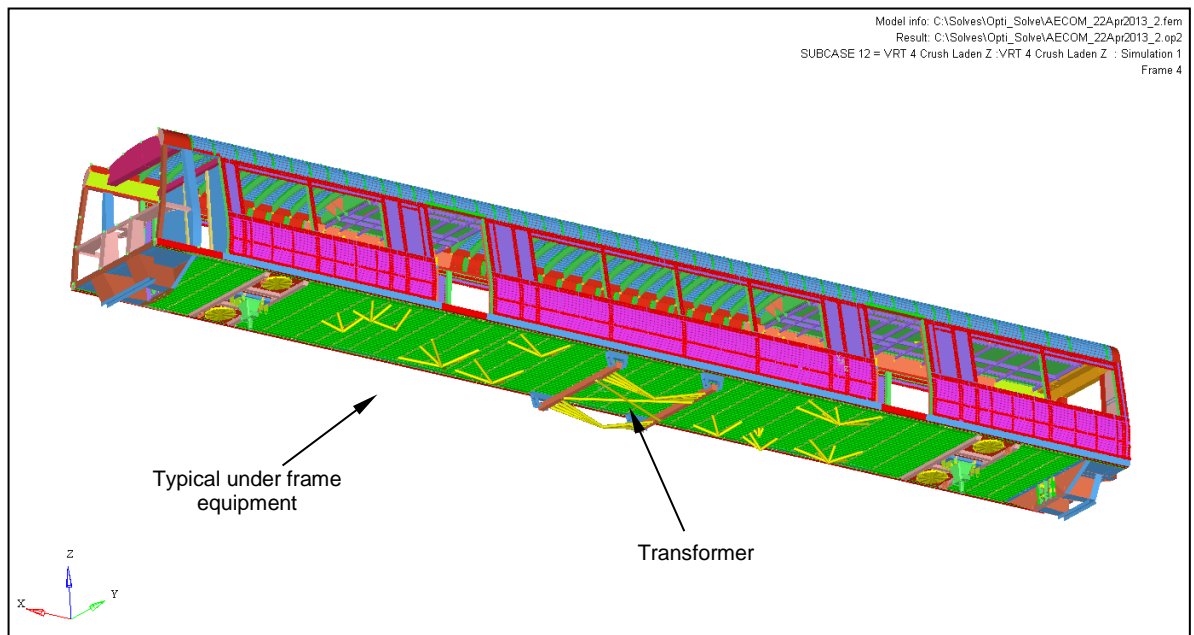


Figure 10 - Underframe Equipment

5.2 Restraints

The model is restrained at the intermediate end coupler in the longitudinal direction (X). The model is also restrained in the lateral and vertical directions (Y & Z) at the rail level. See Figure 11.

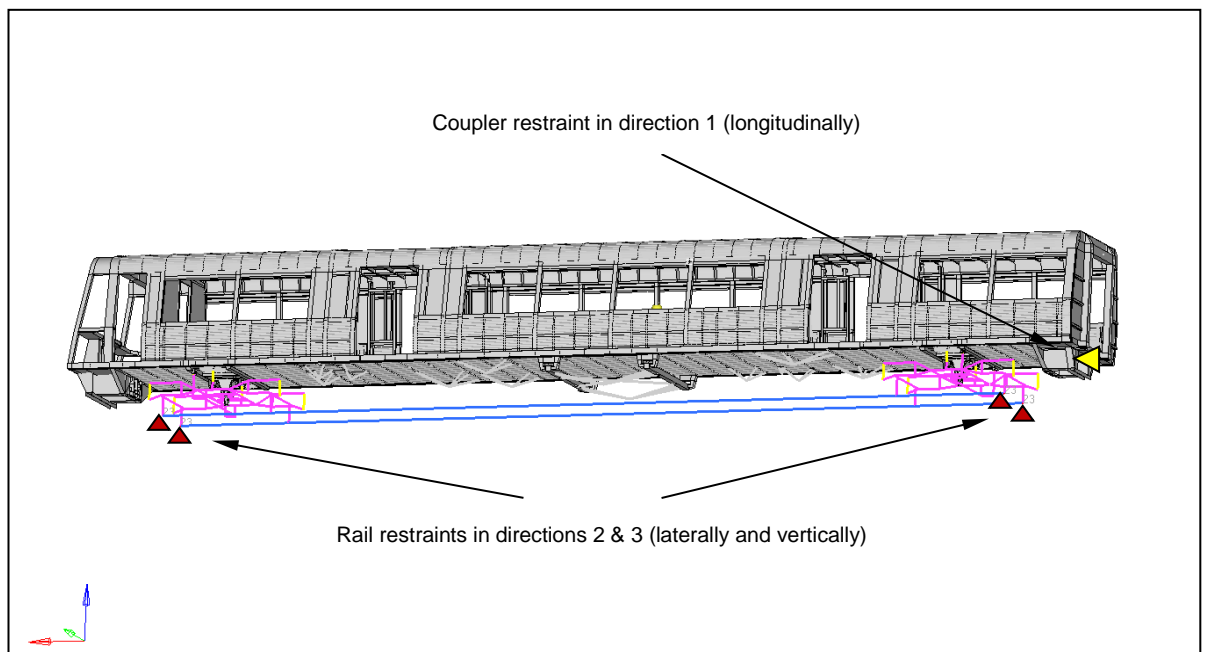


Figure 11 - Model Restraints

5.3 Model Mass

5.3.1 Vehicle Mass Data

The mass data for the analysis was extracted from various sources as tabulated below

Condition	Value	Reference
Car Tare Mass, $[M_{CT}]$	48×10^3 kg	[Ref. 4]
Total Bogie Mass $[M_B]$	16.2×10^3 kg	[Ref. 3] (2 x Powered Bogie)
Tare Mass (Secondary Sprung) $[M_T]$	31.8×10^3 kg	$M_{CT} - M_B$
Tare Mass (Secondary Sprung) Centre of Gravity ARL	1.8m	[Ref. 3]
Average Passenger Mass, $[P_{AV}]$	65kg	e-mail G Bentley, AECOM
Passengers Seated at Laden, $[P_S]$	63	[Ref. 4] & [Ref. 5]
Passengers Standing at Full, $[P_F]$	102	PTA Supplied Data, [Ref. 5]
Passenger Standing at Crush, $[P_C]$	153	PTA Supplied Data, [Ref. 5]
Laden Mass (Secondary Sprung) $[M_L]$	35.9×10^3 kg	$M_T + P_S \times P_{AV}$
Fully Laden Mass (Secondary Sprung) $[M_{FL}]$	42.5×10^3 kg	$M_L + P_F \times P_{AV}$
Crush Laden Mass (Secondary Sprung) $[M_{CL}]$	45.8×10^3 kg	$M_L + P_C \times P_{AV}$

Table 3 - Mass Data for DMA Car

Condition	Value	Reference
Car Tare Mass, $[M_{CT}]$	42×10^3 kg	[Ref. 4]
Total Bogie Mass $[M_B]$	12.6×10^3 kg	[Ref. 3] (1 x Powered Bogie + 1 x Non-Powered Bogie)
Tare Mass (Secondary Sprung) $[M_T]$	29.4×10^3 kg	$M_{CT} - M_B$
Tare Mass (Secondary Sprung) Centre of Gravity ARL	1.8m	[Ref. 3]
Average Passenger Mass, $[P_{AV}]$	65kg	e-mail G Bentley, AECOM
Passengers Seated at Laden, $[P_S]$	63	[Ref. 4] & [Ref. 5]
Passengers Standing at Full, $[P_F]$	102	PTA Supplied Data, [Ref. 5]
Passenger Standing at Crush, $[P_C]$	153	PTA Supplied Data, [Ref. 5]
Laden Mass (Secondary Sprung) $[M_L]$	33.5×10^3 kg	$M_T + P_S \times P_{AV}$
Fully Laden Mass (Secondary Sprung) $[M_{FL}]$	40.1×10^3 kg	$M_L + P_F \times P_{AV}$
Crush Laden Mass (Secondary Sprung) $[M_{CL}]$	43.4×10^3 kg	$M_L + P_C \times P_{AV}$

Table 4 - Mass Data for DMB Car

5.3.2 Underframe Masses

Table 5 lists the underframe masses used for the DMA car model. The centre of gravity in all cases has been estimated at the centre of volume. All centres of gravity are relative to the centre of the vehicle at rail level.

Item No. [Ref. 7]	Description	Mass (kg)	Ref.	Centre of Gravity		
				X (mm)	Y (mm)	Z (mm)
1.U.A6	T.C Box	25	Estimate	6,109	683	708
1.U.C15	PFC Unit (Resistor)	500	[Ref. 6]	3,536	-495	708
1.U.K22	Contacto Box	400	[Ref. 6]	2,167	852	708
1.U.K39	Auxiliary Relay Box	400	[Ref. 6]	-4,946	857	708
1.U.R13	Brake Resistor	200	[Ref. 6]	5,423	564	708
1.U.T31	Main Transformer	1,800	[Ref. 6]	-538	0	635
1.U.U25	Thyristor Converter	370	[Ref. 6]	2,167	-703	708
1.U.V30	Oil Cooler	500	[Ref. 6]	-538	817	385
1.U.V32	Oil Cooler	500	[Ref. 6]	-538	-817	385
1.U.W50	APC Receiver	49	[Ref. 6]	6,260	0	708
1.U.Y35	Auxiliary Compressor	100	[Ref. 6]	-3,260	-730	708
1.U.Y43	Reservoir 14L	50	[Ref. 6]	-4,125	-579	808
1.U.Y44	Reservoir 99L	120	[Ref. 6]	-4,401	-910	708
1.U.Y45	Air Box	100	[Ref. 6]	-5,937	-780	708

Table 5 - Mass Data for the Underframe Equipment DMA Car

5.3.3 Additional Mass Distribution

The following masses have been distributed in key areas to take into account items that are not modelled. The magnitudes are estimated from experience. They are included in the overall mass of the vehicle. All centres of gravity are relative to the centre of the vehicle at rail level.

Description	Mass (kg)	Ref.	Figure No.	Centre of Gravity		
				X (mm)	Y (mm)	Z (mm)
Cab: GRP, glass & desk	400	Estimate	Figure 12	11,291	0	2,284
Inter End: Gangway	110	Estimate	Figure 13	-11,641	0	2,036
Coupler: Cab end	100	Estimate	Figure 14	10,871	0	805
Coupler: Inter end	100	Estimate	-	-10,871	0	805
ACU: Cab end	500	[Ref. 6]	Figure 15	4,375	0	3,645
ACU: Inter end	500	[Ref. 6]	Figure 15	-6,124	0	3,645
Pantograph	250	[Ref. 6]	Figure 15	-8,544	0	3,645
Cantrail Masses	5,534	Calculated [#]	Figure 16	580	0	3,336
Solebar Masses	7,089	Calculated [#]	Figure 17	758	0	1,077

Table 6 - Additional Mass Data

[#] Cantrail and solebar masses have been calculated such that the vehicle tare mass is achieved whilst maintaining the vertical centre of gravity stated in Table 3.

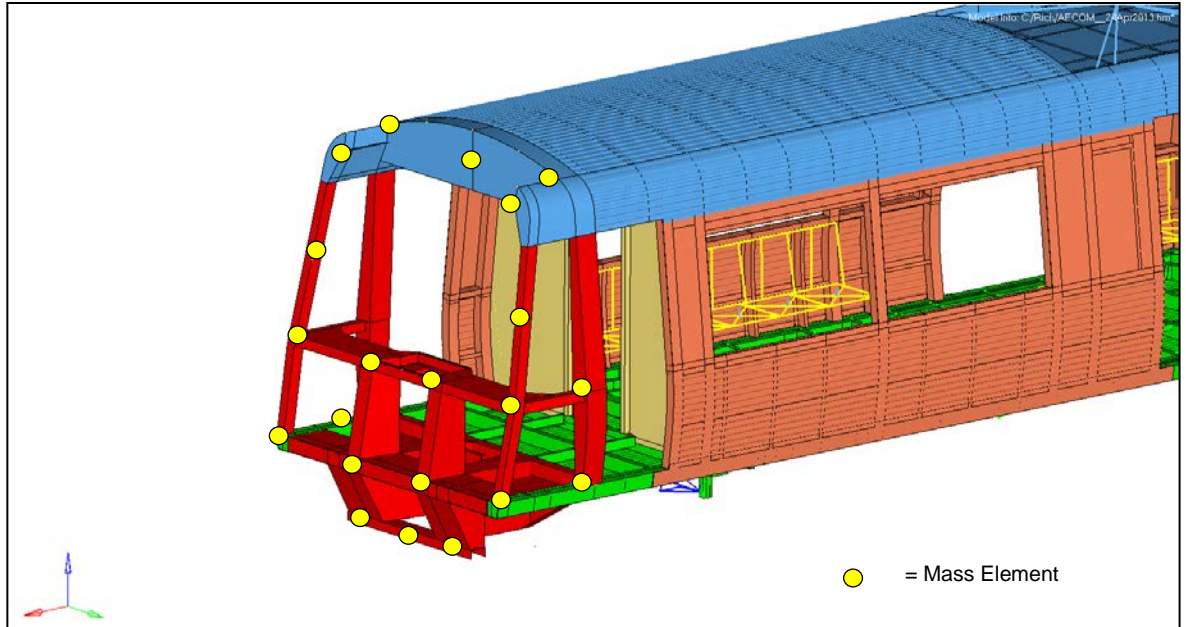


Figure 12 - Cab Mass Distribution

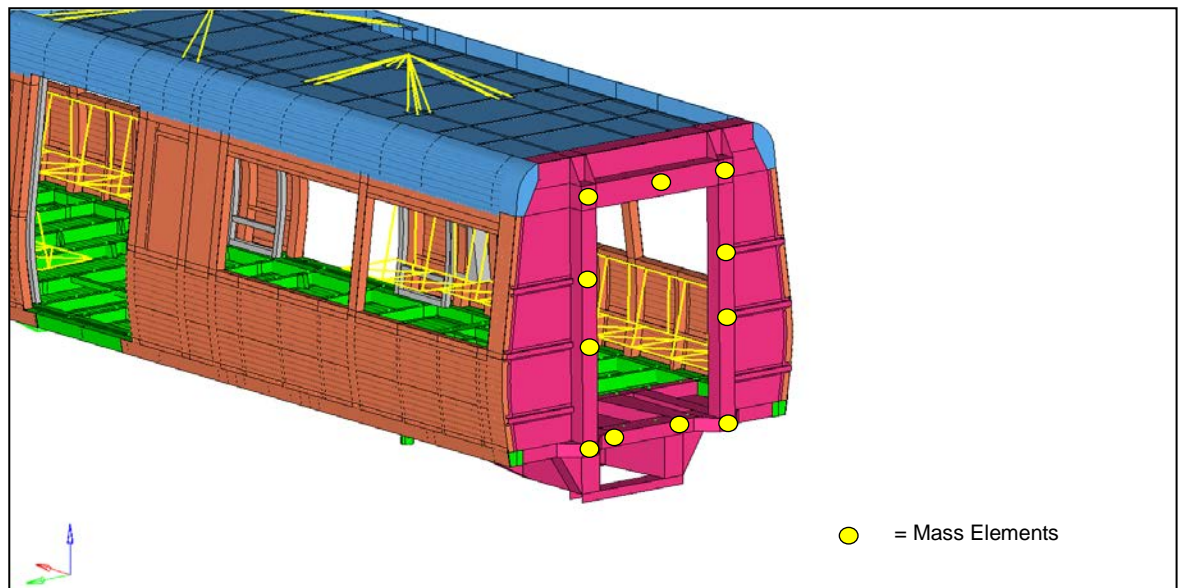


Figure 13 - Intermediate End Masses Distribution

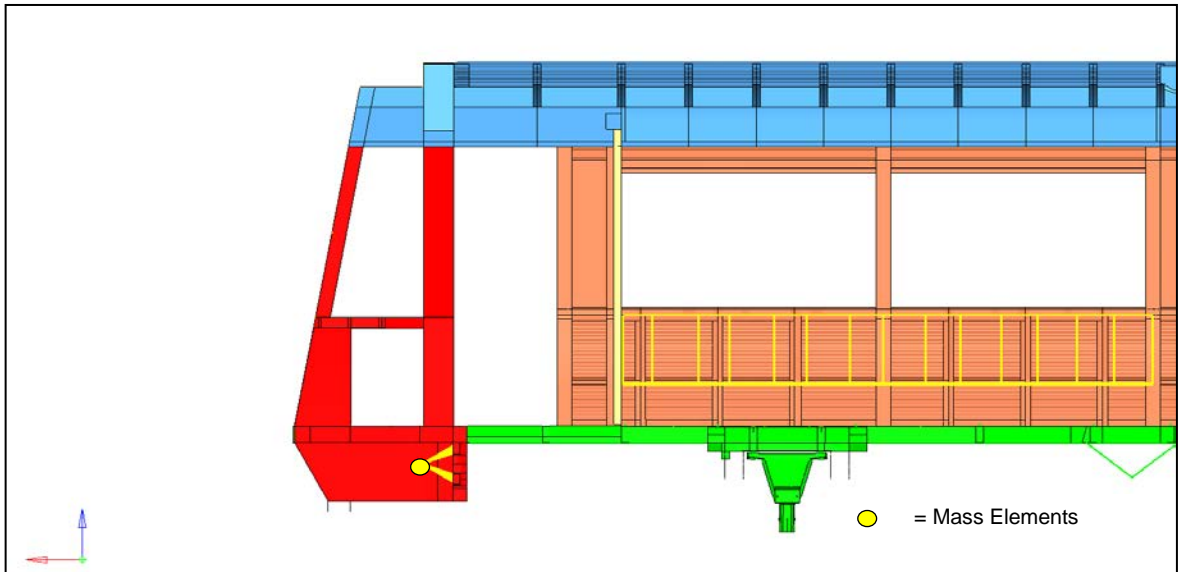


Figure 14 - Coupler Mass Position

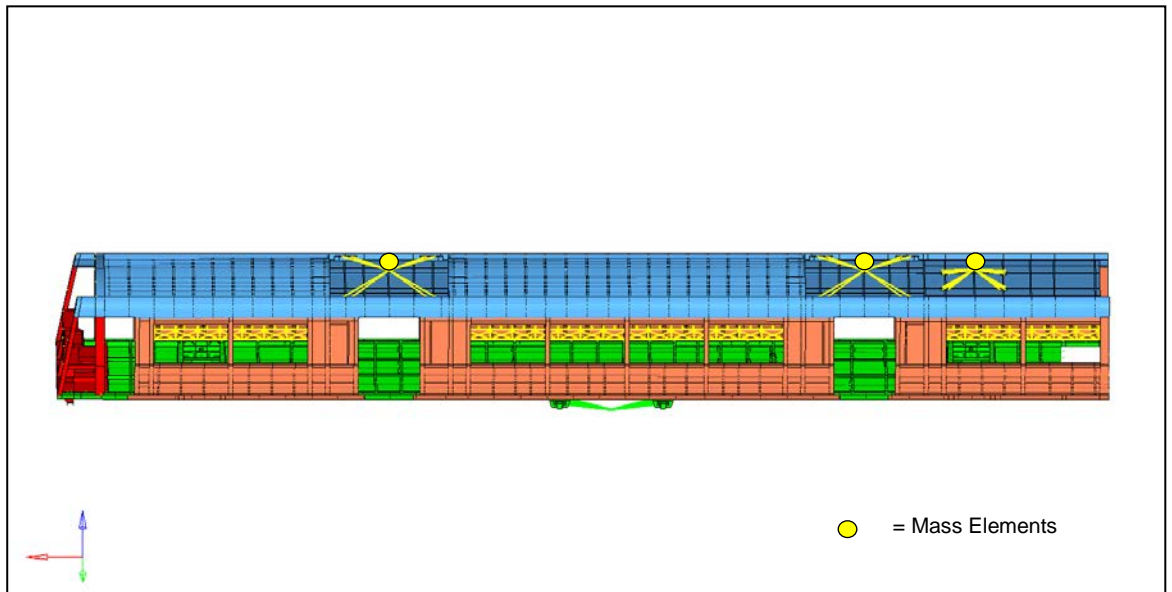


Figure 15 - Air Conditioning and Pantograph Locations

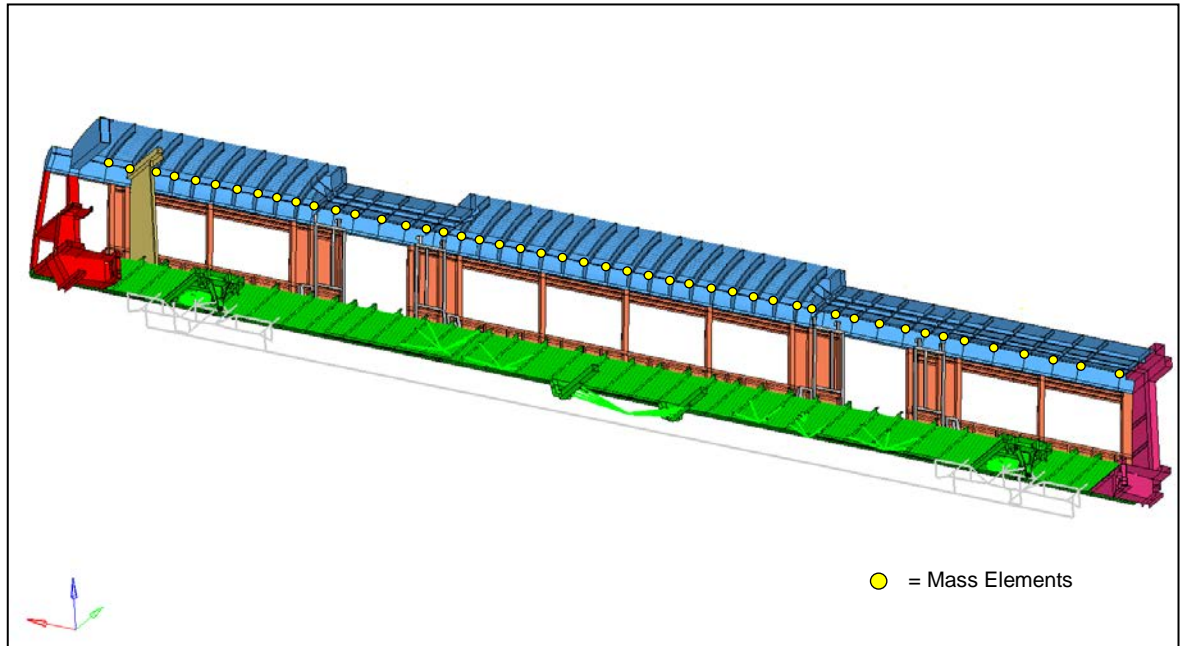


Figure 16 - Cantrail Mass Distribution

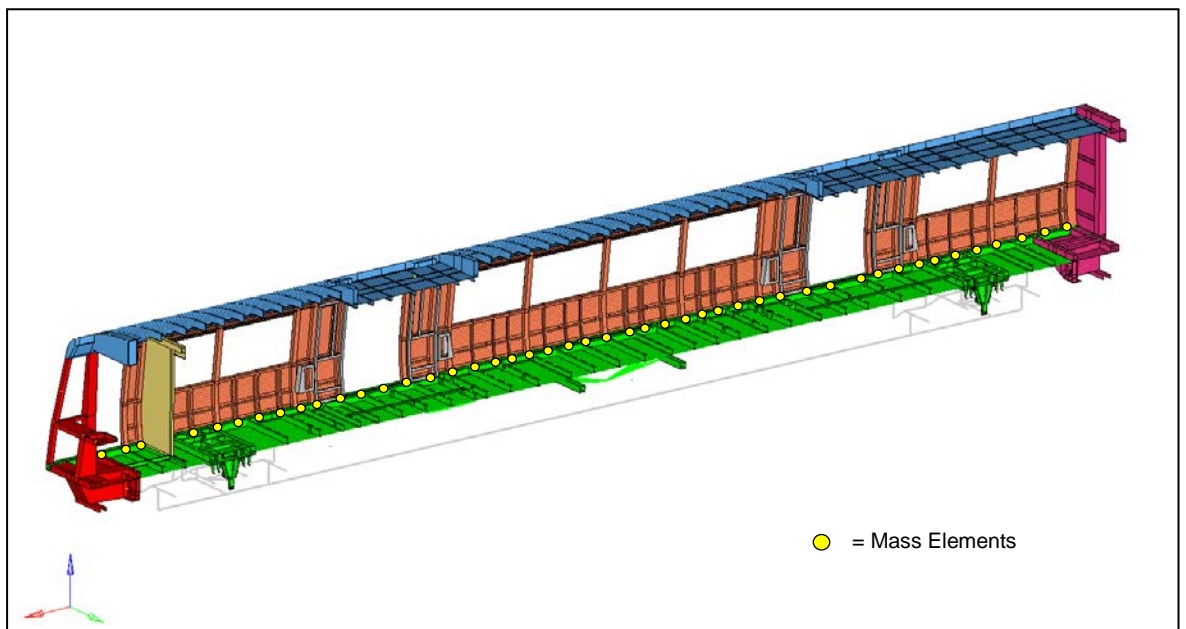


Figure 17 - Solebar Mass Distribution

5.4 Assumptions

There are a number of assumptions that have been made during this analysis that may affect fatigue life as follows:

1. The magnitude of the loads detailed in the load case document [Ref. 1] are in accordance with BS EN 12663 [Ref. 8] and have not been confirmed to be representative of actual operational track induced loading.
2. The masses added to represent non-modelled items have been estimated in magnitude and centre of gravity in the absence of measured data. Section 5.3 details the mass assumptions made.
3. The total vehicle mass is correct to original specification but has not been confirmed as a measured mass.
4. The vehicle centre of gravity is estimated with the absence of actual measured data.
5. It is assumed that the vehicle is manufactured to drawing and that no additional structure exists that is not specified on the drawings.
6. It is assumed that all welding is carried out in accordance with the manufacturing drawings.
7. It is assumed that the interior trim and bodyside glazing does not contribute to the vehicle stiffness or act as carbody structure.
8. All stitch welding specified on the manufacturing drawings has been treated as continuously welded due to the non-specific nature of the weld spacing.
9. It has been assumed that floor to ceiling grabpoles are not structural.

6 Load Cases

The loads applied to the FEA model are detailed in the Load Case document [Ref. 1], a summary of these load cases are as follows:

6.1 Inertia Load Cases

Table 7 lists the track induced loads experienced during vehicle operation.

Load Case	Mass Condition	Acceleration		Number of cycles
LNG 1	Tare	$\pm 0.15g$	X-Axis	0.5×10^6
LNG 2	Laden	$\pm 0.15g$		8.6×10^6
LNG 3	Fully Laden	$\pm 0.15g$		0.8×10^6
LNG 4	Crush Laden	$\pm 0.15g$		0.1×10^6
Total Cycles				10×10^6
LAT 1	Tare	$\pm 0.15g$	Y-Axis	0.5×10^6
LAT 2	Laden	$\pm 0.15g$		8.6×10^6
LAT 3	Fully Laden	$\pm 0.15g$		0.8×10^6
LAT 4	Crush Laden	$\pm 0.15g$		0.1×10^6
Total Cycles				10×10^6
VRT 1	Tare	$(1 \pm 0.15)g$	Z-Axis	0.5×10^6
VRT 2	Laden	$(1 \pm 0.15)g$		8.6×10^6
VRT 3	Fully Laden	$(1 \pm 0.15)g$		0.8×10^6
VRT 4	Crush Laden	$(1 \pm 0.15)g$		0.1×10^6
Total Cycles				10×10^6

Table 7 - Inertia Load Cases

6.2 Static Load Cases

Table 8 lists the track induced loads experienced while the vehicle is stationary and passengers are boarding and alighting.

Load Case	Mass Condition	Vertical Acceleration (Z-Axis)	Number of cycles
PAS 1.1	0.33 x Crush	- 1g	1,984,450
PAS 1.2	0.50 x Crush	- 1g	6,890
PAS 1.3	0.66 x Crush	- 1g	5,400
PAS 1.4	0.83 x Crush	- 1g	2,200
PAS 1.5	1.00 x Crush	- 1g	1,000
Total Cycles			2,000,000

Table 8 - Passenger Loading/Unloading Load case

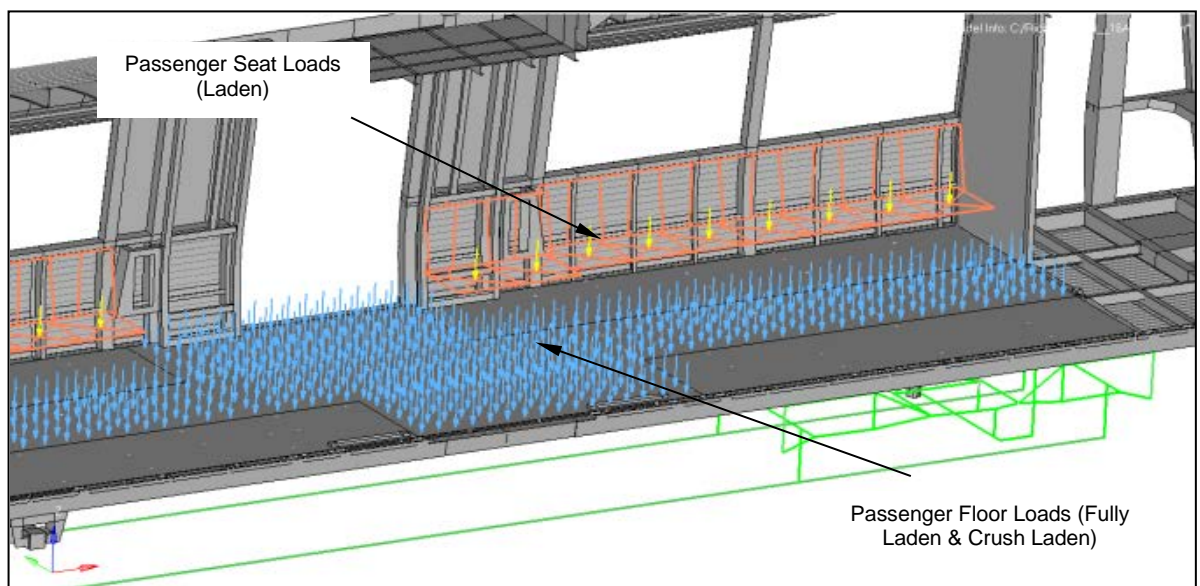


Figure 18 - Passenger Load Cases

6.3 Track Twist Load Cases

Table 9 lists the track induced loads experienced due to track out of plane tolerances.

Load Case	Twist Range [mm]		Cycles/km	Number of cycles
TWS 1.1	5.8	(10%)	600	2520 x 10 ⁶
TWS 1.2	8.7	(15%)	22	92.4 x 10 ⁶
TWS 1.3	14.6	(25%)	8	33.6 x 10 ⁶
TWS 1.4	20.4	(35%)	3	12.6 x 10 ⁶
TWS 1.5	29.2	(50%)	2	8.4 x 10 ⁶
TWS 1.6	40.8	(70%)	1.5	6.3 x 10 ⁶
TWS 1.7	58.3	(100%)	0.2	0.84 x 10 ⁶
			Total Cycles	2674.14x 10⁶

Table 9 - Track Twist Load Case

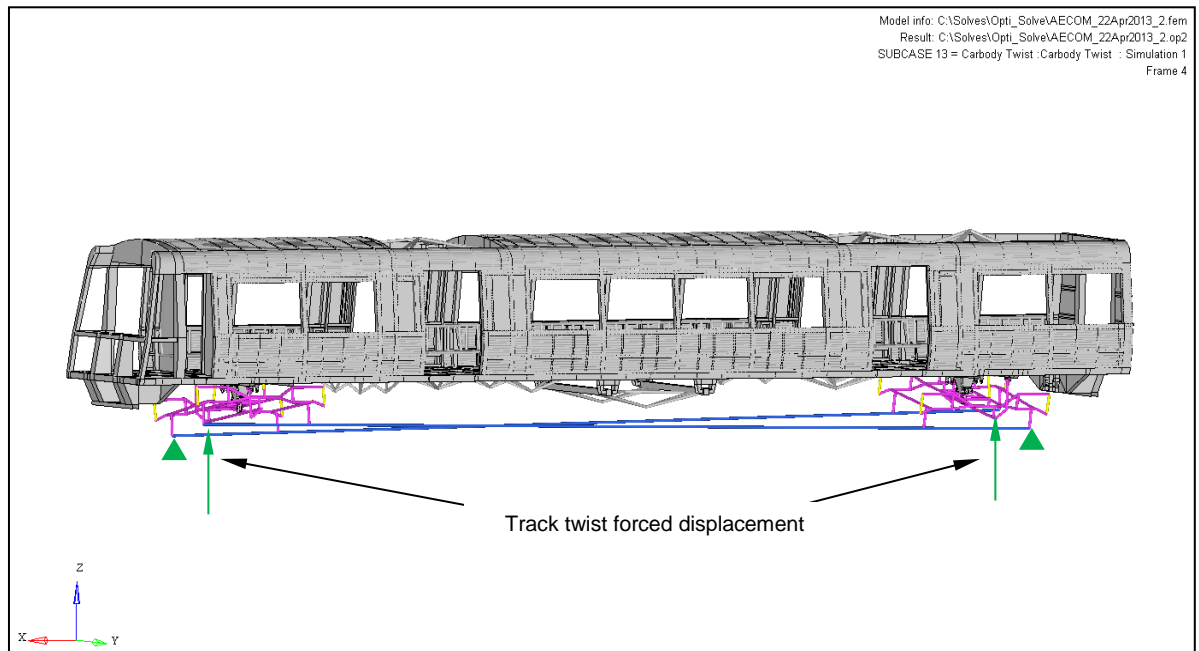


Figure 19 - Track Twist Load Cases

6.4 Lateral Damper Load Case

Table 10 lists load that would be found at the lateral damper connection.

Load Case	Load	Number of cycles
BLD 1.0	$\pm 1.3 \times 6\text{kN}$	10×10^6
	Total Cycles	10×10^6

Table 10 - Bogie Lateral Damper Load case

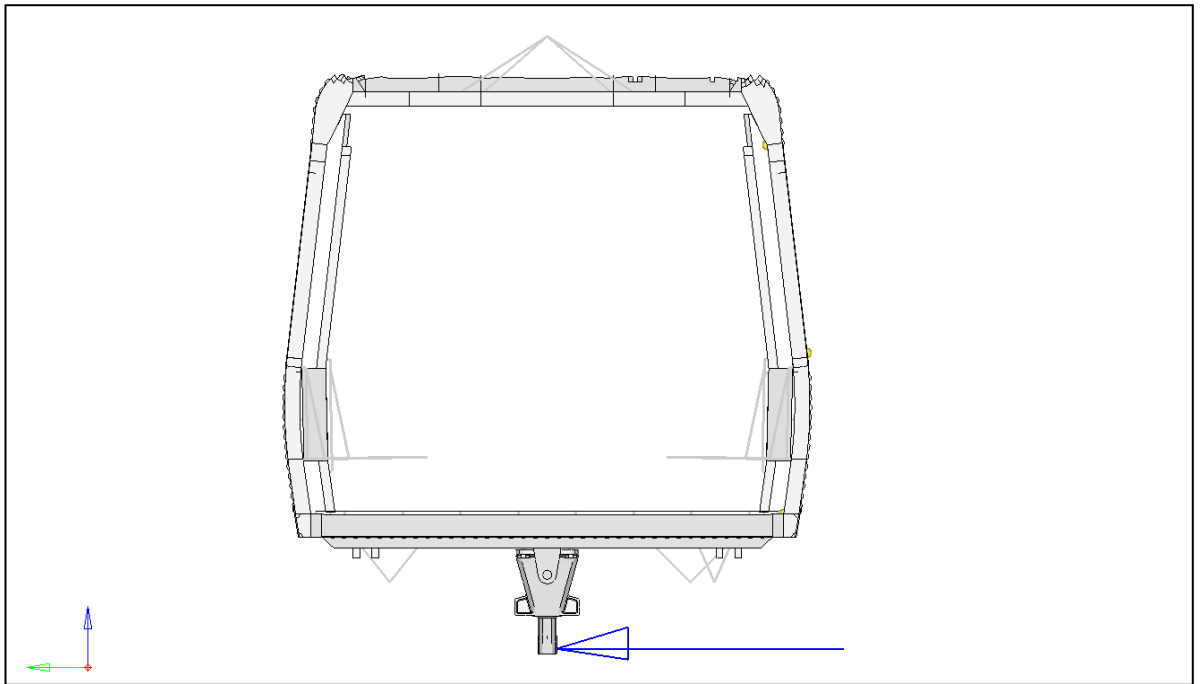


Figure 20 - Lateral Damper Load Case

7 Analysis Results

Analysis has been conducted using the damage tolerant method detailed in Eurocode 3, [Ref. 2]. Based on the wide spectrum of loads that the vehicle will experience over its service life the fatigue assessment will use the variable amplitude S-N curve.

7.1 Structural Steel Framework and Surface Panelling

Nominal stresses have been extracted at one element away from the stress concentration. The element density in the areas of high stress has been refined so that stress extraction is close to the concentration. Typically the refined mesh has a 7.5mm element length. This dimension is based on an estimation of where a strain gauge would be if it were to be tested.

In total six areas the carbody have been identified as not achieving a life of 30 years. Of these six areas Table 11 identifies the lowest life found in each area. The stress plots and detailed fatigue data are in Appendix A.

Location	Weld Class	Worst Load Case	Cumulative Damage	Life (Years)	Figure No.	Table No.
Door Corner Bottom	36	VRT 2	27.02	1.1	Figure 21	Table 14
Cab Back Wall Bottom	36	LAT 2	17.60	1.7	Figure 22	Table 15
Waistrail	36	VRT 2	12.43	2.4	Figure 23	Table 16
Window Stiffener	36	VRT 2	9.72	3.1	Figure 24	Table 17
Door Corner Top	80	VRT 2	9.66	3.1	Figure 25	Table 18
Body Side Column	36	VRT 2	8.60	3.5	Figure 26	Table 19

Table 11 - Summary of all Results for Framework and Panelling

7.2 Spot welds

The vehicle external skins are spot welded to the supporting structural steel framework using thousands of 6mm spot welds.

Eurocode 3, [Ref. 3], does not specify a weld class or an analysis method for spot welds. Reference is therefore made to a paper presented by S J Maddox at the International Institute of Welding (IIW) annual conference in 1997, [Ref. 10]. The paper presents evidence that the local stress range can be assessed against a Class 125 based on the following calculation of local stress range:

$$\Delta\sigma_L = \frac{2P}{CT} + \frac{3P}{WT}$$

Where P is the applied shear load, C is the weld circumference, W is the sample width per spot and T is the material thickness. This calculation is only valid for spot welds loaded in shear as the tensile performance of spot welds has been demonstrated to be extremely poor.

In total the FEA model contains 12,979 spot welds. The forces in each of the spot welds were returned from the FEA for all 14 load cases. Examination of the spot weld forces demonstrated that the tensile loading was insignificant when compared to the shear loading therefore the local stress range calculation was valid. The local stress, as per the above method, was calculated for each element and a fatigue damage calculation was performed for the most highly stressed spot welds.

In total 10 spot welds were found to have a life of less than the 30 year design life requirement. These spot welds were centred on two areas of the vehicle. Of these two areas Table 12 identifies the lowest life found in each area. The stress plots and detailed fatigue data is in Appendix A.

Location	Weld Class	Worst Load Case	Cumulative Damage	Life (Years)	Figure No.	Table No.
Door Corner Top	125	VRT 2	4.86	6.2	Figure 27	Table 20
Roof Stiffener	36	VRT 2	1.98	15.2	Figure 28	Table 21

Table 12 - Summary of all Results for Spot Welds

7.3 Bolted Joints

Two bolted joints have been assessed as structurally critical to the safe operation of the vehicle and therefore requiring fatigue assessment. The bolts will be assessed using a Class 50 detail category for failure in the bolt thread in accordance with Eurocode 3,[Ref. 2]. Taking each joint assessment in turn:

7.3.1 Centre Pin Bracket to Bolster Joint

The centre pin translates horizontal loads from the bolster to the carbody. Six off M30 grade 8.8 bolts are used to make the joint at each centre pin. Each bolt is torqued to 1470Nm in accordance with manufacturing drawing W45051. The forces in each of the bolts were returned from the FEA for all 14 load cases and run through a spread sheet based fatigue calculation which checks whether or not the stress ranges induced in the bolts achieve infinite life. The results of the spread sheet calculation are listed in Table 22 for the first 30 highest stress ranges.

It can be seen that out of all the load cases there are two bolts under load case LAT4 that do not achieve an infinite life. Considering the fact that all other load cases achieve infinite life there is no need to calculate a cumulative damage and a singular damage calculation for these bolts can be undertaken. Both bolts have a stress range of 20.289MPa which calculates to a damage for a Class 50 feature of 0.001 indicating an acceptable life in excess of 30 years.

7.3.2 Coupler Mounting Joint

The couplers are mounted to the carbody using four off M36 grade 8.8 bolts. Each bolt is torqued to 800Nm in accordance with manufacturing drawing W45105. The forces in each of the bolts were returned from the FEA for all 14 load cases and run through a spread sheet based fatigue calculation which checks whether or not the stress ranges induced in the bolts achieve infinite life. The results of the spread sheet calculation are listed in Table 23 for the first 30 highest stress ranges.

It can be seen that all bolts achieve an infinite life so no further damage summation is required.

8 Conclusions

Throughout the carbody structure, six areas of the carbody framework and two areas of spot welds have been identified to have fatigue lives less than 30 years under the load cases applied. These areas are:

Carbody Framework:

1. All door aperture bottom corners.
2. Cab back wall door apertures bottom corners.
3. Waistrails on both sides forward of cab end passenger doors.
4. Window stiffeners on both sides above cab end bolster.
5. All door aperture top corners.
6. Bodyside columns on both sides above the cab end bolster.

Spot Welds:

1. All door aperture top corners.
2. End of roof stiffeners rear of HVAC well at the cab end.

The vertical inertia load cases (VRT) produce the most damage, followed by the lateral inertia cases (LAT) with the exception of the cab backwall area which suffers most for the lateral load cases. It is also noted that the longitudinal load cases (LNG) result in zero damage. The most damaging passenger loading condition is laden which would be expected based on the fact that the majority of cycles are in the laden condition, see Table 7.

The locations identified to have low fatigue lives are typical of this type of design of carbody. The A-series carbody design suffers from having welds exactly where the geometrical stress concentrations are likely to be. These stress concentrations, combined with weld throat stress factors necessary when assessing fillet welds, yields very low life predictions.

A number of the critical locations are where fillet welds have been used. These welds fall into the lowest weld classification designated by Eurocode 3 of Class 36 for a failure from the throat of the weld. For assessment of failure from the weld throat it is necessary to factor the stresses up by the ratio of adjoining plate thickness to throat thickness so that the stress in the weld throat can be considered. The stresses in these locations are factored up accordingly to account for this. It has been noted, via a preliminary investigation by AECOM, that the weld sizes in two locations investigated appear to be significantly larger than that stated on the drawing. If the weld throat size becomes significantly larger than the plate thickness then failure through the weld throat becomes unlikely and failure from the weld toe becomes more likely. Based on the geometry we have in this rail vehicle, failure from the weld toe falls into a higher category of Class 80. It is recommended that a thorough dimensional investigation using a weld gauge is carried out for the critical welds identified in this report. This may allow the Class 36 welds to be re-categorised as Class 80 welds, which will return a significantly higher fatigue life. Section 9 discusses the effects on fatigue life further.

A fatigue analysis of the critical bolted joints has been undertaken. The results suggest that all bolted joints meet the 30 year life requirement.

The analysis has achieved its goal of identifying the highly stressed areas of the vehicle so as to allow further on-track strain gauge testing to be undertaken to more accurately predict actual fatigue life.

9 Discussions & Recommendations

Considering the vehicles have been in service for 22 years it would suggest that there is a possibility of cracks in the structure at the locations identified in section 7. These six locations require surface inspection to determine if any cracks exist or to the extent of the cracking. It is recommended that surface inspection includes some form of non-destructive testing (NDT) such as dye-penetrant testing to examine for surface breaking cracks.

Why then, given that the vehicles have already served a 22 year life, have the predicted cracks have not been noticed or the train failed catastrophically? There are four possible explanations:

1. The FEA model does not represent the actual vehicle.
2. The loading is too severe, meaning the actual A-series carbody doesn't see the loadings applied.
3. There are cracks present in the vehicle structure and have not propagated and therefore have not been noticed.
4. The fatigue analysis methodology is too conservative.
5. The railcar manufacture is not in accordance with the design drawings.

Taking each item above as a discussion point:

1. FEA Model
 - The FEA model has been checked and is believed to be a true geometrical representation of the drawings/information supplied. It would be evident in the photo imagery that exists if there is significant additional structure on the vehicles that is not represented in the drawings and there appears to be no such evidence. There is some evidence that the welds are larger than stated on the drawing and this may allow some weld re-classifications if it can be confirmed.
 - It is possible that more accurate mass information may affect the predicted fatigue life but it is thought unlikely that a significant affect will be realised by just small redistributions of mass unless:
 - i. The total vehicle mass is incorrect.
 - ii. The mass of the centre grouping of underframe equipment (main transformer and oiler cooler group) is significantly less in reality than has been estimated. This group of items is estimated to weigh 2.8T which is over half the mass of the entire underframe equipment package and is located in the dead centre of the vehicle.
2. Loadings
 - It is possible that the track condition is sufficiently good and is maintained to such levels throughout the vehicle life, such that the inertia loads experienced in reality are much lower than that stated in the European standard [Ref. 8]. This would be borne out by the logic that the European standard needs to cover all track types across many countries and needs to remain design safe. To do this it would be understandable if there were some inherent conservatism built into the figures used.
 - It is possible that the vehicle experiences less patronage than that estimated in the creation of the load case document [Ref. 1]. Considering that in the current analysis we can predict that the vehicle would not be able to spend its entire life just in the tare condition, the effects of passenger density will only have a relatively small effect on life.

3. Cracks

- It is possible that cracks have developed in the areas of concern and have gone un-noticed to date. The stresses identified in the low life areas are, as can be seen in the stress plots, at localised stress concentrations. It is possible for cracks to have developed in the door corners without propagating to a significant extent once the initial stress concentration has been relieved. These cracks may not noticeably affect the overall structural performance of the vehicle. This is all conjecture and cannot be proven without further work, but it could explain the findings.
- If cracks are present it is possible that they are only “hair line” and may not be seen without cleaning up the local area and carrying out non-destructive testing.

4. Fatigue Analysis Methodology

- SN curves contained in Eurocode 3, [Ref. 2], have an inherent amount of conservatism built in to ensure safe design. Part of the SN curve conservatism stems from the fact the standard needs to cover all types of steel. In our case we are using stainless steel which has a high ultimate tensile strength to yield ratio and may therefore be more resistant to crack initiation and propagation.

5. Manufacture not to Design

- There is some evidence that the welds are larger than stated on the drawing as explained in section 8. Only two areas have been studied to date and dimensional checks have yet to be made, but if further investigation confirms this to be the case it would mean that a Class 36 weld could be considered as a Class 80. This, together with the removal of the weld throat stress factor, can make a significant improvement in life predictions as demonstrated in Table 13 which is a rework of the results Table 14.

Fatigue Eurocode 3		Stress [Mpa]			Damage	Damage
		Max	Min	Worst	Class	Class
		Prin	Prin		36	80
LNG 1	Longitudinal Tare	0.1	-6.5	6.5	0.00	0.00
LNG 2	Longitudinal Laden	0.1	-6.9	6.9	0.00	0.00
LNG 3	Longitudinal Fully Laden	0.3	-6.9	6.9	0.00	0.00
LNG 4	Longitudinal Crush Laden	0.3	-6.9	6.9	0.00	0.00
LAT 1	Lateral Tare	34.36	-0.6	34.4	0.22	0.00
LAT 2	Lateral Laden	34.4	-0.7	34.4	3.74	0.00
LAT 3	Lateral Fully Laden	32.0	-0.7	32.0	0.28	0.00
LAT 4	Lateral Crush Laden	30.8	-0.7	30.8	0.03	0.00
VRT 1	Vertical Tare	47.2	-1.6	47.2	0.56	0.01
VRT 2	Vertical Laden	54.6	-1.7	54.6	14.97	0.21
VRT 3	Vertical Fully Laden	74.7	-2.3	74.7	3.57	0.09
VRT 4	Vertical Crush Laden	84.6	-2.4	84.6	0.65	0.02
PAS	Passenger Loading/Unloading	124.4	-2.8	124.4	1.57	0.00
TWS	Track Twist	0.4	-54.2	54.2	1.43	0.02
BLD	Lateral Damper	0.1	0.0	0.1	0.00	0.00
Cumulative damage					27.02	0.35
Years					1.1	86.2

Table 13 - Example Effect of Weld Re-classification

The following actions are recommended to progress the life assessment of the A-series railcars.

1. The proposed work outlined as Phase 2 in the project plan is embodied. This will allow the high stress areas of the carbody identified during this analysis to be strain gauged so that more accurate life predictions based on actual vehicle loadings can be made. The findings of this work will also allow adjustment of the FEA based load cases if the on-track loadings are significantly different to those estimated.
2. The areas of the vehicle where this report has identified a life lower than the 30 year design life should be tested for the presence of cracking by thoroughly cleaning the welds and conducting non-destructive testing (such as dye-penetrant testing). This includes the spot welds.
3. It is recommended that a thorough dimensional investigation using a weld gauge is carried out for the critical welds identified in this report. This should identify if and where the carbody manufacture differs from design and may enable the Class 36 welds to be re-categorised.

References

- [Ref. 1] Fatigue Load Cases Document for the A-series Railcar C3262-001 – Issue D.
- [Ref. 2] Eurocode 3: Design of steel structures- Part 1-9: Fatigue BS EN 1993-1-9:2005
- [Ref. 3] 3EAM 0-0052 “Description of Traction Control System for Perth EMU”
- [Ref. 4] PTA Drawing 60232 issue B & 60234 issue B, “Outline Drawings for Railcars”
- [Ref. 5] PTA A-series Floor Area Diagrams, (included as appendix A of [Ref. 1])
- [Ref. 6] Excel Spreadsheet from AECOM “FEA Mass Inputs as at 270213.xlsx”
- [Ref. 7] Walkers Ltd Drawing: Layout, Misc Under frame Eqst B1-W45104
- [Ref. 8] BS EN 12663, Railway applications. Structural requirements of railway vehicle bodies
- [Ref. 9] BS7608:1993 “Fatigue Design and Assessment of Steel Structures”.
- [Ref. 10] Maddox S J: 'International conference on the performance of dynamically loaded structures'. IIW 50th Annual Assembly Conference 1997

Appendix A – Stress Results

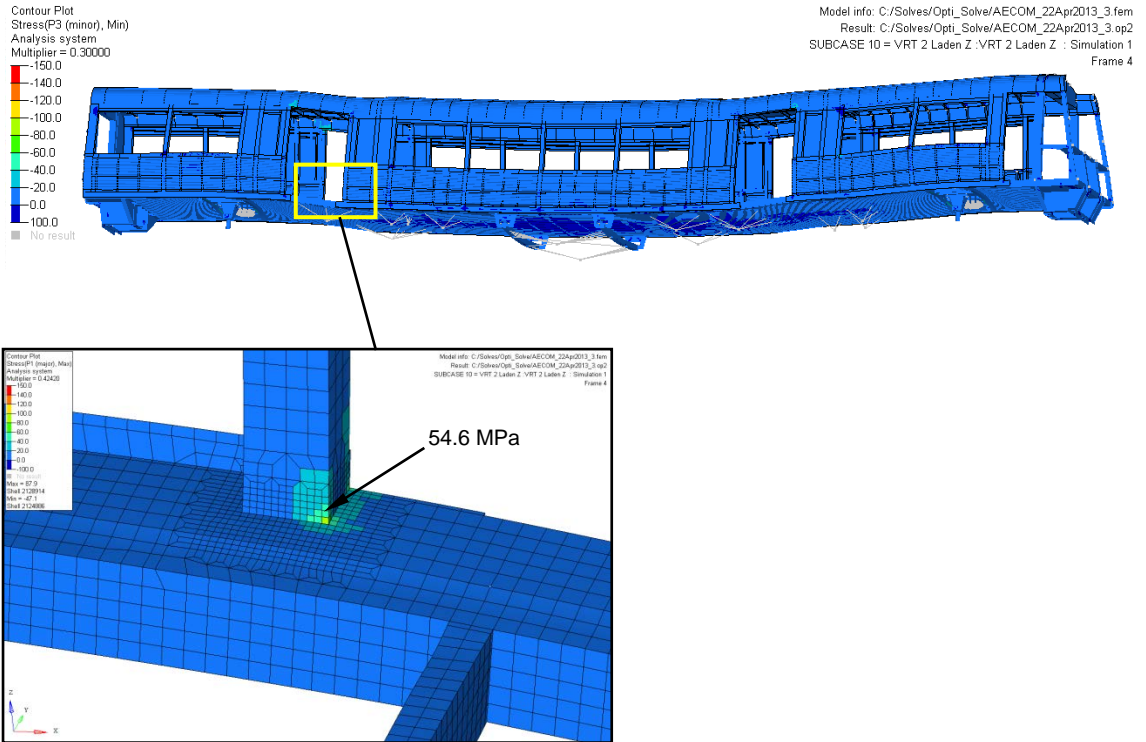
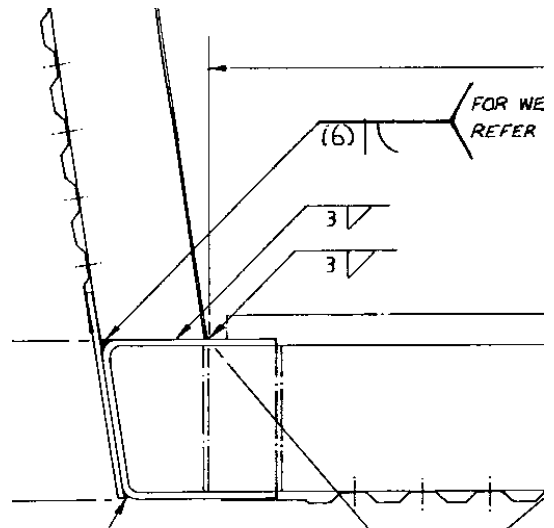


Figure 21 - Bottom Door Corner Stress Plot – VRT 2 Vertical Laden (Max Prin, MPa)

Fatigue Eurocode 3

		Stress [Mpa]			Damage
		Max Prin	Min Prin	Worst	Class
LNG 1	Longitudinal Tare	0.1	-6.5	6.5	0.00
LNG 2	Longitudinal Laden	0.1	-6.9	6.9	0.00
LNG 3	Longitudinal Fully Laden	0.3	-6.9	6.9	0.00
LNG 4	Longitudinal Crush Laden	0.3	-6.9	6.9	0.00
LAT 1	Lateral Tare	34.36	-0.6	34.4	0.22
LAT 2	Lateral Laden	34.4	-0.7	34.4	3.74
LAT 3	Lateral Fully Laden	32.0	-0.7	32.0	0.28
LAT 4	Lateral Crush Laden	30.8	-0.7	30.8	0.03
VRT 1	Vertical Tare	47.2	-1.6	47.2	0.56
VRT 2	Vertical Laden	54.6	-1.7	54.6	14.97
VRT 3	Vertical Fully Laden	74.7	-2.3	74.7	3.57
VRT 4	Vertical Crush Laden	84.6	-2.4	84.6	0.65
PAS	Passenger Loading/Unloading	124.4	-2.8	124.4	1.57
TWS	Track Tw ist	0.4	-54.2	54.2	1.43
BLD	Lateral Damper	0.1	0.0	0.1	0.00
Cumulative damage				27.02	
Years				1.1	



Extract from W45260 Sheet 2/2
 Assembly, DMA Car Body
 showing a 3 mm fillet weld in the high stress location.
 This weld is a Class 36 for failure at the throat
 (Material thickness 3mm
 Weld Throat = $3 \times 1/\sqrt{2} = 2.12\text{mm}$
 Material thickness > Effective throat
 Therefore stress factor required: x1.414)

Table 14 - Bottom Door Corner Fatigue Damage Results

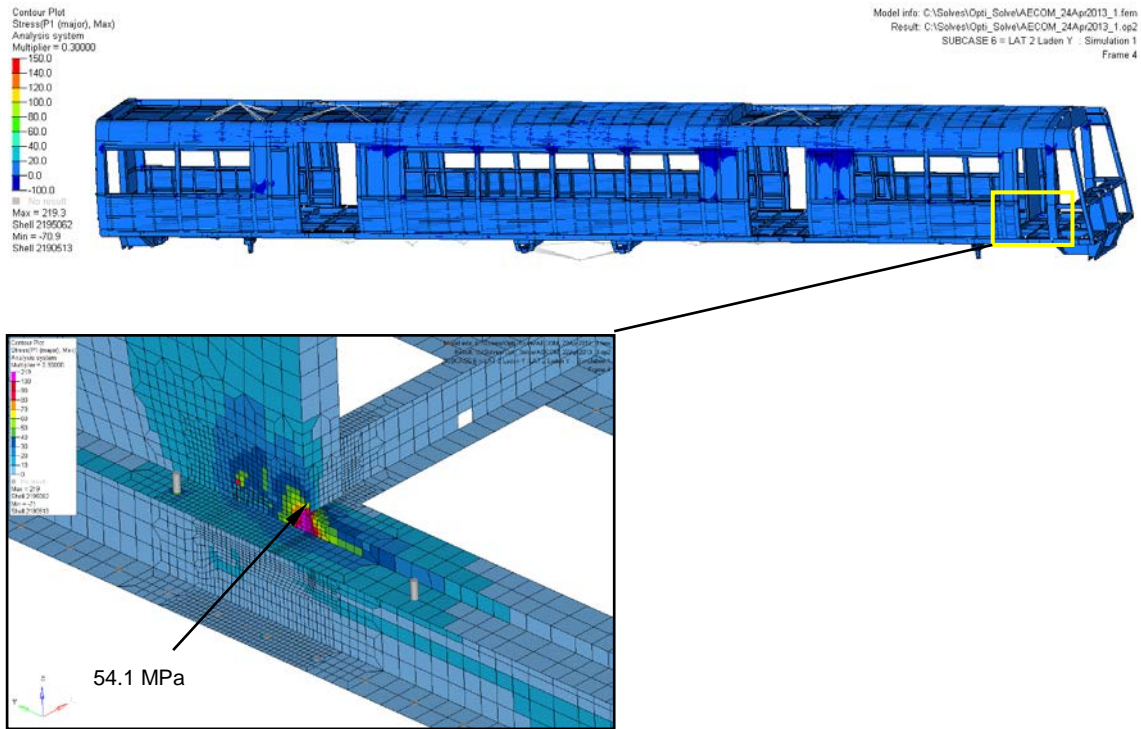
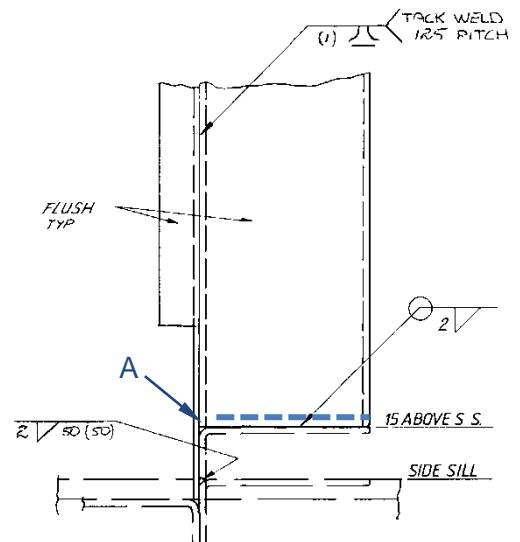


Figure 22 - Cab Back Wall Bottom Stress Plot – LAT 2 Vertical Laden (Max Prin, MPa)

Fatigue Eurocode 3		Stress [Mpa]			Damage
		Max Prin	Min Prin	Worst	Class
LNG 1	Longitudinal Tare	1.2	-0.9	1.2	0.00
LNG 2	Longitudinal Laden	1.4	-0.9	1.4	0.00
LNG 3	Longitudinal Fully Laden	1.1	-0.8	1.1	0.00
LNG 4	Longitudinal Crush Laden	1.0	-0.7	1.0	0.00
LAT 1	Lateral Tare	51.01	-20.6	51.0	0.71
LAT 2	Lateral Laden	54.1	-21.8	54.1	14.55
LAT 3	Lateral Fully Laden	56.2	-22.7	56.2	1.52
LAT 4	Lateral Crush Laden	57.2	-23.2	57.2	0.20
VRT 1	Vertical Tare	2.4	-1.1	2.4	0.00
VRT 2	Vertical Laden	2.5	-1.2	2.5	0.00
VRT 3	Vertical Fully Laden	3.4	-1.8	3.4	0.00
VRT 4	Vertical Crush Laden	3.7	-2.1	3.7	0.00
PAS	Passenger Loading/Unloading	4.5	-3.4	4.5	0.00
TWS	Track Tw ist	38.5	-15.8	38.5	0.51
BLD	Lateral Damper	0.0	0.0	0.0	0.00
Cumulative damage				17.50	
				Years 1.7	



Extract from W45268
 Assembly, Partition Wall, showing a 2mm fillet weld
 This weld is a Class 36 for failure at the throat along the dotted blue line added to the image above. There is a natural weld prep running along the front at point A which gives this area a Class 80 detail for failure through the weld toe. The lowest life was found to be in the Class 36 weld.
 (Material thickness 1.6mm
 Weld Throat = $2 \times 1/\sqrt{2} = 1.414\text{mm}$
 Material thickness > Effective throat
 Therefore stress factor required: x1.132)

Table 15 - Cab Back Wall Bottom Fatigue Damage Results

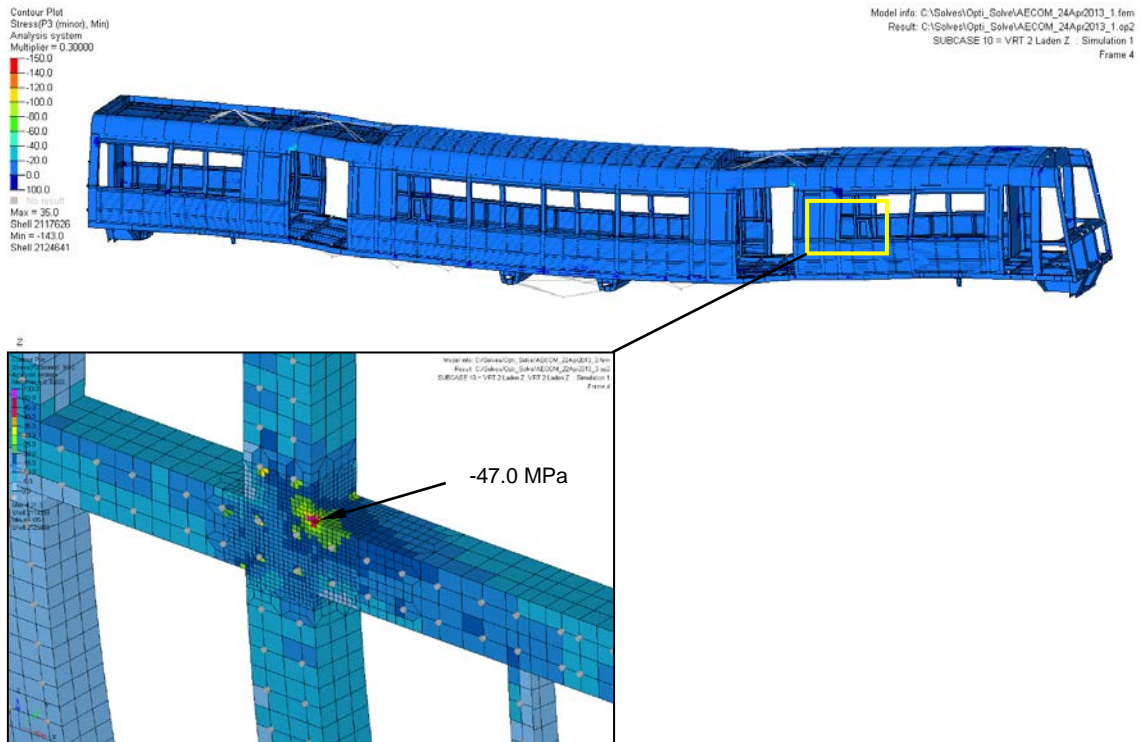
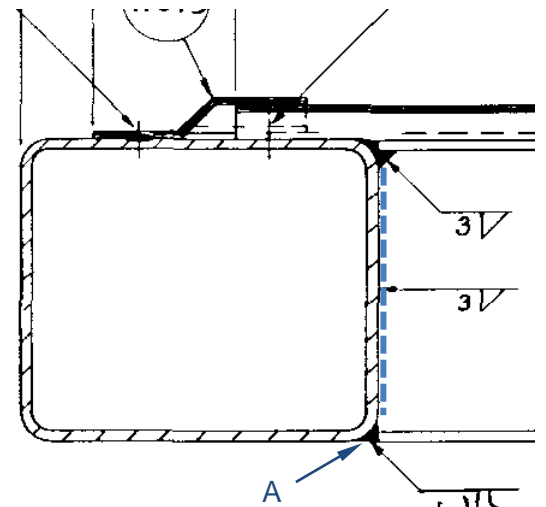


Figure 23 - Waistrail Stress Plot – VRT 2 Vertical Laden (Min Prin, MPa)

Fatigue Eurocode 3

		Stress [Mpa]			Damage
		Max Prin	Min Prin	Worst Prin	Class
LNG 1	Longitudinal Tare	0.8	-8.3	8.3	0.00
LNG 2	Longitudinal Laden	0.8	-8.7	8.7	0.00
LNG 3	Longitudinal Fully Laden	0.9	-9.1	9.1	0.00
LNG 4	Longitudinal Crush Laden	0.9	-9.2	9.2	0.00
LAT 1	Lateral Tare	0.566	-4.0	4.0	0.00
LAT 2	Lateral Laden	0.6	-3.8	3.8	0.00
LAT 3	Lateral Fully Laden	0.6	-4.7	4.7	0.00
LAT 4	Lateral Crush Laden	0.6	-5.3	5.3	0.00
VRT 1	Vertical Tare	4.2	-42.6	42.6	0.42
VRT 2	Vertical Laden	4.9	-47.0	47.0	9.55
VRT 3	Vertical Fully Laden	6.2	-58.3	58.3	1.70
VRT 4	Vertical Crush Laden	7.0	-64.0	64.0	0.28
PAS	Passenger Loading/Unloading	9.4	-71.1	71.1	0.23
TWS	Track Twist	30.2	-3.1	30.2	0.25
BLD	Lateral Damper	0.0	0.0	0.0	0.00
Cumulative damage					12.43
Years					2.4



Extract from W45255
 Assembly, Wall No. 5 showing a 3 mm fillet weld.
 This weld is a Class 36 for failure at the throat along the dotted blue line added to the image above. There is a natural weld prep running along the front at point A which gives this area a Class 80 detail for failure through the weld toe. The lowest life was found to be in the Class 36 weld.
 (Material thickness 4mm
 Weld Throat = $3 \times 1/\sqrt{2} = 2.12\text{mm}$
 Material thickness > Effective throat
 Therefore stress factor required: 1.89)

Table 16 - Waistrail Fatigue Damage Results

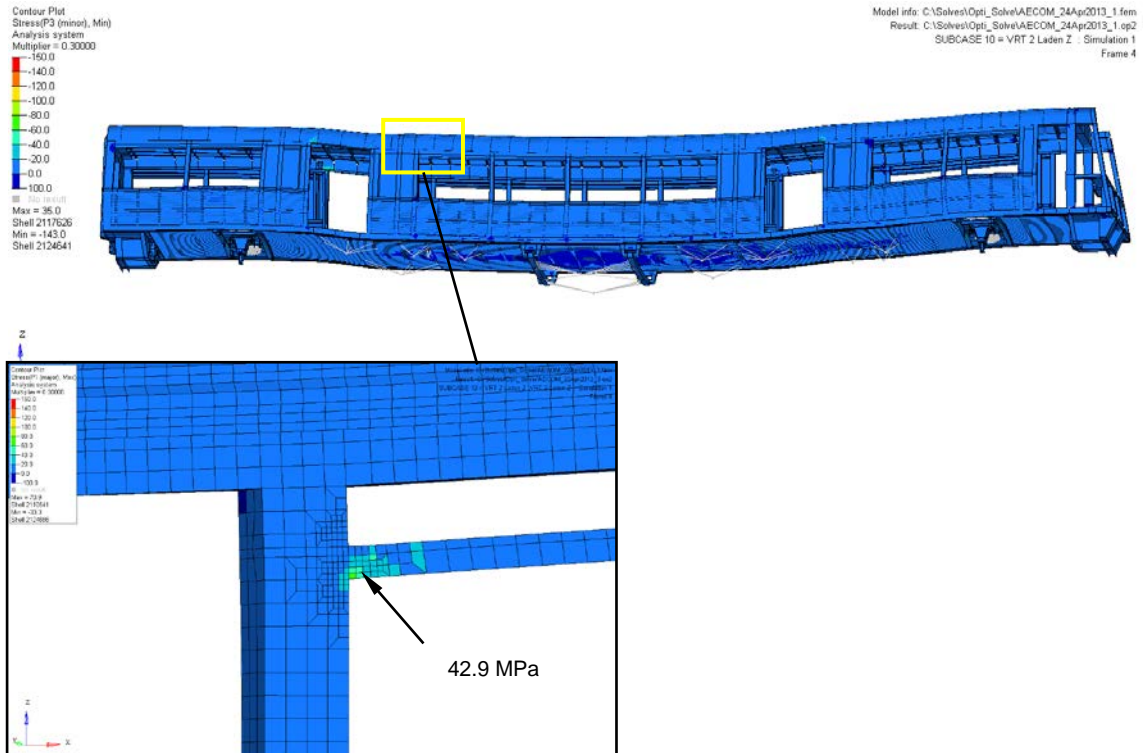
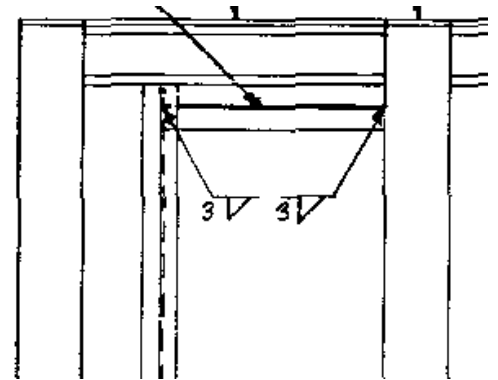


Figure 24 - Window Stiffener Stress Plot – VRT 2 Vertical Laden Max Prin, (MPa)

Fatigue Eurocode 3		Stress [Mpa]			Damage
		Max Prin	Min Prin	Worst Prin	Class
		8.8	-0.2	8.8	0.00
LNG 1	Longitudinal Tare	8.8	-0.2	8.8	0.00
LNG 2	Longitudinal Laden	9.0	-0.3	9.0	0.00
LNG 3	Longitudinal Fully Laden	9.4	-0.3	9.4	0.00
LNG 4	Longitudinal Crush Laden	9.6	-0.3	9.6	0.00
LAT 1	Lateral Tare	0.5	-5.4	5.4	0.00
LAT 2	Lateral Laden	0.5	-5.7	5.7	0.00
LAT 3	Lateral Fully Laden	0.5	-5.5	5.5	0.00
LAT 4	Lateral Crush Laden	0.5	-5.4	5.4	0.00
VRT 1	Vertical Tare	37.6	-1.1	37.6	0.28
VRT 2	Vertical Laden	42.9	-1.2	42.9	7.27
VRT 3	Vertical Fully Laden	54.2	-1.6	54.2	1.36
VRT 4	Vertical Crush Laden	59.8	-1.7	59.8	0.23
PAS	Passenger Loading/Unloading	74.0	-2.0	74.0	0.28
TWS	Track Tw ist	1.0	-31.7	31.7	0.29
BLD	Lateral Damper	0.0	0.0	0.0	0.00
Cumulative damage				9.72	
Years				3.1	



Extract from W45251
 Assembly, Wall No. 1 showing a 3 mm fillet weld.
 This weld is a Class 36 for failure at the throat.
 (Material thickness 1.8mm
 Weld Throat = $3 \times 1/\sqrt{2} = 2.12\text{mm}$
 Material thickness < Effective throat
 Therefore no stress factor required)

Table 17 - Window Stiffener Fatigue Damage Results

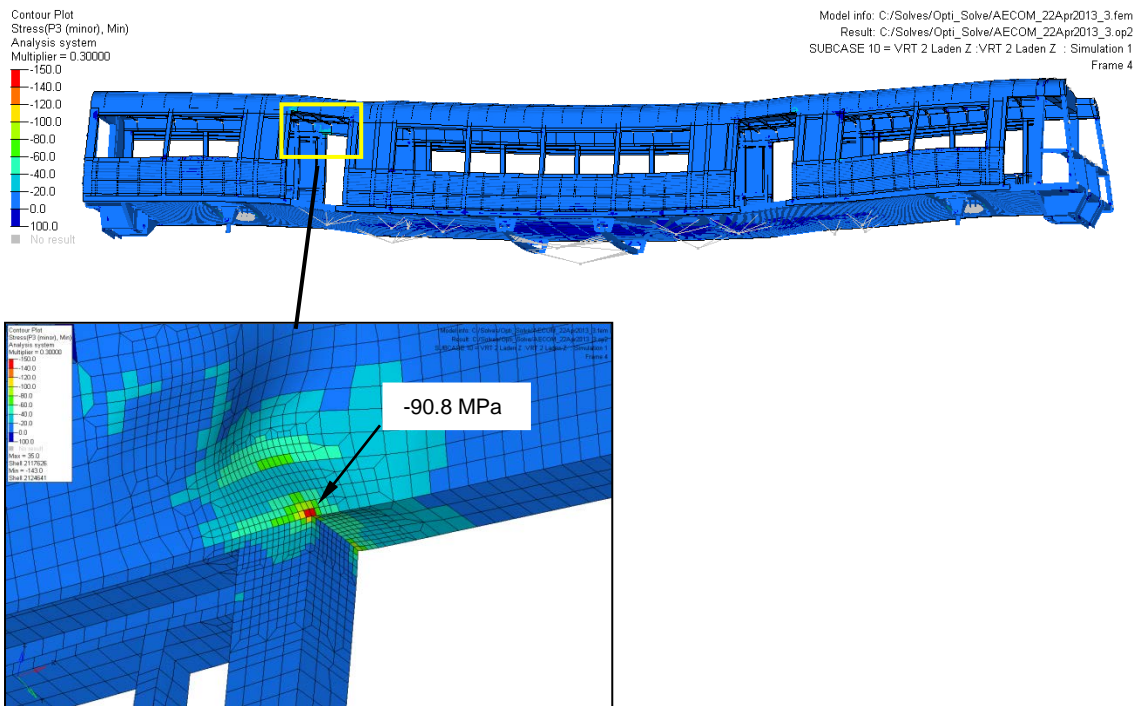
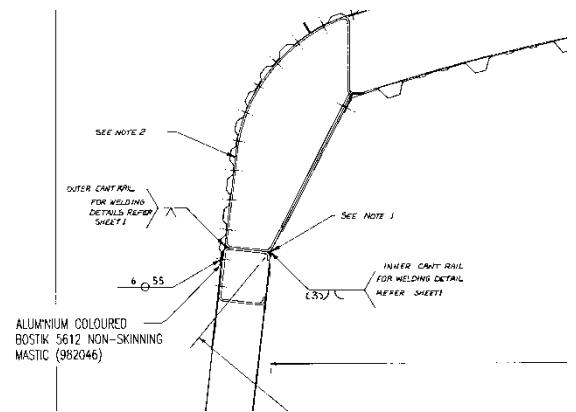


Figure 25 - Top Door Corner Stress Plot – VRT 2 Vertical Laden (Min Prin, MPa)

Fatigue Eurocode 3

		Stress [Mpa]			Damage
		Max	Min	Worst	Class
		Prin	Prin		80
LNG 1	Longitudinal Tare	16.1	-0.7	16.1	0.00
LNG 2	Longitudinal Laden	17.1	-0.7	17.1	0.00
LNG 3	Longitudinal Fully Laden	17.6	-0.7	17.6	0.00
LNG 4	Longitudinal Crush Laden	17.9	-0.7	17.9	0.00
LAT 1	Lateral Tare	12.1	-50.9	50.9	0.05
LAT 2	Lateral Laden	12.5	-52.0	52.0	0.92
LAT 3	Lateral Fully Laden	12.0	-48.4	48.4	0.06
LAT 4	Lateral Crush Laden	11.8	-46.6	46.6	0.01
VRT 1	Vertical Tare	4.5	-79.9	79.9	0.25
VRT 2	Vertical Laden	4.7	-90.8	90.8	6.28
VRT 3	Vertical Fully Laden	6.8	-111.4	111.4	1.08
VRT 4	Vertical Crush Laden	7.9	-121.8	121.8	0.18
PAS	Passenger Loading/Unloading	11.3	-139.7	139.7	0.13
TWS	Track Tw ist	95.7	-11.0	95.7	0.72
BLD	Lateral Damper	0.0	0.0	0.0	0.00
Cumulative damage					9.66
Years					3.1



Extract from W45260 Sheet 2/2
 Assembly, DMA Car Body showing
 3 mm full penetration butt weld
 This weld is a Class 80 for failure at the weld toe.

Table 18 - Top Door Corner Fatigue Damage Results

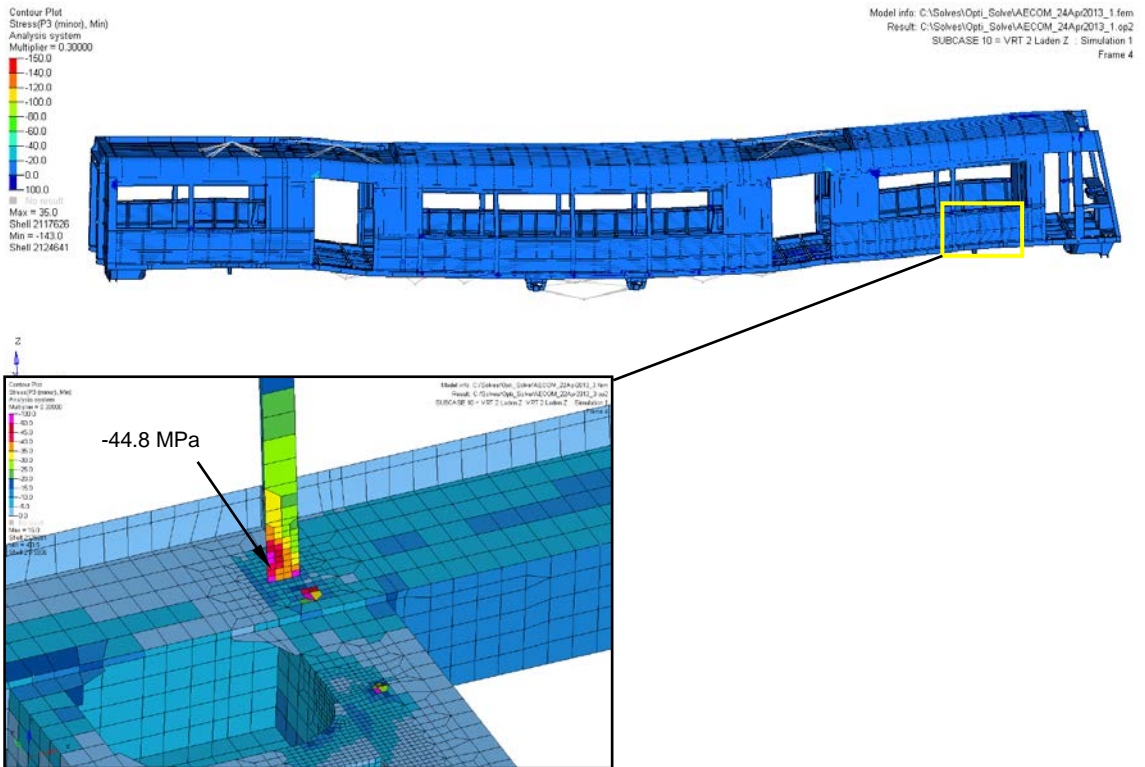
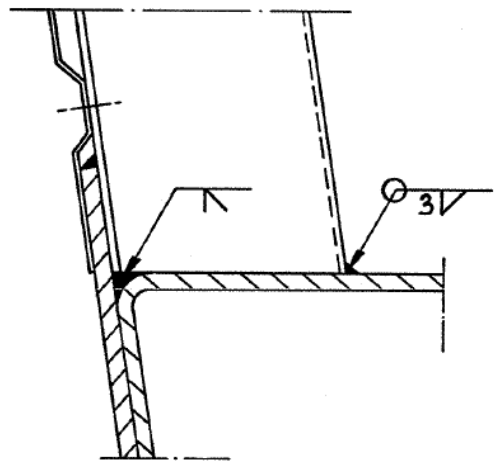


Figure 26 - Bodsides Column Stress Plot – VRT 2 Vertical Laden (Min Prin, MPa)

Fatigue Eurocode 3		Stress [Mpa]			Damage
		Max Prin	Min Prin	Worst	Class
LNG 1	Longitudinal Tare	0.0	-4.7	4.7	0.00
LNG 2	Longitudinal Laden	0.0	-4.3	4.3	0.00
LNG 3	Longitudinal Fully Laden	0.0	-4.5	4.5	0.00
LNG 4	Longitudinal Crush Laden	0.0	-4.7	4.7	0.00
LAT 1	Lateral Tare	0.3	-13.2	13.2	0.00
LAT 2	Lateral Laden	0.3	-12.3	12.3	0.00
LAT 3	Lateral Fully Laden	0.3	-13.5	13.5	0.00
LAT 4	Lateral Crush Laden	0.3	-14.1	14.1	0.00
VRT 1	Vertical Tare	0.3	-38.6	38.6	0.31
VRT 2	Vertical Laden	0.3	-42.7	42.7	7.14
VRT 3	Vertical Fully Laden	0.4	-48.0	48.0	0.95
VRT 4	Vertical Crush Laden	0.4	-50.7	50.7	0.14
PAS	Passenger Loading/Unloading	0.3	-40.6	40.6	0.00
TWS	Track Twist	0.4	-21.1	21.1	0.05
BLD	Lateral Damper	0.1	0.0	0.1	0.00
Cumulative damage				8.60	
				Years	3.5



Extract from W45260 Sheet 1/2
 Assembly, DMA Car Body showing a 3mm fillet weld.
 This weld is a Class 36 for failure at the throat.
 (Material thickness 1.8mm
 Weld Throat = $3 \times 1/\sqrt{2} = 2.12\text{mm}$
 Material thickness < Effective throat
 Therefore no stress factor required)

Table 19 - Bodsides Column Fatigue Damage Results

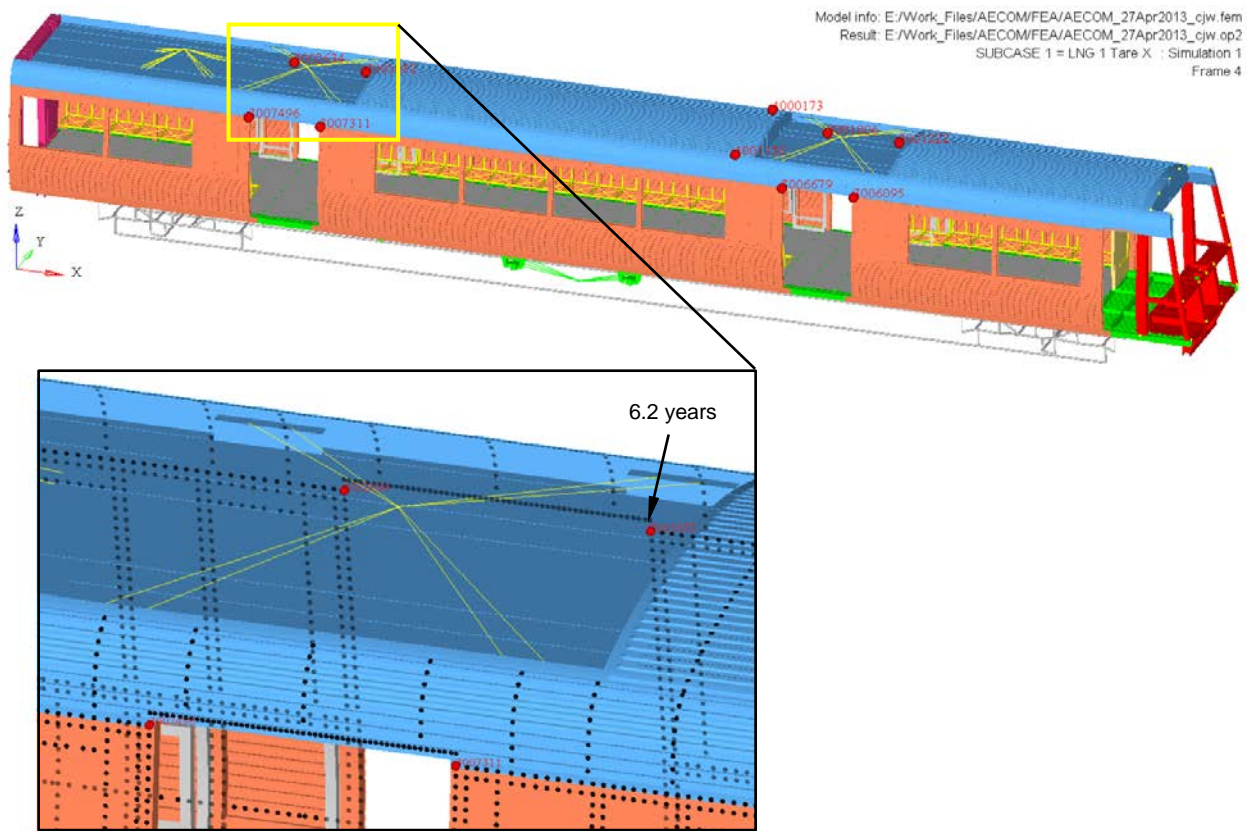


Figure 27 - Life Limiting Spot Weld Location in Door Corners

Fatigue Eurocode 3			Damage
		Local Stress	Class
		[Mpa]	125
LNG 1	Longitudinal Tare	23.3	0.00
LNG 2	Longitudinal Laden	24.5	0.00
LNG 3	Longitudinal Fully Laden	25.1	0.00
LNG 4	Longitudinal Crush Laden	25.5	0.00
LAT 1	Lateral Tare	56.2	0.01
LAT 2	Lateral Laden	57.3	0.16
LAT 3	Lateral Fully Laden	54.8	0.01
LAT 4	Lateral Crush Laden	53.6	0.00
VRT 1	Vertical Tare	100.0	0.13
VRT 2	Vertical Laden	116.4	3.46
VRT 3	Vertical Fully Laden	139.9	0.56
VRT 4	Vertical Crush Laden	151.6	0.09
PAS	Passenger Loading/Unloading	172.1	0.04
TWS	Track Twist	122.8	0.40
BLD	Lateral Damper	0.2	0.00
Cumulative damage			4.86
Years			6.2

Table 20 - Door Corners Spot Weld Damage Results

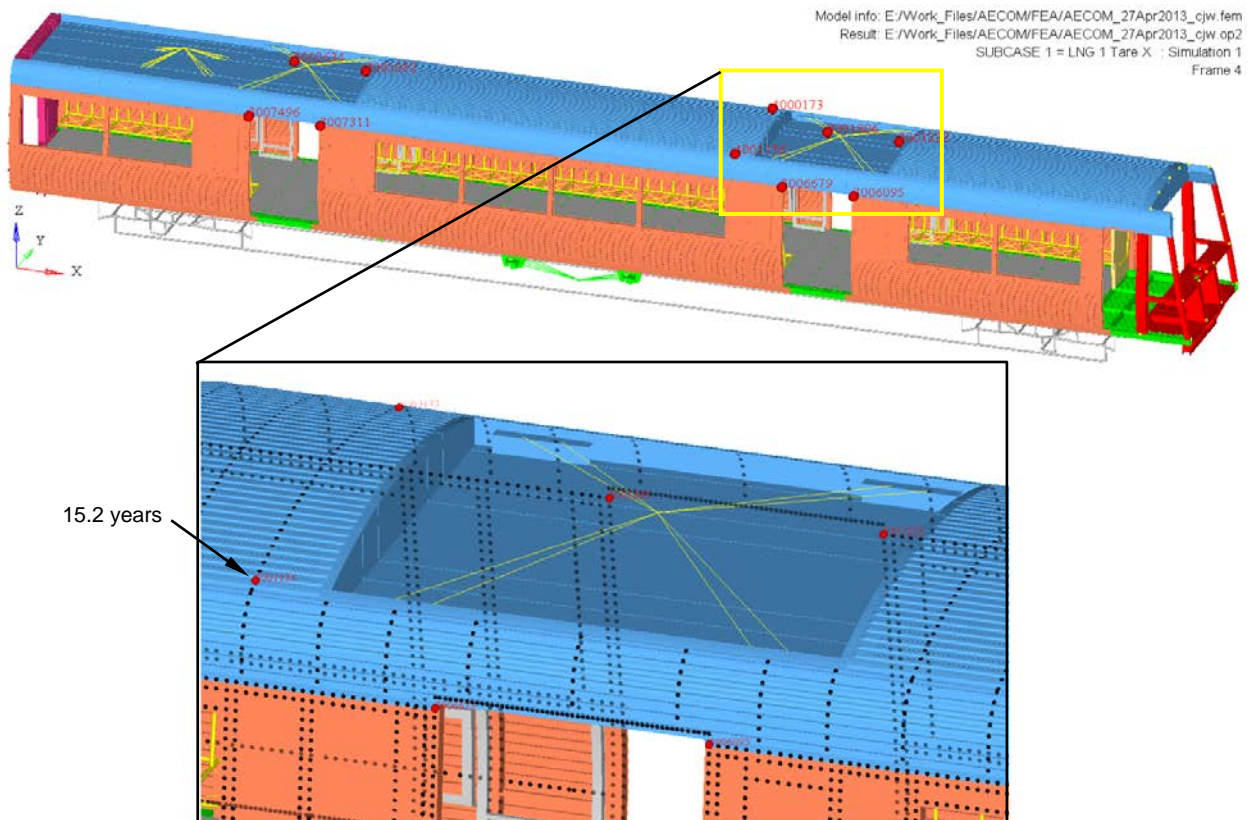


Figure 28 - Life Limiting Spot Weld Location in Roof Stiffeners

		Local Stress	Damage
		[Mpa]	Class
			125
LNG 1	Longitudinal Tare	11.9	0.00
LNG 2	Longitudinal Laden	11.4	0.00
LNG 3	Longitudinal Fully Laden	10.8	0.00
LNG 4	Longitudinal Crush Laden	10.6	0.00
LAT 1	Lateral Tare	10.5	0.00
LAT 2	Lateral Laden	12.2	0.00
LAT 3	Lateral Fully Laden	15.7	0.00
LAT 4	Lateral Crush Laden	17.4	0.00
VRT 1	Vertical Tare	79.5	0.05
VRT 2	Vertical Laden	90.8	1.60
VRT 3	Vertical Fully Laden	110.7	0.28
VRT 4	Vertical Crush Laden	120.6	0.04
PAS	Passenger Loading/Unloading	136.8	0.00
TWS	Track Twist	18.6	0.00
BLD	Lateral Damper	0.0	0.00
Cumulative damage			1.98
		Years	15.2

Table 21 - Roof Stiffeners Spot Weld Damage Results

Bolt Data

Bolt size	M 30
Bolt grade	8.8
Yield stress [MPa]	640
Ultimate stress [MPa]	800
Shear area	560.6
Prestress _{max} [MPa]	459
Prestress _{min} [MPa]	415
Preload _{max} [N]	257250
Preload _{min} [N]	232750

Calculation Factors

Fatigue Class, $\sigma_C(2 \times 10^6)$	50	
Knee Point, $\sigma_D(5 \times 10^6)$	36.85	
Variable Amplitude Cut Off, $\sigma_L(100 \times 10^6)$	20.23	
Joint stiffness (Φ)	0.22	
Torque Tightening Factor (k)	0.2	
Prestress _{max} % of yield stress	72%	
Friction coefficient (μ)	0.15	+/- 10%
Tightening Torque (Nm)	1470	+/- 5%
Size Effect Factor (Ks)	1.000	

Results Summary

	Value	Loadcase	Result
Min RF slip	1.92	LAT4	OK

Equations

Tightening Torque

Preload_{max} = Torque_{max} / k x bolt size

Preload_{min} = Torque_{min} / k x bolt size

Slip Check:

Applied Shear Load < $\mu_{min} \times \{Preload_{min} - (1 - \Phi) \times Axial\ Load\}$

Fatigue Ratio:

If there is no slippage then: Stress Ratio = $\sigma_{range} = (\Phi \times Faxial_{range} / A)$

If there is slippage then joint fails. Slippage under fatigue is not permitted

Load Case	Element No.	Applied Loads [N]				Slip Calculations			Fatigue Calculations	
		Faxial Range (Element X) [N]	Shear 1 Range (Element Y) [N]	Shear 2 Range (Element Z) [N]	Resultant Shear [N]	Allowable shear force [N]	Reserve on slip	Slipage	Stress Range in bolt [MPa]	Infinite Life
LAT4	2071766-A	51700	23600	11200	13061	25977	2.0	No Slip	20.289	NO
LAT4	2071800-A	-51700	-23600	11200	13061	25977	2.0	No Slip	20.289	NO
LAT4	2079734-A	-51100	24600	-11300	13536	26040	1.9	No Slip	20.054	YES
LAT4	2079700-A	51100	-24600	-11300	13536	26040	1.9	No Slip	20.054	YES
LAT3	2079734-A	-47700	23000	-10600	12663	26398	2.1	No Slip	18.720	YES
LAT3	2079700-A	47700	-23000	-10600	12663	26398	2.1	No Slip	18.720	YES
LAT3	2071766-A	47500	21700	10300	12010	26420	2.2	No Slip	18.641	YES
LAT3	2071800-A	-47500	-21700	10300	12010	26420	2.2	No Slip	18.641	YES
LAT4	2071745-A	-46900	21100	10100	11696	26483	2.3	No Slip	18.406	YES
LAT4	2071706-A	46900	-21100	10100	11696	26483	2.3	No Slip	18.406	YES
LAT4	2079649-A	45900	21900	-10100	12058	26588	2.2	No Slip	18.013	YES
LAT4	2079683-A	-45900	-21900	-10100	12058	26588	2.2	No Slip	18.013	YES
LAT3	2071745-A	-43000	19400	9280	10753	26893	2.5	No Slip	16.875	YES
LAT3	2071706-A	43000	-19400	9280	10753	26893	2.5	No Slip	16.875	YES
LAT3	2079683-A	-42900	-20400	-9440	11239	26904	2.4	No Slip	16.836	YES
LAT3	2079649-A	42900	20400	-9430	11237	26904	2.4	No Slip	16.836	YES
LAT2	2079734-A	-41100	19900	-9110	10943	27093	2.5	No Slip	16.130	YES
LAT2	2079700-A	41100	-19900	-9110	10943	27093	2.5	No Slip	16.130	YES
LAT2	2071766-A	39200	18000	8470	9947	27293	2.7	No Slip	15.384	YES
LAT2	2071800-A	-39200	-18000	8470	9947	27293	2.7	No Slip	15.384	YES
LAT1	2079734-A	-36900	17800	-8190	9797	27536	2.8	No Slip	14.481	YES
LAT1	2079700-A	36900	-17800	-8180	9795	27536	2.8	No Slip	14.481	YES
LAT2	2079649-A	36700	17500	-8070	9636	27557	2.9	No Slip	14.403	YES
LAT2	2079683-A	-36700	-17500	-8070	9636	27557	2.9	No Slip	14.403	YES
LAT2	2071706-A	35200	-15800	7590	8764	27715	3.2	No Slip	13.814	YES
LAT2	2071745-A	-35200	15800	7580	8762	27715	3.2	No Slip	13.814	YES
LAT1	2071766-A	34200	15700	7380	8674	27820	3.2	No Slip	13.422	YES
LAT1	2071800-A	-34200	-15700	7380	8674	27820	3.2	No Slip	13.422	YES
LAT1	2079649-A	32900	15600	-7230	8597	27957	3.3	No Slip	12.911	YES
LAT1	2079683-A	-32900	-15600	-7230	8597	27957	3.3	No Slip	12.911	YES

Table 22 - Summary of all Results for M30 Bolts

Bolt Data

Bolt size	M 36
Bolt grade	8.8
Yield stress [MPa]	640
Ultimate stress [MPa]	800
Shear area	816.7
Prestress _{max} [MPa]	143
Prestress _{min} [MPa]	129
Preload _{max} [N]	116667
Preload _{min} [N]	105556

Calculation Factors

Fatigue Class, $\sigma_C(2 \times 10^6)$	50
Knee Point, $\sigma_D(5 \times 10^6)$	36.85
Variable Amplitude Cut Off, $\sigma_L(100 \times 10^6)$	20.23
Joint stiffness (Φ)	0.22
Torque Tightening Factor (k)	0.2
Prestress _{max} % of yield stress	22%
Friction coefficient (μ)	0.15 +/- 10%
Tightening Torque (Nm)	800 +/- 5%
Size Effect Factor (Ks)	0.955

Results Summary

	Value	Loadcase	Result
Min RF slip	380.53	LAT1	OK

Equations

Tightening Torque

Preload_{max} = Torque_{max} / k x bolt size

Preload_{min} = Torque_{min} / k x bolt size

Slip Check:

Applied Shear Load < μ_{min} x (Preload_{min} - (1 - Φ) x Axial Load)

Fatigue Ratio:

If there is no slippage then: Stress Ratio = $\sigma_{range} = (\Phi \times Faxial_{range} / A)$

If there is slippage then joint fails. Slippage under fatigue is not permitted

Load Case	Element No.	Applied Loads [N]				Slip Calculations			Fatigue Calculations	
		Faxial Range (Element x) [N]	Shear 1 Range (Element Y) [N]	Shear 2 Range (Element Z) [N]	Resultant Shear [N]	Allowable shear force [N]	Reserve on slip	Slipage	Stress Range in bolt [MPa]	Infinite Life
LNG4	4001951-A	33801	0	0	0	10691	>9999	No Slip	8.699	YES
LNG4	4001952-A	33801	0	0	0	10691	>9999	No Slip	8.699	YES
LNG4	4001953-A	33528	0	0	0	10720	>9999	No Slip	8.629	YES
LNG4	4001954-A	33528	0	0	0	10720	>9999	No Slip	8.629	YES
LNG3	4001951-A	31347	0	0	0	10949	>9999	No Slip	8.068	YES
LNG3	4001952-A	31347	0	0	0	10949	>9999	No Slip	8.068	YES
LNG3	4001953-A	31095	0	0	0	10976	>9999	No Slip	8.003	YES
LNG3	4001954-A	31095	0	0	0	10976	>9999	No Slip	8.003	YES
LNG2	4001951-A	26442	0	0	0	11466	>9999	No Slip	6.805	YES
LNG2	4001952-A	26441	0	0	0	11466	>9999	No Slip	6.805	YES
LNG2	4001954-A	26229	0	0	0	11488	>9999	No Slip	6.750	YES
LNG2	4001953-A	26228	0	0	0	11488	>9999	No Slip	6.750	YES
LNG1	4001951-A	23417	0	0	0	11784	>9999	No Slip	6.027	YES
LNG1	4001952-A	23416	0	0	0	11784	>9999	No Slip	6.026	YES
LNG1	4001954-A	23228	0	0	0	11804	>9999	No Slip	5.978	YES
LNG1	4001953-A	23227	0	0	0	11804	>9999	No Slip	5.978	YES
VRT1	4001953-A	152	0	75	37	14234	381.0	No Slip	0.039	YES
VRT2	4001953-A	152	0	75	37	14234	381.0	No Slip	0.039	YES
VRT3	4001953-A	152	0	75	37	14234	381.0	No Slip	0.039	YES
VRT4	4001953-A	152	0	75	37	14234	381.0	No Slip	0.039	YES
VRT1	4001954-A	151	0	75	37	14234	381.0	No Slip	0.039	YES
VRT2	4001954-A	151	0	75	37	14234	381.0	No Slip	0.039	YES
VRT3	4001954-A	151	0	75	37	14234	381.0	No Slip	0.039	YES
VRT4	4001954-A	151	0	75	37	14234	381.0	No Slip	0.039	YES
LAT1	4001952-A	111	75	0	37	14238	380.5	No Slip	0.029	YES
LAT2	4001952-A	111	75	0	37	14238	380.5	No Slip	0.029	YES
LAT3	4001952-A	111	75	0	37	14238	380.5	No Slip	0.029	YES
LAT4	4001952-A	111	75	0	37	14238	380.5	No Slip	0.029	YES
LAT1	4001954-A	110	75	0	37	14238	381.6	No Slip	0.028	YES
LAT2	4001954-A	110	75	0	37	14238	381.6	No Slip	0.028	YES

Table 23 - Summary of all Results for M36 Bolts

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Appendix I

QR Corrosion Report

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ROLLINGSTOCK ASSETS

ABN: 47564947264

Report

INSPECTION OF EMU UNDERFRAME FOR CORROSION

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1.0 Introduction

A concern was raised about the condition of the mild steel sections of the underframe on the EMU fleet after the issue of corrosion was identified in the headstock of the series 1 double deck intercity cars built by Comeng that operated in Sydney. An investigation was commenced to identify the specific regions where mild steel was located on the EMU fleet. There were 3 main regions identified as regions of interest, these were; side sills, bolster and headstock. With the headstock and bolster primarily made up of mild steel whilst only small areas were found in the side sills.

The investigation found that the EMU units 13 onwards had the largest quantity of mild steel. A search was conducted on the older units (EMU 13 – EMU 24) on SAP and found 4 units that had a water leak problem Units 12,19,22,23. The next unit of these to have work done at Redbank was Unit 23. So it was decided that this would be the unit to be investigated. The outcomes from these investigations should help give an indication on whether the EMU fleet are to be decommissioned or are to be overhauled again.

2.0 Testing

Due to time constraints the whole underframe under the plywood flooring could not be tested, therefore testing of the unit was focused at the B end of the M car. The reasoning behind this decision was that water leaks from the pantograph are a common occurrence and subsequent water from these leaks ends up in this region. Therefore it was assumed that if corrosion was to be found, it would be highly likely to find corrosion at the B end. Holes were drilled at other region in the plywood flooring so that a full overview could be assembled of the M car.

Measuring the thickness of the headstock and bolster was conducted with an ultrasonic thickness tester underneath the carriage and where the floor was removed inside the carriage. The side sills were ultrasonic tested where the floor had been raised. Where the holes were drilled in the plywood floor of the carriage an endoscope was used to inspect for corrosion. The endoscope would not give a quantitative result it would still give an indication of the amount of corrosion present.

Due to the complexity of reaching the bogie side parts of the bolster, readings were taken from EMU 71 under refurbishment at Redbank. This also gave the opportunity to take some extra headstock readings to obtain a larger data sample. Extra data was also obtained of the floor and side sill through EMU 14 when it was removed from service with water leaks inside the carriage.

3.0 Results

The thickness measurements of the under carriage of the headstock on EMU 23 are shown in table 1 & 2.

Table 1: Headstock A of EMU 23

Headstock A End EMU 23				
Part No.	LHS Thickness	Actual Thickness	RHS Thickness	Actual Thickness
1906	8	8	8	8
1907	8	8	8	8
1915	6	6	6	6
1917	8	8	8	8
1919	6	6	6	6
1924	6	6	6	6
1925	4	4	4	4

Table 2: Headstock B End EMU 23

Headstock B End EMU 23				
Part No.	LHS Thickness	Actual Thickness	RHS Thickness	Actual Thickness
1906	8	8	8	8
1907	8	8	8	8
1915	6	6	6	6
1917	8	8	8	8
1919	6	6	6	6
1924	6	6	6	6
1925	4	4	4	4

Table 3 shows the actual and specified thicknesses of the square headstock region on EMU 71

Table 3: Square Headstock of DM car EMU 71

Square Headstock DM car 71 [*]		
Item No.	Specified Thickness	Actual Thickness
1907	8mm	8mm
1915	6mm	6mm
1917	8mm	9mm
1924	6mm	6mm
1925	4mm	4mm

* Note both sides were analysed and found to be the same

The thickness measurements of the undercarriage of the bolster on EMU 71 are shown below in table 4.

Table 4: Square Bolster Region DM EMU 71

Bolster Region DM car EMU 71*		
Item No.	Specified Thickness	Actual Thickness
1603	6mm	6mm
1604	6mm	6mm
1613	8mm	8mm
1614	4mm	4mm
1645	4mm	4mm
1646	4mm	4mm
1647	4mm	4mm
1648	4mm	4mm
1649	4mm	4mm
1650	4mm	4mm
1651	4mm	4mm
1654	4mm	4mm
1655	4mm	4mm
1656	6mm	6mm
1657	6mm	6mm
1658	4mm	4mm
1740	6mm	6mm
1742	6mm	6mm

The reason EMU 71 was inspected was because it had had its entire bogie components removed which made all the bolster parts easily accessible.

During the inspection of EMU 23 some corrosion was found on the headstock floor of the carriage.



Figure 1a: Headstock Floor on EMU 23 showing corroded areas



Figure 1b: A piece of rust that was taken from the headstock floor. (Note beam underneath is 100mm wide)

3 areas were measured in the headstock region where this rust was found to be at its worst.



Figure 2: Area of corrosion on the headstock floor on EMU 23



Figure 3: Area of corrosion on the headstock floor on EMU 23



Figure 4: Area of corrosion on the headstock floor on EMU 23

The thicknesses of the metal for each of these images are:

Table 5 Thickness of rusted areas on EMU 23

	Drawing Thickness	Actual Thickness
Figure 2	8	6.1
Figure 3	8	6.7
Figure 4	8	6.1

There was corrosion found on the backing bar located between the side sill and the head stock on EMU 23.

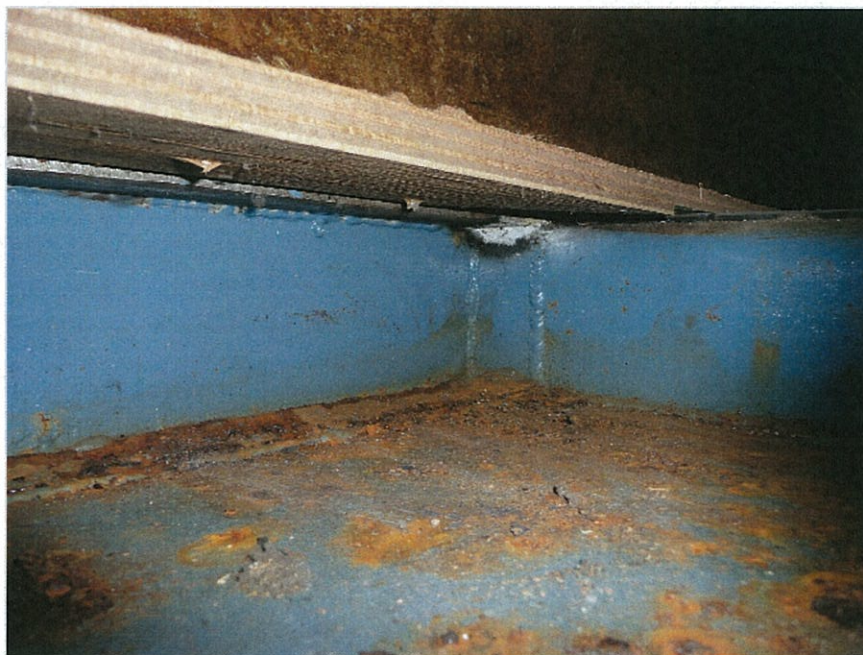


Figure 5: Shows the rusted backing plate



Figure 6: A piece of rust taken from the backing plate

An inspection was undertaken on the headstock floor on EMU 14

Table 6: Undercarriage headstock thickness on EMU 14 1B End				
Part No.	LHS Thickness	Actual Thickness	RHS Thickness	Actual Thickness
1531	10	10	10	10
1901	8	8	8	8
1905	6	6	6	6
1907	8	8.5	8	8
1909	4	4	4	4



Figure 7: Image of the headstock floor on EMU 14

4.0 Discussion

The results show that the structural areas of the undercarriage of the car that the metal integrity is excellent. None of the readings on either of the side sills, head stocks or bolsters show signs of corrosion. The floor did show signs of corrosion, particularly in the floor of the headstock and the backing bar which joins the floor to the side sill. However, none of these areas are of a structural importance and can be cut out and replace. The thickness of the corroded parts of the floor showed a loss of nearly $\frac{1}{4}$ of its original thickness (up to 1.9mm). The loss in backing bar could not be record due to the uneven surface of the rust, but as shown in figure 6 it is quite substantial. The corrosion of the backing bar is probably caused by a mixture between being water logged and being at the joint of the stainless steel sill and the mild steel floor. The dissimilar metals of the mild steel and stainless steel could have assisted in the corrosion mild steel. This is depicted in the diagram below (figure 8). It should be noted that the corrosion found on the backing bar is surface rust and posed no risk to the welded joint underneath which joins the side sill to the floor.

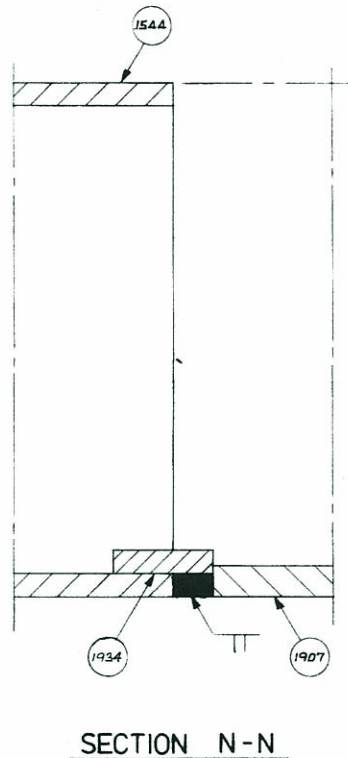


Figure 8

The backing bar is item 1934, the sill is 1544 and the floor is 1907

Drilling of holes in the plywood flooring on EMU 23 found many of the sections filled with insulation preventing the inspection of the side sill and floor regions as it was extremely difficult to move the insulation through a small hole. The drilling did however find 1 section without insulation which was in the bolster floor compartment. The section had a pool of water. The water looked like it had recently seeped in as there was very little corrosion in this section, the water was to be sucked out and dried as best possible.

Whilst the study was being conducted, EMU 14 was found to have a large amount of water on the floor of the headstock region causing it to run out from underneath the plywood floor and out the side sills. It visually appeared that there was little corrosion of the steel sections of the floor, with the dark sections from the picture taken (figure 7) being mostly made up of tar used to stop corrosion. Testing of the floor of EMU 14 showed no evidence of corrosion with all sections tested

being at least that of the specified drawing with some measurement slightly exceeding the recommended thickness; this is because paint was not removed for thickness testing.

5.0 Recommendations

From the sampling taken from the units in this study, there appears to be little problem with corrosion as a whole, with no evidence showing corrosion in any of the structural members. Therefore it is recommended that:

- The current maintenance undertaken at overhauls on the undercarriage is maintained, painting of headstocks, bolsters and side sills and tarring of the undercarriage floors.
- The life of the underframe can be extended past the next overhaul, although a larger study of all the EMU fleet should be conducted in the future to ensure all vehicles are of a track worthy nature.
- Investigate ways that the water can be relieved from the floor compartments, as this will help prevent corrosion into the future
- Cut out rusted parts of the floor and replace as the they are found

6.0 Referenced Drawings

B1 – EMU 154/3
B1 – EMU 155/3
B1 – EMU 157
B1 – EMU 158
B1 – EMU 161/2
B1 – EMU 181/3
B1 – EMU 191/3

Appendix J

Risk Assessment

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Project Name		PTA A Series EMU Railcar Review - Strategic Risk Register																						
Project Number		60283889																						
Hazard Reference Number	Category	Description of Risk	Option	Causes	Impacts	Safety	PTA Transport Services	Operational	Economic	Environmental	Patronage	Reputation/Political	Compliance	Risk Assessment		Proposed Additional Risk Control	Actionee	Due Date	Risk Assessment		Comments			
														Likelihood	Consequence				Likelihood	Consequence				
1	1	Schedule of maintenance contract	1 - Straight replacement at end of life	Non-synchronisation of maintenance contract term and remaining design life of A-series	Expense of early termination or extension of maintenance contract, reliability risk if taking maintenance in-house	Y	Y	Y						Rare	Major	4	Synchronisation of first phase of maintenance contract and decommissioning of fleet			Rare	Moderate	3		
2	2	Schedule of maintenance contract	2 - Life with existing technology and/or minor enhancement of the railcar	Non-synchronisation of maintenance contract term and remaining design life of A-series	Expense of early termination or extension of maintenance contract, reliability risk if taking maintenance in-house	Y	Y	Y						Unlikely	Major	8	Synchronisation of second phase of maintenance contract and decommissioning of fleet (Option 2a)			Rare	Moderate	3		
3	3	Schedule of maintenance contract	3 - Re-engineering life	Non-synchronisation of maintenance contract term and remaining design life of A-series	N/A	Y	Y									0						0		
4	1	Removal of maintenance contractor	1 - Straight replacement at end of life	Maintenance contractor failing to achieve terms of contract or insolvency of supplier occurs	Sourcing replacement maintenance contractor problematic and costly, Low reliability during learning curve for new maintenance provider or if taking maintenance in-house	Y	Y				Y	Y		Unlikely	Moderate	6	Collaborative working and knowledge sharing initiatives			Rare	Moderate	3		
5	2	Removal of maintenance contractor	2 - Life with existing technology and/or minor enhancement of the railcar	Maintenance contractor failing to achieve terms of contract or insolvency of supplier occurs	Sourcing replacement maintenance contractor problematic and costly, Low reliability during learning curve for new maintenance provider or if taking maintenance in-house	Y	Y				Y	Y		Unlikely	Moderate	6	Collaborative working and knowledge sharing initiatives			Rare	Moderate	3		
6	3	Removal of maintenance contractor	3 - Re-engineering life	Maintenance contractor failing to achieve terms of contract or insolvency of supplier occurs	Sourcing replacement maintenance contractor problematic and costly, Low reliability during learning curve for new maintenance provider or if taking maintenance in-house	Y	Y				Y	Y		Possible	Moderate	9	Collaborative working and knowledge sharing initiatives			Unlikely	Moderate	6		
7	1	Increased maintenance costs	1 - Straight replacement at end of life	Maintenance contractor not achieving desired targets, Units experienced more wear than expected	on-time running performance decreases, people perceive the system as unreliable				Y					Rare	Moderate	3				Rare	Moderate	3		
8	2	Increased maintenance costs	2 - Life with existing technology and/or minor enhancement of the railcar	Maintenance contractor not achieving desired targets, Units experienced more wear than expected	on-time running performance decreases, people perceive the system as unreliable				Y					Possible	Major	12	Continuation with existing maintenance contract or novate the contract of new rolling stock supplier			Unlikely	Major	8		
9	3	Increased maintenance costs	3 - Re-engineering life	Maintenance contractor not achieving desired targets, Units experienced more wear than expected	on-time running performance decreases, people perceive the system as unreliable				Y					Almost certain	Catastrophe	25	Extend the re-engineering programme, budget for future escalation			Possible	Major	12	Replace A-series with new rolling stock	
10	1	Terms and conditions of maintenance contract require adjustment	1 - Straight replacement at end of life	Modifications to train require amendments affecting scope of maintenance deliverables	Financial impact of less favourable terms of maintenance contract				Y				Y	Rare	Insignificant	1	Avoid modifying train such that maintenance contract is affected			Rare	Insignificant	1		
11	2	Terms and conditions of maintenance contract require adjustment	2 - Life with existing technology and/or minor enhancement of the railcar	Modifications to train require amendments affecting scope of maintenance deliverables	Financial impact of less favourable terms of maintenance contract				Y				Y	Possible	Moderate	9	Train enhancements are aesthetic rather than functional and will not require additional maintenance, novate the maintenance contract lease to the supplier of new trains			Unlikely	Moderate	6		
12	3	Terms and conditions of maintenance contract require adjustment	3 - Re-engineering life	Modifications to train require amendments affecting scope of maintenance deliverables	Financial impact of less favourable terms of maintenance contract				Y				Y	Possible	Major	12	Novate the maintenance contract lease to the supplier of new trains			Possible	Major	12		
13	1	Obsolescence	1 - Straight replacement at end of life	Materials and spares supply are not supportable in longer terms due to outdated technology	Reliability and availability drops due to lack of components to support maintenance. Lack of planning to replace obsolete components leads to financial impact of re-design and replacement at short notice			Y	Y					Possible	Moderate	9	Obsolescence planning with maintenance contractor, OEM support incorporated in overhauls and materials support programmes			Unlikely	Minor	4		
14	2	Obsolescence	2 - Life with existing technology and/or minor enhancement of the railcar	Materials and spares supply are not supportable in longer terms due to outdated technology	Reliability and availability drops due to lack of components to support maintenance. Lack of planning to replace obsolete components leads to financial impact of re-design and replacement at short notice			Y	Y					Likely	Moderate	12	Obsolescence planning with maintenance contractor, OEM support incorporated in overhauls and materials support programmes			Possible	Moderate	9		
15	3	Obsolescence	3 - Re-engineering life	Materials and spares supply are not supportable in longer terms due to outdated technology	Reliability and availability drops due to lack of components to support maintenance. Lack of planning to replace obsolete components leads to financial impact of re-design and replacement at short notice			Y	Y					Almost certain	Major	20	Expand scope of re-engineering works			Possible	Major	12	Replace A-series with new rolling stock	
16	1	Bogie fatigue	1 - Straight replacement at end of life	Cracks in bogie appear resulting from long term use	Safety risk associated with derailment potential, financial impact due to increased maintenance and rectification works	Y	Y	Y	Y		Y	Y		Rare	Catastrophe	5	Conduct FEA fatigue life study, undertake regular asset inspections, conduct NDT and ultrasonic testing of frames, identification of issues prior to failure			Rare	Major	4		
17	2	Bogie fatigue	2 - Life with existing technology and/or minor enhancement of the railcar	Cracks in bogie appear resulting from long term use	Safety risk associated with derailment potential, financial impact due to increased maintenance and rectification works	Y	Y	Y	Y		Y	Y		Unlikely	Catastrophe	10	Conduct FEA fatigue life study, undertake regular asset inspections, conduct NDT and ultrasonic testing of frames, identification of issues prior to failure			Unlikely	Major	8		
18	3	Bogie fatigue	3 - Re-engineering life	Cracks in bogie appear resulting from long term use	Safety risk associated with derailment potential, financial impact due to increased maintenance and rectification works	Y	Y	Y	Y		Y	Y		Possible	Catastrophe	15	Conduct FEA fatigue life study, undertake regular asset inspections, conduct NDT and ultrasonic testing of frames, regular inspection regimes			Possible	Major	12		
19	1	Degrading reliability of systems	1 - Straight replacement at end of life	Ageing systems experiencing extensive mechanical wear leading to component failures	Train fails frequently and availability is limited	Y			Y			Y		Possible	Minor	6	Conduct RCM analysis, avoid deferring maintenance and overhauls			Unlikely	Minor	4		
20	2	Degrading reliability of systems	2 - Life with existing technology and/or minor enhancement of the railcar	Ageing systems experiencing extensive mechanical wear leading to component failures	Train fails frequently and availability is limited	Y			Y			Y		Likely	Moderate	12	Conduct RCM analysis, avoid deferring maintenance and overhauls, replace worn components ad-hoc			Possible	Moderate	9		
21	3	Degrading reliability of systems	3 - Re-engineering life	Ageing systems experiencing extensive mechanical wear leading to component failures	Train fails frequently and availability is limited	Y			Y			Y		Unlikely	Major	8	Conduct RCM analysis, avoid deferring maintenance and overhauls, plan for worn component replacement and build into re-engineering scheme			Unlikely	Major	8		
22	1	Underframe equipment housing requires replacement	1 - Straight replacement at end of life	Extensive corrosion to the underframe equipment housing not maintainable	Safety risk of underframe component collapse, financial impact with equipment box replacement	Y		Y	Y					Possible	Major	12	Conduct patch repairs as necessary, inspect secondary retention			Unlikely	Major	8		
23	2	Underframe equipment housing requires replacement	2 - Life with existing technology and/or minor enhancement of the railcar	Extensive corrosion to the underframe equipment housing not maintainable	Safety risk of underframe component collapse, financial impact with equipment box replacement	Y		Y	Y					Unlikely	Major	8	Renovate underframe boxes as necessary, install secondary retention on all boxes			Rare	Major	4		
24	3	Underframe equipment housing requires replacement	3 - Re-engineering life	Extensive corrosion to the underframe equipment housing not maintainable	Safety risk of underframe component collapse, financial impact with equipment box replacement	Y		Y	Y					Unlikely	Major	8	Renovate all underframe boxes, install secondary and tertiary retention on all boxes			Rare	Major	4		
25	1	Electrical fires and earthing faults	1 - Straight replacement at end of life	Electrical insulation has degraded over time and becomes conductive	Safety risk with electrical fire, system reliability rapidly deteriorates with loss in insulative properties	Y	Y		Y			Y		Rare	Moderate	3	Conduct sample inspections of looms during major overhauls			Rare	Moderate	3		
26	2	Electrical fires and earthing faults	2 - Life with existing technology and/or minor enhancement of the railcar	Electrical insulation has degraded over time and becomes conductive	Safety risk with electrical fire, system reliability rapidly deteriorates with loss in insulative properties	Y	Y		Y			Y		Unlikely	Major	8	Conduct sample tests of looms during major overhauls			Rare	Major	4		
27	3	Electrical fires and earthing faults	3 - Re-engineering life	Electrical insulation has degraded over time and becomes conductive	Safety risk with electrical fire, system reliability rapidly deteriorates with loss in insulative properties	Y	Y		Y			Y		Possible	Major	12	Conduct routine tests across the fleet			Unlikely	Major	8		
28	1	Fire performance insufficient	1 - Straight replacement at end of life	Fire systems and train design do not optimise fire retardancy or passenger egress	Fires are uncontrollable, passenger egress is inhibited	Y	Y		Y			Y		Rare	Catastrophe	5	Installation of fire/smoke detection system earlier than planned			Rare	Major	4		
29	2	Fire performance insufficient	2 - Life with existing technology and/or minor enhancement of the railcar	Fire systems and train design do not optimise fire retardancy or passenger egress	Fires are uncontrollable, passenger egress is inhibited	Y	Y		Y			Y		Unlikely	Catastrophe	10				Unlikely	Catastrophe	10		
30	3	Fire performance insufficient	3 - Re-engineering life	Fire systems and train design do not optimise fire retardancy or passenger egress	Fires are uncontrollable, passenger egress is inhibited	Y	Y		Y			Y		Unlikely	Catastrophe	10				Unlikely	Catastrophe	10		
34	1	Crash worthiness not aligned with modern standards	1 - Straight replacement at end of life	Units have no energy absorption system inherent in the design and lack anti-climber devices to protect units from over-riding in collisions	Passengers and driver are at risk of injury or death in collisions	Y		Y				Y	Y	Rare	Catastrophe	5	Install anti climbers in addition to existing scope			Rare	Catastrophe	5	System feature ATP as a crash mitigation measure	
35	2	Crash worthiness not aligned with modern standards	2 - Life with existing technology and/or minor enhancement of the railcar	Units have no energy absorption system inherent in the design and lack anti-climber devices to protect units from over-riding in collisions	Passengers and driver are at risk of injury or death in collisions	Y		Y				Y	Y	Rare	Catastrophe	5				Rare	Catastrophe	5	System feature ATP as a crash mitigation measure	
36	3	Crash worthiness not aligned with modern standards	3 - Re-engineering life	Units have no energy absorption system inherent in the design and lack anti-climber devices to protect units from over-riding in collisions	Passengers and driver are at risk of injury or death in collisions	Y		Y				Y	Y	Rare	Catastrophe	5				Rare	Catastrophe	5	Replace A-series with new rolling stock	
37	1	Poor public perception of units	1 - Straight replacement at end of life	Poor aesthetic appearance of unit exterior frontage and interiors lacking modern furnishings	Patronage figures drop due to passengers preferring to choose other means of transport						Y			Rare	Minor	2	Modal shift to other transport means unlikely as the services will not be compensated by more road infrastructure			Rare	Minor	2		
38	2	Poor public perception of units	2 - Life with existing technology and/or minor enhancement of the railcar	Poor aesthetic appearance of unit exterior frontage and interiors lacking modern furnishings	Patronage figures drop due to passengers preferring to choose other means of transport						Y			Unlikely	Moderate	6	Aesthetic improvement for Option 2b			Unlikely	Moderate	6		
39	3	Poor public perception of units	3 - Re-engineering life	Poor aesthetic appearance of unit exterior frontage and interiors lacking modern furnishings	Patronage figures drop due to passengers preferring to choose other means of transport						Y			Possible	Moderate	9	Conduct interior refurbishment with info-tainment system			Possible	Moderate	9		
40	1	Driver perception and comfort	1 - Straight replacement at end of life	Cab design outdated, design has less ergonomic features by comparison to modern designs with implementation of human factors in the design	Drivers prefer to avoid A-series and pick faults with units, reliability and on-time running drops	Y						Y		Possible	Moderate	9	Replace cab desk lighting with LEDs			Unlikely	Moderate	6		
41	2	Driver perception and comfort	2 - Life with existing technology and/or minor enhancement of the railcar	Cab design outdated, design has less ergonomic features by comparison to modern designs with implementation of human factors in the design	Drivers prefer to avoid A-series and pick faults with units, reliability and on-time running drops	Y						Y		Likely	Moderate	12	Install new driver seats and improve aesthetic features, bring forward installation of Cab HVAC			Possible	Moderate	9		
42	3	Driver perception and comfort	3 - Re-engineering life	Cab design outdated, design has less ergonomic features by comparison to modern designs with implementation of human factors in the design	Drivers prefer to avoid A-series and pick faults with units, reliability and on-time running drops	Y						Y		Almost certain	Moderate	15	Improve ergonomics of cab control equipment and replace cab desk lighting with LEDs			Likely	Moderate	12		
43	1	DDA compliance	1 - Straight replacement at end of life	Interior design does not comply with requirements of DDA standard	Failure to comply with requirements resulting in removal from service of fleet until compliant	Y						Y		Unlikely	Moderate	6	Plan to undertake modifications in line with requirements			Rare	Moderate	3		
44	2	DDA compliance	2 - Life with existing technology and/or minor enhancement of the railcar	Interior design does not comply with requirements of DDA standard	Failure to comply with requirements resulting in removal from service of fleet until compliant	Y						Y		Possible	Moderate	9	Plan to undertake modifications in line with requirements			Unlikely	Moderate	6		
45	3	DDA compliance	3 - Re-engineering life	Interior design does not comply with requirements of DDA standard	Failure to comply with requirements resulting in removal from service of fleet until compliant	Y						Y		Possible	Moderate	9	Plan to undertake modifications in line with requirements			Unlikely	Moderate	6		
46	1	Energy consumption remains high	1 - Straight replacement at end of life	Units have dated systems and do not optimise energy usage	Poor public and political perception that units are operating inefficiently, Resource drain on Western Power and financial risk long term with increasing power costs				Y	Y				Likely	Moderate	12				Likely	Moderate	12		

Project Name		PTA A Series EMU Railcar Review - Strategic Risk Register																					
Project Number		60283889																					
Hazard Reference Number	Category	Description of Risk	Option	Causes	Impacts	Safety	PTA Transport Services	Operational	Economic	Environmental	Patronage	Reputation/Political	Compliance	Risk Assessment		Proposed Additional Risk Control		Actionee	Due Date	Risk Assessment		Comments	
														Likelihood	Consequence	Acceptable or Further Treatment	Likelihood			Consequence			

Risk Matrix

	1	2	3	4	5
Probable	H	H	E	E	E
Likely	M	H	H	E	E
Possible	L	M	H	E	E
Unlikely	L	L	M	H	E
Rare	L	L	M	H	H

Insignificant	1
Minor	2
Moderate	3
Major	4
Catastrophe	5

Rare	A
Unlikely	B
Possible	C
Likely	D
Probable	E

Options

- 1 - Straight replacement at end of life
- 2 - Life with existing technology and/or minor enhancement of the railcar
- 3 - Re-engineering life

Likelihood	consequence				
	Insignificant	Minor	Moderate	Major	Catastrophe
Almost certain	5	10	15	20	25
Likely	4	8	12	16	20
Possible	3	6	9	12	15
Unlikely	2	4	6	8	10
Rare	1	2	3	4	5

Per-mitigation

Maintenance cc Technical Risk Political Risk

3	13	17	33	1-5	Pre-mitigation
5	8	21	34	6-9	
2	7	10	19	10-14	
1	2	6	9	15+	

Post mitigation

Maintenance cc Technical Risk Political Risk

6	15	17	38	1-5	Post mitigation
3	6	21	30	6-9	
2	4	8	14	10-14	
0	0	0	0	15+	

Pre-mitigation (Option 1 Option 2 Option 3

0	0	0	1
<6	12	1	2
<10	17	12	7
<15	19	18	14
>14	0	1	5

Pre-mitigation Pre-Mitigation Pre-Mitigation Pre-Mitigation Option 3

1-5	12	1	1
6-9	5	11	5
10-14	2	6	7
15+	0	1	5

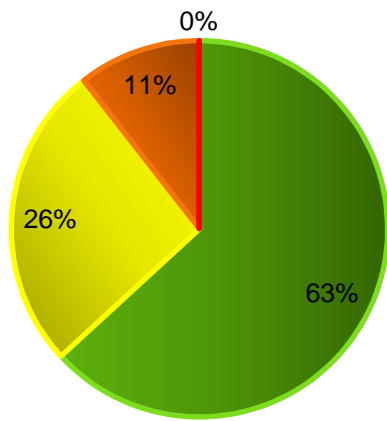
Post-mitigation Option 1 Option 2 Option 3

0	0	0	1
<6	16	5	3
<10	18	17	11
<15	19	19	19
>14	0	0	0

Post-mitigation Post-Mitigation Post-Mitigation Post-Mitigation Option 3

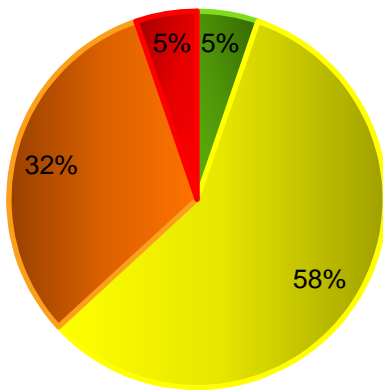
1-5	16	5	2
6-9	2	12	8
10-14	1	2	8
15+	0	0	0

■ 1-5 ■ 6-9 ■ 10-14 ■ 15+



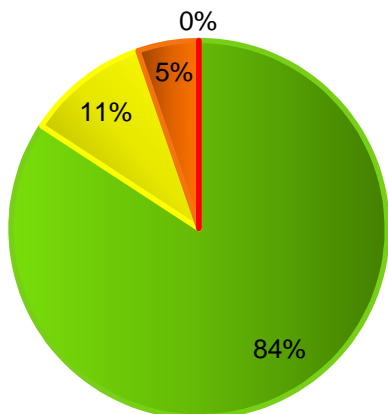
Option 1 Pre mitigation

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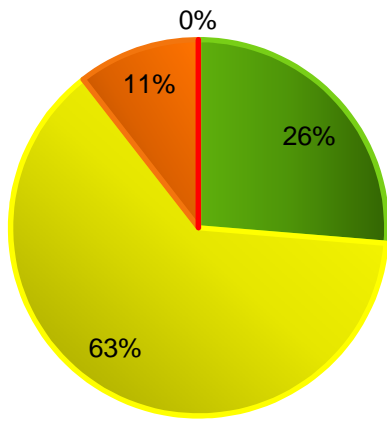
Option 1 Post mitigation

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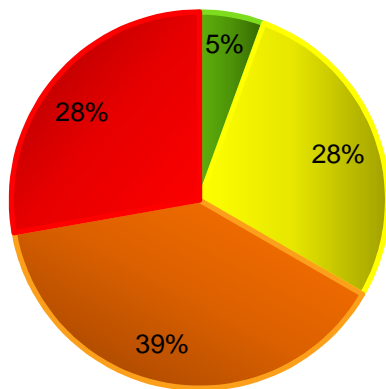
Option 2 Pre mitigation

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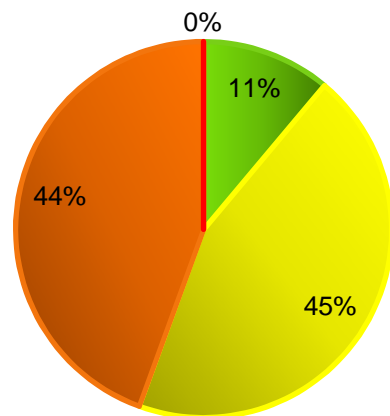
Option 2 Post mitigation

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Option 3 Pre mitigation

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Option 3 Post mitigation

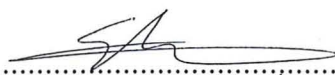


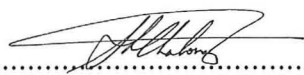
Public Transport Authority of Western Australia
Strategic Review of the A Series Railcar Fleet's Future

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Author : William Wachsmann
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1. EXECUTIVE SUMMARY

Interfleet Technology was engaged by the Public Transport Authority of Western Australia (PTA) to undertake a strategic review of the A Series railcar fleet with a view to determining the most appropriate option for its long term future.

The current condition and performance of the A Series railcars can be summarised as follows:

- The car body structures and exteriors appear to be in good condition.
- The bogie has been maintained well and no fatigue cracks are apparent.
- The car interiors are in excellent condition. The A Series railcars are in a very similar condition to the newer B Series railcars.
- The cars have very good compliance with DDA requirements
- The fleet availability is high with only 1 spare set held out of service during the peak periods.
- The reliability performance remains below the KPI of 50,000km per lost time incident. While the proposed upgrades will improve on this, it is questionable as to whether this KPI is realistic for the A Series railcars.
- The A Series railcars are fitted with phase control DC traction and an older version of a solid state auxiliary converter. These systems are becoming outmoded with a declining level of OEM support expected over time. However, they have proved to be reasonably reliable and critical spare parts can be procured.

In summary the A Series railcars are in good general condition and the existing systems deliver a good level of technical performance.

In accordance with the brief, a set of upgrade options has been investigated. Costs for each option were then estimated using either data from manufacturers and equipment suppliers or, where this wasn't available, an estimate based on Interfleet's experience and expertise.

The fleet options have been developed as follows:

- Option 1: This option allows for engineering upgrades to address reliability issues for continued operation through to 35 years. It also offers some further minor upgrades in terms of safety features and passenger amenity. The cost for the upgrade work is estimated to be \$7M.
- Option 2: This option involves the modifications outlined for option 1 plus upgrades to further address reliability issues for continued operation through to 40 years, passenger amenity and DDA compliance. The cost for the upgrade work is estimated to be \$9M.
- Option 3: This option involves a major upgrade, the main part being the installation of AC traction. This will provide a more reliable traction system which should see improved performance through to a 55 year life. The cost for the upgrade is estimated to be \$115M.

The fatigue design and condition of the car body structure and bogies are the foundation of any decision regarding a life extension program. There is insufficient design documentation available upon which to make a life extension judgement for both the bogie and the car

body. Consequently Interfleet could not gain an appropriate level of confidence that the structures could last longer than the design life of 30 years without fatigue issues. It is recommended that a structural finite element analysis (FEA) is undertaken of both the body and bogies prior to a decision being made regarding life extension.

The distance between Lost Time Incidents for the fleet does not meet the KPI of 50,000km. Considering the design of the A Series railcars and their low level of redundancy and comparing this with other systems the KPI figure is considered high.

Maintenance cash flows have been extrapolated from the existing data and future cash flows for upgrades have been estimated. Maintenance costs, in cents per car km, are represented graphically in section 13. Because of the current pro-active maintenance regime it is felt that maintenance costs will not increase markedly as the A Series railcars age. After upgrades maintenance costs should decrease and this is most marked following the upgrade to AC traction which is included in option 3.

A Net Present Value (NPV) analysis has been undertaken assuming two alternatives. The first assumes that the replacement fleet for options 1 and 2 is 48 x 3 car sets similar to the B series. The second alternative assumes that the replacement fleet for options 1 and 2 is 24 x 4 car sets, a new type of train for Perth which takes into account the concern regarding limited platform lengths on the Heritage lines. For both alternatives, option 3, lengthening the service life of the A Series railcar to 55 years, is the most attractive option from a financial point of view.

Two risk workshops were undertaken with the management team of Transperth Train Operations. The outcome of these workshops indicates that the level of risk is relatively similar between the three options.

Contingent upon the bogie and body fatigue life, option 3, lengthening the service life of the A Series railcar to 55 years, is the recommended option. This is based on the risk profile being similar between the three options and option 3 having the best Net Present Value (NPV).

2. INTRODUCTION

The Transperth division of the PTA operates a range of services including Train Operations. Transperth employs two different types of Electric Multiple Unit (EMU) Railcars - the A Series and the B Series. The A Series is the focus of this review.

The A Series were manufactured in Maryborough, Queensland and were supplied by Walkers, (now Downer EDI Rail), and ABB, (in 1988 ADtranz, now Bombardier), to the PTA in two separate contracts as follows:

- 43 sets delivered between 1991 and 1993;
- 5 sets delivered between December 1998 and March 1999.

The A Series railcars are a two car set with DC traction and are powered from a 25 kV AC overhead line system. Each two car set is powered by six traction motors and is capable of 110 km/hr. The two cars are permanently coupled as a set. Coupling to other sets is made via a Scharfenberg automatic coupler.

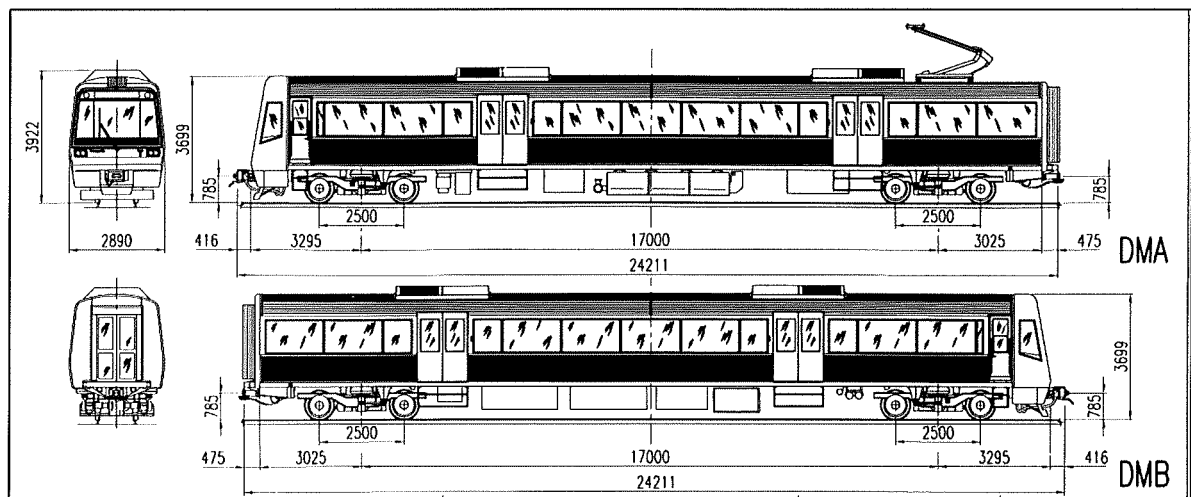


Figure 1: General Arrangement of the A Series EMU

The design life of the A Series railcars was specified as 30 years, however based on eighteen years operating experience, PTA consider the cars to have a nominal 35 year life. Studies by MTRC in Hong Kong indicate that it is practical to extend the life of metro style railcars even beyond this limit. With this in mind, PTA is reviewing options regarding the A Series fleet's future.

In studies such as these, key issues that need to be taken into include:

- Passenger amenity and disabled access requirements – will a 35 year or 55 year old train satisfy passenger requirements for comfort, amenity and access? Will passenger demands for features common in modern trains rule out lengthening the life of current rolling stock?

- The specified design life is an important factor with respect to the car-body and bogies. Usually the design life is linked with an estimate of minimum fatigue life. As such, it is reasonable to assume that fatigue damage may commence and will likely become an escalating issue with extended operating life of the vehicles.
- The vehicles are fitted with equipment, the technology of which is now outmoded. In particular the DC traction control system, auxiliary converter and Train Management System. The sourcing of spare parts may become increasingly difficult.
- Typically fleet maintenance costs escalate with age. It may become un-economic to lengthen the life of the trains. Also reliability tends to decrease resulting in a drop in passenger service quality.

Interfleet has reviewed various options for the fleet's future from a technical point of view and then evaluated them, both financially through Net Present Value (NPV) analysis and strategically by outlining the risks for each option and linking these to the PTA's long term aspirations.

3. OBJECTIVES

The objective of the engagement is to develop a robust strategic review and analysis of options in relation to the future of the A Series fleet. The report is to encompass the following items:

1. A preliminary assessment of the general condition and performance of the A Series railcars.
2. A consideration of the following:
 - Straight replacement of the fleet at the end of 35 years, considering the nominal service life is 30 years;
 - Service life extension to 40 years and beyond;
 - Re-engineering to extend life to 50 years plus. Following review of the PTA's strategic time-line Interfleet have fixed this at 55 years;
 - Other relevant options or combination of options as identified as part of this process.
3. Budget estimate of costs of all options considered.
4. Performance targets suitable for each option, and how these targets support the achievement of PTA's on time running target of 95% of scheduled services being within four minutes of timetable.
5. A summary of the risks associated with each of the options, based upon those identified via a strategic risk assessment.
6. A recommendation as to which option is preferred and why this option has been selected.

It is understood that this review will assist PTA management in developing business requirements and their conversion into a specification for the future of the A Series fleet. The outcomes of this study will assist PTA to develop a well planned and managed approach to maintenance, operation, enhancement and disposal to ensure maximisation of the return on the A Series fleet investment whilst accommodating changing business requirements.

PTA's purpose, as outlined in the Strategic Plan 2009-2013 is:

"to increase the use of public transport through the provision of customer-focused, safe and cost-effective passenger transport services"

and its aim as:

"to make public transport an attractive and sustainable choice for connecting people and places".

These Strategic Objectives will help dictate the Asset Management Policy and Strategy used by PTA. PAS 55 is the British Standards Institution's (BSI) Publicly Available Specification for the optimized management of physical assets and defines Asset Management as:

"Systematic & coordinated activities and practices through which an organisation optimally and sustainably manages its physical assets and their associated performance, risks and expenditures over their lifecycle for the purpose of achieving its organisational strategic plan."

The five key stages in an asset life cycle are illustrated in the diagram below:



Figure 2: The Asset Lifecycle

The A Series fleet is currently in the Operation & Maintenance stage of their asset life. It is noted that a proactive approach to the maintenance of the A Series fleet by PTA has allowed some enhancement of the assets that have improved reliability, safety and passenger amenity.

The outcome of this strategic review will assist PTA with their Asset Management Policy and Strategy. It enables the development of a robust Asset Management Plan for the A Series fleet that will ensure the current and future strategic objectives of the organisation are met.

4. METHODOLOGY

The methodology applied to the task consisted of the following steps

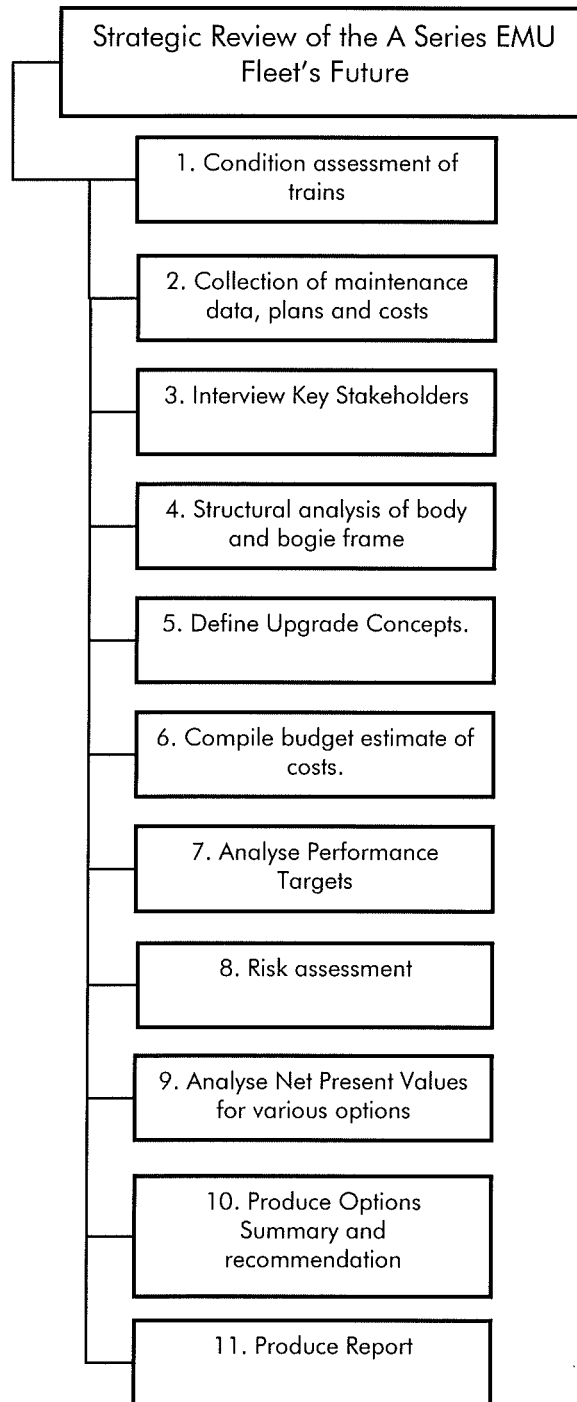


Figure 3: Methodology Flow Chart

1. Undertake a physical assessment of car condition to determine whether there are any corrosion or structural issues that may impact on the ability of the cars to operate through to their design life or have their life extended. Then undertake a gap analysis to document and highlight the differences in passenger amenity levels and safety features, including Disability Discrimination Act compliance, between the A Series railcars and the more modern B Series railcars.
2. Collect and review existing PTA data, including maintenance plans, capital and major periodic maintenance plans, current reliability and availability data, and component design and life cycle data relevant to the task. Analyse the data and feedback gathered during the data collection, interviews, vehicle inspections and supplier discussions to identify and quantify the key issues affecting the performance of the fleet, including any which may impact on any proposed life extension.
3. Interview key stakeholders to obtain comment from a wide cross section of PTA personnel involved with maintenance and operations in order to identify areas of concern and seek comment on the ability of the existing equipment to perform satisfactorily through to its design life and any proposed life extension.
4. Review structural analyses undertaken on the car body and bogie frame to gain a level of confidence that the train structure can last beyond the design life without fatigue issues.
5. Develop a range of feasible upgrade scenarios.
6. Analyse Reliability targets for each option.
7. Hold a workshop to work with stakeholders as selected by PTA to indentify risks with the various options. When the risks are identified, assess the risks as per the PTA risk matrix and consider treatments to mitigate the risks.
8. Estimate a series of cash flows associated with the various options under consideration and undertake a Net Present Value (NPV) analysis to judge the economic implications for each option.
9. Combine the NPV analysis, risk assessment and reliability performance analysis to discuss the merits of the various options and provide a recommendation.
10. Produce a report summarising the findings of the review.

5. FLEET HISTORY AND DISPOSITION

5.1. FLEET OVERVIEW

The A Series were manufactured by Walkers, now Downer EDI Rail, and ABB / ADtranz, now Bombardier in Maryborough and were delivered progressively in two tranches. The first tranche of 43 sets were delivered between 1991 and 1993. The second tranche of 5 sets were delivered over four months from late 1998 to 1999.

The A Series run, in the main, on the Heritage lines of Fremantle, Armadale and Midland. With the delivery of more B Series railcars less A Series are required on the Mandurah and Joondalup lines. Two contracts for B Series trains have been let. The first contract for 31 x 3 car sets and the second for 15 sets. Consequently when the current B Series supply contract is complete the Transperth fleet will comprise of 48 A Series sets and 46 B Series sets.

The majority of the A series sets have been in operation between 16 and 18 years with five sets delivered later having operated for approximately 12 years.



Figure 4: A Series EMU train

The Technical Specifications issued at the time of build specified a design life of 30 years, however based on eighteen years operating experience, PTA consider the cars to have a nominal 35 year life.

The A Series railcar bodies are made from stainless steel, including structural members, which has resulted in excellent corrosion resistance and an attractive appearance.

The propulsion system utilises thyristor switched, phase angle controlled rectifiers to power six 195kW DC traction motors. Power to the traction control unit is via two nominal 1000VAC secondary windings from the main transformer. The traction motors also have their armature and field windings separately wired

(separately excited – SEPEX) which allows for improved control. Phase Angle Control with DC motors is a well proven system, however, since the later half of the 1990s this system has been superseded by AC traction.

The brake is a blended electric rheo-static and electro-pneumatic disc brake. Use of the rheo-static brake is maximised to reduce brake pad and disc wear. The traction system cannot employ re-generative braking.

Each set is fitted with a solid state, thyristor based converter to power the auxiliary circuits. The main loads arise from the two air-conditioning units per car. As well, there is the air compressor, the low voltage circuits powering the lights, battery charger and control circuits.

5.2. CAR CONFIGURATION

The A Series railcars are configured as permanent two-car pairs. The first car (DMA) is fitted with a pantograph, underneath which the main transformer is located. This car has two powered bogies. The second car (DMB) has one powered bogie and one unpowered bogie. The table below provides a summary of the technical specification for the A Series railcars.

Item	Specification / Supplier
Train 2-car set length	48.4 metres
Gauge	1067mm
Power Supply	25 kV AC overhead
Passenger capacity	Seated – 126 Standing – 256
Total tare mass 2-car set	90 Tonnes
Maximum service speed	110 km/h
Body shell	Stainless steel structure
Traction system (DC)	Thyristor switched, phase angle controlled rectifiers. Supplied by ASEA (now Bombardier).
Traction motors (DC)	6 x 195kW DC Traction Motors per set
Braking system	Davies & Metcalfe EP control
Bogies	Fabricated steel
Auxiliary power	Thyristor controlled rectifier coupled with a forced commutated thyristor inverter. Supplied by ASEA (now Bombardier).

Table 1: A Series EMU train

6. OPERATIONS

The A Series railcars and B Series railcars are operated in a mixture of one and two set trains on both peak and non-peak services.

The A Series railcars are gradually beginning to operate exclusively on the Fremantle, Armadale and Midland lines. Reliability was observed to suffer when they operated on the higher speed Mandurah and Joondalup lines where the B Series reach a speed of 130km/hr. With the high speed and long distances involved the B Series operate a higher number of kilometres

The following shows the current approximate annual car kilometres:

Train Type	Average Annual Distance
A Series railcars	140,000km
B Series railcars	250,000km

Table 2: Annual Car Kilometres Run per Car Type

The nominal fleet availability requirement is listed in the following table:

	A Series railcars
Number of sets	48
Service operation requirement in peaks.	45
Spare (Gross)	3
Undergoing General Overhaul (GO)	1
Undergoing modification	1
Maintenance Spare (Net)	1

Table 3: A Series Railcar Availability

Low level maintenance is carried out either between the AM and PM peaks or at night.

7. MAINTENANCE

The A Series cars are maintained at Transperth Claisebrook Railcar Maintenance Depot, which is located at 122 Kensington Street, East Perth.

Claisebrook has approximately 100 staff within Rolling Stock Engineering of which:

- 8% are PTA Employees
- 51% are from EDI Downer for engineering and trade staff
- 23% are from Spotless Cleaning Service.
- 9% are private contractors.

Based on interviews with the Rolling Stock Engineering staff at Claisebrook a number of observations have been made. These are set out below.

The system of maintenance at the Claisebrook depot is based on a pro-active style of reliability based maintenance. The planned maintenance regime for the railcars typically matches that provided by the Original Equipment Manufacturers (OEMs), however, overhaul intervals have not been necessarily adhered to. Rather the condition of subsystems is continually assessed and if a subsystem is still within operable limits the overhaul interval is lengthened.

Overhaul interval cycles as specified by the OEMs are typically conservative. OEMs cannot be expected to fully appreciate the operating regime for every particular application of their equipment. It can occur that a sub-system or component may be overhauled even though it still may have more operating hours left before it becomes a failure risk or the asset value is threatened. Condition monitoring allows overhaul cycles to be optimised thus reducing costs.

Rolling Stock Engineering has a policy of pro-actively reviewing sub-system performance and acting to improve areas of sub-optimal design to reduce failures and increase maintenance cycle intervals. This should be considered an investment that will reduce failure and maintenance costs as the trains enter the second half of their operational life. Examples of such projects already in place include:

- Traction motor reliability improvement;
- Engineering improvements to the auto coupler;
- Modifications to the main air compressor assembly;
- Replacement of the traction gearbox case with an aluminium case; and,
- Improved corrosion protection for window frames.

Examples of other projects under development include:

- A new more robust design of aluminium extrusion for the saloon door track;
- Improved design of door support brackets; and,
- New door control unit incorporating solid state switches which addresses the failure of relays required to switch at high rates.

Many railway operators experience a marked increase in the gradient of the steady state maintenance cost vs age curve for their rolling stock as it approaches the end of life. For

undertaking a financial analysis of the various options outlined in section 12, excluding major overhauls, and barring unforeseen events, a relatively flat steady state maintenance curve has been assumed. An incremental increase over time has been assumed.

It is considered prudent to budget for incremental annual increases as increasingly there will be failures that are unforeseen. For example, QR operational staff indicate the Brisbane EMUs that entered service in 1979 are beginning to experience faults not seen before.

7.1. MAINTENANCE REGIME

The maintenance regime has been developed over time and is currently set up as follows:

- "A" Service – 4 weekly
- "B" Service – 12 weekly
- "C" Service – 36 weekly
- "D" Service – 72 weekly
- "E" Service – 144 weekly
- "F" Service – First Major Service & Refurbishment (General Overhaul)

The maintenance is cycled in the following manner:

AABAABAACAABAABAADAABAABAACAABAABAAE

A comprehensive railcar maintenance database is employed that has captured all the maintenance information for the A Series fleet since they were introduced in 1991. Failure trends are closely monitored.

7.2. CURRENT MAINTENANCE COSTS

Maintenance Costs are compiled by the Engineering Manager on a yearly basis. PTA provided Interfleet with 10 years of maintenance data from financial year 1999-2000 to 2008-2009.

Costs captured by PTA include:

- Actual spend;
- Vandalism;
- Modifications;
- Lifts and Escalators;
- General Overhaul; and,
- Cleaning.

Costs were brought into 'today's dollars' by PTA by using the Consumer Price Index (CPI) as per the Australian Bureau of Statistics.

The maintenance costs are calculated on a cents per car kilometre basis using costs and odometer readings provided by PTA, (see Table 4). These costs include routine maintenance, cleaning and General Overhaul (GO), but do not include vandalism, modifications, and lifts & escalators. These costs are considered to be the 'steady state' maintenance costs for the A Series that is used in the Net Present Value analysis.

As components such as air compressors, inter-car couplers, flooring, doors and door tracks are overhauled their performance and reliability is often improved. Over time, PTA has been able to source more components directly from global component manufacturing OEMs and not necessarily the local Australian railcar manufacturing OEM.

Financial Year	Cost (2009 \$) / car km travelled
1999-2000	\$0.62
2000-2001	\$0.66
2001-2002	\$0.73
2002-2003	\$0.77
2003-2004	\$0.65
2004-2005	\$0.86
2005-2006	\$0.95
2006-2007	\$0.91
2007-2008	\$0.82
2008-2009	\$0.83

Table 4: Routine maintenance costs

As outlined above, discussions and demonstrations by Rolling Stock Engineering at the Claisebrook depot have indicated that the A Series maintenance regime differs from many other operations as it has a far more pro-active, reliability centred approach. A team of engineers at the Claisebrook depot work on improvements and make judgements regarding overhaul intervals.

Consequently, modifications and enhancements to the A Series railcars have occurred earlier in the asset's life than would be the case with other railway operators. But it is felt that this investment will pay dividends in the later half of the asset's life. Rather than a rising cost curve, with a lower initial cost, the A Series may expect a 'flatter' maintenance cost curve over the life of the asset. Estimated maintenance cost curves are outlined in section 13.

8. VEHICLE PERFORMANCE AND RELIABILITY

Fleet performance and reliability is measured by a number of key performance indicators (KPIs) and reported in a weekly communications section report.

8.1. FLEET RELIABILITY

PTA defines a failure as a delay of 4 minutes or greater. The target for kilometres travelled between failures is 50,000 km. The A Series cars are currently achieving close to 25,000 km travelled between a lost time incident (LTI).

The target for kilometres travelled per cancellation is 200,000 km, which is currently being met by the A Series.

The A Series are allocated 5 concessions per week. Data provided by PTA indicate that the fleet is currently meeting this requirement.

8.2. A SERIES FAILURES AND PEAK DELAYS

Reliability figures provided by PTA were analysed to gain an understanding of systems and sub-systems that have been experiencing a high number of faults.

Failure data over a two year span was analysed and the output of the analysis is presented in the Pareto graph below:

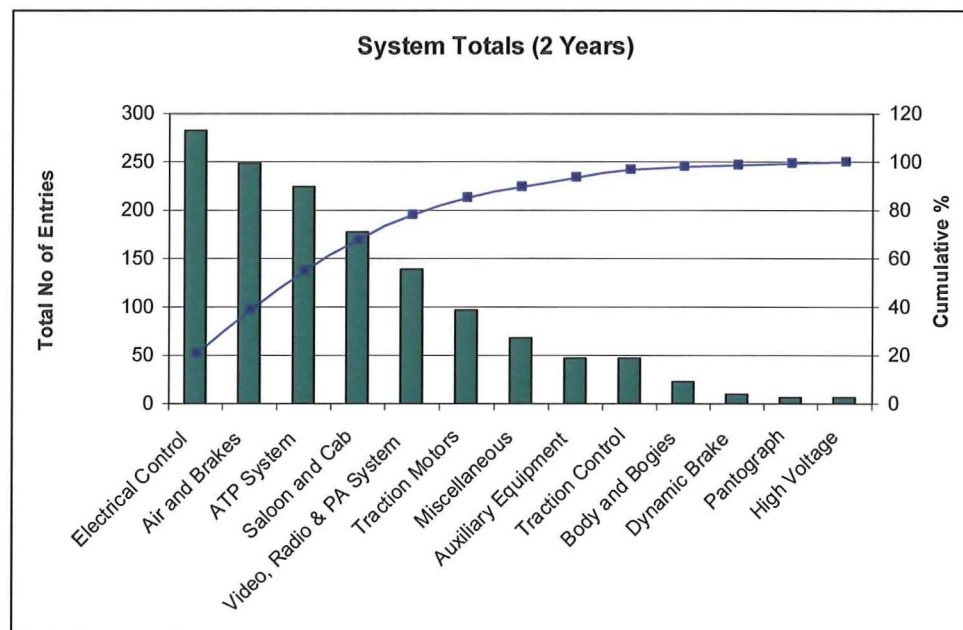


Figure 5: System Failures over 2 years

It can be seen that over 20% of failures on the A Series are attributed to electrical control. The 'Top 6' entries for failures on the A Series are electrical control, air and brakes, ATP System, saloon and cab (including doors), video, radio & PA system and traction motors. Combined, these six systems contribute to approximately 85% of all A Series failures.

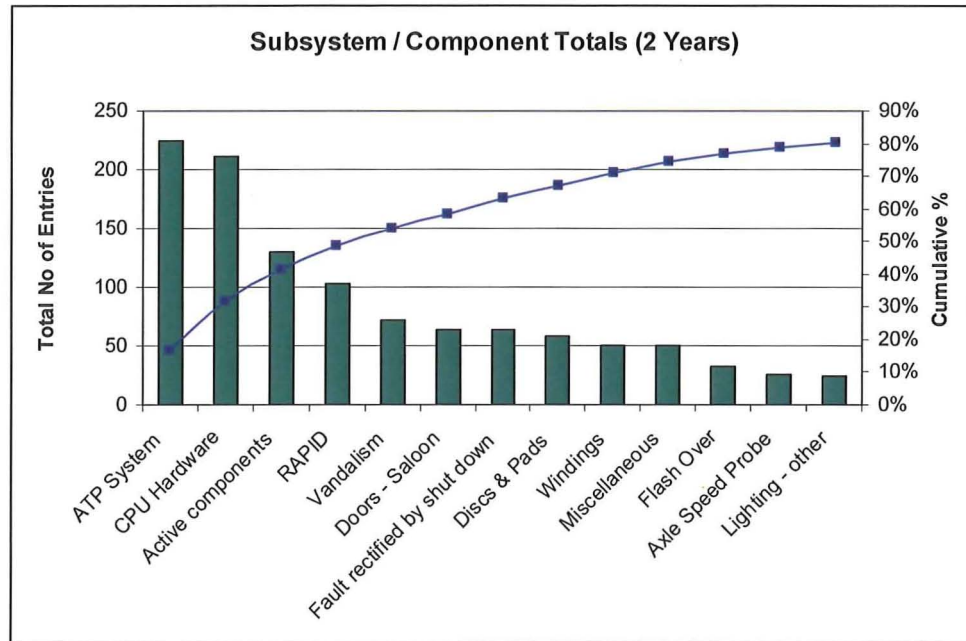


Figure 6: Sub-system failures over 2 years

The failure data of the sub-systems was analysed in a similar manner to the system data.

The most failures were attributed to the ATP System in general and not to any particular subsystems associated with the ATP. Together, ATP System, CPU hardware, active components, RAPID, vandalism and saloon doors attributed close to 60% of all subsystem failures.

It is understood that the ATP System will be going through an upgrade in the near future, with the aim of reducing the number of failures. It is also understood that PTA will be looking to install a European Railway Transport Management System (ERTMS) across their network in the near future. It is noted that there were 103 failures (7% of total) attributed to RAPID over the past two years. It is understood that the RAPID modification programme has been rolled out across the A Series fleet over the past few years. The number of failures attributed to RAPID may be due to the 'infancy' stage of this system.

When comparing reliability performance between fleets it is important to consider the level of redundancy for the critical sub-systems on a train. Unlike the B Series railcars, the A Series railcars have only one major sub-system per set. Longer trains, such as the various styles of EMUs in Hong Kong, have a far higher level of redundancy. For example the 12 car 25kV AC EMUs formerly operated by KCRC

have up to 6 levels of redundancy. With headways as low as 90 seconds reliability is vital but the longer trains have the advantage that in the case of a sub-system failure, the train will still operate in service.

The upgrades proposed within the three options (outlined in section 13) will improve reliability; however, a level of 50,000 km between an LTI may not be achieved. Experience indicates that this target may be too high. In Melbourne, the latest contract for the train operators specified a mean distance between failure (assuming a time window of 5 minutes) of 15,000 km for the newer Siemens and Alstom trains. In Sydney, the reliability target for the Millennium trains is 100,000 km and this is similar for the new OSCar trains. It needs to be noted that both of the Sydney trains, being 4 car sets, have an added level of redundancy built into their design and are a far younger train incorporating the latest technology. Similarly this is true with the Melbourne trains.

With the added level of redundancy included on the Melbourne and Sydney trains it can be considered that the 50,000 km between LTI for the A Series railcars is equivalent to the requirement for the Sydney trains. That is, 50,000 km between LTI per level of major system redundancy. Also the Melbourne trains are far newer than the A Series railcars and their targets are lower than the level currently being achieved with the A Series. Consequently, it is reasonable to expect that the A Series railcars with their older equipment would achieve a lower distance between LTI. A stretch target above the current level of 25,000 km may be achieved with improvements in ATP and RAPID reliability. Also, the installation of a test rack for the TMS should also impact in a positive manner.

9. REVIEW OF FLEET CONDITION - METHOD AND COMPARISON WITH THE B SERIES RAILCARS

9.1. STAKEHOLDER INTERVIEWS

A number of interviews were held with key PTA stakeholders in order to:

- Understand the strengths and weaknesses associated with the A Series railcars from an engineering, maintenance and operations perspective;
- Understand how the cars are perceived in terms of their levels of technology, their compliance with regulations and legislation, and their standing against new trains; and
- Understand the range of improvements considered to be needed or wanted and to understand the priorities for these.

PTA Personnel

Name	Position
Jeff Steedman	Business Manager
Hugh Smith	Executive Director, Strategic Asset Management
Rodney Vermeulen	Rolling stock Engineering Manager
Elwyn Gearon	Assistant Operations Manager
Pat Italiano	General Manager, Transperth Train Operations
Jason Tan	Claisebrook Depot Electrical Engineer
John Churchman	Claisebrook Depot Maintenance Supervisor
Ishari Howpe Liyanage	Engineering Student
Geoff Hingston	Rolling stock Electrical Engineer
Kenny Currin	Claisebrook Depot Technical Officer
Max Wheeler	Claisebrook Depot Technical Officer
Mitch Sideris	Consultant Rolling stock engineer
Reg Carmody	Claisebrook Depot Technical Officer
Stephen Binks	Claisebrook Depot Technical Officer
Ross Freight	Claisebrook Depot Air Conditioning contractor

Other organisations

Name	Position
Jerry Jirasek	Downer EDI Design Manger
Paul Thorley	QR Operating Manager Mayne Depot
Garry Bulgarelli	Bombardier Director Services and Projects
Klaus Gaebhard	Transtechnik GmbH Sales Manager Australia and Asia
Harry Hanegraf	Faiveley Transport
David Barry	Alltrack Solutions

Charles Tsang	EAO
Curt Plumer	Voith Turbo
Trent Chitterton	Simplex Fire Products
Peter Myburgh	Atlas Copco
Bill Laidlaw	Toshiba International Corp
Oliver Zaude	Vossloh-Keiper
Harry Casimatis	Eaton Electric Systems

Table 5: People Interviewed

Interfleet engineers in Australia and in the United Kingdom have contributed with their experience on similar trains and technology upgrades.

9.2. CAR INSPECTIONS

Car inspections have been carried out and no corrosion is evident in the body, headstock, bolster or bogies. In general the condition of the car body from a passenger amenity point of view is very good considering the life of the majority of the fleet is 18 years and they have travelled in the order of 2.5 million kilometres. Presentation of the trains has a high priority in the Claisebrook depot.

The major subsystems on the trains have been reviewed and they have been maintained so that they are in a good condition. Over time, engineering reviews have been carried out on many of the sub-systems which have resulted in areas of weakness being addressed. A number of examples of this work have been highlighted in section 7 and it is felt that this engineering intervention will increase system reliability and reduce the typical steep increase in maintenance costs that occurs with a train fleet as it ages.

9.3. GAP ANALYSIS

9.3.1. PASSENGER AMENITY

A gap analysis was carried out to identify the main differences with respect to passenger amenity between the A Series railcars and the more modern B Series railcars. Passenger demands for features available in modern trains often rule out lengthening the life of current rolling stock. Also an important aspect is access for disabled people.

The A Series railcars compare very favourably with a younger train in regard to passenger amenity and disabled access requirements. The main area of discrepancy is that the emergency door release is above the door and is not accessible to a wheelchair bound person. The fleet is well presented and if the maintenance and presentation effort is continued then the A Series railcar life should be able to be extended without negative feedback from passengers.

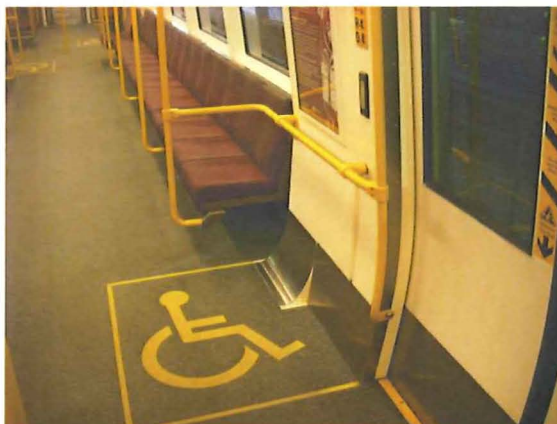
To illustrate this, a visual comparison is provided below. While the front of the trains reflect the period in which they were designed, on a passenger amenity basis it is difficult to discern any significant difference between the two series.



A Series - Exterior



B Series - Exterior



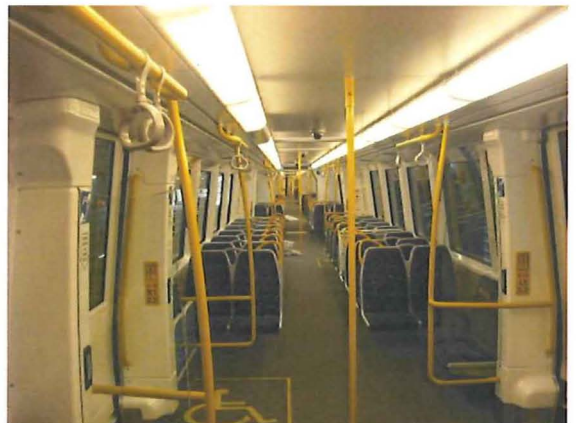
A Series Saloon



B Series Saloon



A Series Seating Arrangement



B Series Seating Arrangement



A Series Gangway



B Series Gangway



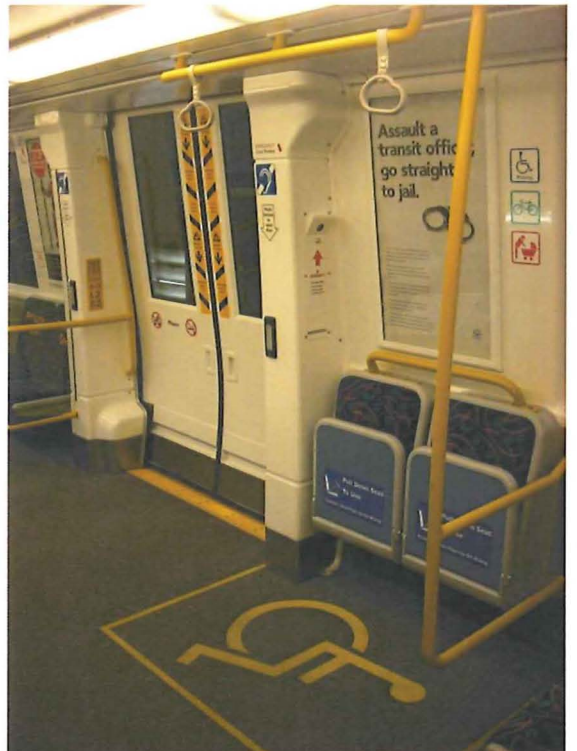
A Series – Passenger Information and CCTV



B Series – Passenger Information and CCTV



A Series - Doorway



B Series – Doorway



A Series – Emergency Door Release (above door).

NB The Internal Emergency Door Release is higher than allowed by DDA requirements



B Series – Emergency Door Release



A Series – External Panelling



B Series – External Panelling

Figure 7: Visual Comparison between the A Series railcars and B Series railcars.

9.3.2. EQUIPMENT

Technology had advanced between the procurement of the A Series railcars and the B Series. The main areas that are affected include:

- Propulsion;
- Auxiliary power; and,
- Train Management System (TMS).

The propulsion system on the B Series employs AC induction traction motors coupled with a modern Insulated Gate Bipolar Transistor

(IGBT) based control system. It also allows regenerative braking that is not available on the A Series railcars. This system offers many advantages by way of higher reliability and lower maintenance costs.

Auxiliary power is generated through an IGBT based inverter which also has advantages of higher reliability and efficiency.

The B Series train management is accomplished through the use of a distributed computer control system which provides a greater amount of information than is available on the A Series. This assists both the driver and maintenance staff to fault find. Also the TMS system itself, being a modern system should have a higher level of reliability.

The main differences from an equipment point of view are summarised below.

A Series railcars	B Series railcars	Implication for A Series railcars
2 Car set	3 car set	Can be coupled into multiple sets to increase passenger capacity.
Top speed 110 km/hr	Top speed 130 km/hr	Not able to reliably perform to timetable on the Joondalup and Mandurah lines.
DC traction	AC traction	Higher maintenance costs, decreased reliability.
1 thyristor traction converter	2 IGBT traction converters	No redundancy resulting in service failures and decreased availability. Older design of converter is less reliable. Similarly with auxiliary power system.
Air-conditioning from saloon for driver.	Drivers cab air-conditioner	Driver has less control but if this is accepted then fewer systems to maintain.
Pneumatic sliding saloon doors	Electric sliding plug doors	Higher maintenance costs, decreased reliability.
No smoke detection	VESDA smoke detection	Fewer systems to maintain. Less emphasis on smoke detection due to end saloon doors. However a lower level of fire safety detection.
Some critical circuit breakers on underframe	All critical circuit breakers above floor level	Leads to increased time to rectify in service failures.

Table 6: Main Differences between fleets

10. SUMMARY OF FLEET CONDITION

Detailed information has been gathered about the various sub-systems on the A Series railcars and this is provided in Appendix 1. Based on the information gathered the current condition of the A Series railcars can be summarised as follows:

- The car body structures and exteriors appear to be generally in good condition. No corrosion or significant fatigue cracks have been identified.
- The bogie has been maintained well. No fatigue cracks have been identified in the bogie frame, however, there is insufficient design documentation available upon which to make a life extension judgement for both the bogie and the car body. Consequently Interfleet could not gain an appropriate level of confidence that the structures could last 30-55 years without fatigue issues. It is recommended that a structural finite element analysis (FEA) is undertaken of both the body and bogies prior to a decision being made regarding life extension.
- The car interiors are in excellent condition. The A Series railcars are in a very similar condition to the newer B Series railcars.
- The cars have very good compliance with DDA requirements including good wheelchair access. The retrofit of a modern passenger information system completes the main requirements for this aspect of passenger amenity.
- The fleet availability is high with only 1 spare set held out of service during the peak periods.
- The reliability remains below the KPI of 50,000km per lost time incident. This may be addressed by the modifications planned. An important one of these being the ATP upgrade, however, it is questionable as to whether this KPI is realistic for the A Series railcars.
- The A Series railcars are fitted with phase control DC traction and an older version of a solid state auxiliary converter. These systems are becoming outmoded with a declining level of OEM support expected over time. However, they have proved to be reliable and critical spare parts can be procured. Also the dedicated electronics workshop at Claisebrook has proved that it can repair the control electronics for these devices. Consequently, unless something unforeseen occurs it is expected that these systems can be maintained to 35 life and beyond to 40 years.

In summary the A Series railcars are in good general condition and the existing systems deliver a good level of technical performance.

11. UPGRADE ISSUES

Upgrade issues fall into one of three basic categories:

- To replace components which will not continue to function for the duration of the originally defined car service life of 30 years or any life extension period;
- To replace components which are expected to be significantly affected by obsolescence; and,
- To bring the functionality of equipment or systems into line with modern railcars and world's current best practice. Upgrades which fall into this category are not required to maintain operation but are recommended to maintain the current high standards of appearance of the fleet or to provide functionality that is available on modern rolling stock.

11.1. SAFETY AND RISK MANAGEMENT

In the years since the A Series railcars were introduced technology has developed and certain areas impacting on safety have developed. Many of these have been considered and upgrades have been undertaken on the fleet. Areas upgraded since the trains were introduced include those features being introduced as part of the RAPID modification – CCTV systems for passenger security, passenger information systems and data logging.

Other areas that can be considered include:

- Fitting of smoke detection systems; and,
- Regulated internal emergency door releases.

These items have been included in option 3.

11.2. DISABILITY STANDARDS FOR ACCESSIBILITY

The requirements for rolling stock in relation to disabled access are contained in the Disability Standards for Accessible Public Transport Act. Generally it is reasonable to assume that any life extension for the rolling stock will require a high level of compliance with the act.

The A Series railcars already have a high level of compliance with the act, however, an area that will need attention, particularly if a life extension is undertaken, is the internal emergency door release. This is currently located above the saloon doors and will need to be re-located to a lower position. This would bring the A Series railcars into line with the B Series railcars.

11.3. CRASHWORTHINESS AND STRUCTURAL INTEGRITY

Modern crashworthiness requirements centre on the amount of energy that the structure must be able to absorb in a crash situation without significant deformation of the passenger areas, and is normally achieved through the design

of 'crumple zones' in the vehicle ends. Such structures are designed to deform in a controlled, defined manner.

Crashworthiness as originally specified in the A Series railcars is on a par with contemporary specifications. Interfleet understand that during the early years of operation an A Series railcar collided with the Armadale dock and suffered structural damage to the front drag box, the cab doorway as well as some minor side wall crumple between the cab and #4 saloon door. An analysis of the damage indicated that the train behaved in a manner that was relatively close to that predicted by the designer.

While a finite element structural analysis was not available for the A Series railcars a review was undertaken on the Finite Element Analysis (FEA) undertaken by Bombardier on the B Series car body. This report, however, was not of a standard that would enable Interfleet to verify the requirements of the original specification. Refer to section 18.1 Car Body for a discussion regarding structural issues.

Improvement could be gained in the transmission of longitudinal loads that occur in end-on collisions by the fitment of anti climb devices. These are fitted to the B Series railcars. These devices improve the probability of impact forces remaining along the longitudinal axis of the cars. The anti-climb teeth prevent adjacent car ends from moving over the other, and allow more controlled deformation. While it appears feasible to fit anti climbers to the A Series railcars, a full design analysis would be necessary to determine the actual practicality and effectiveness of doing so.



Figure 8: An example of a train with anti climbers

For the purpose of developing life extension options anti climbers have been included in the cost calculations for option 3.

11.4. TECHNOLOGICAL UPGRADES

11.4.1. TRACTION UPGRADE

Since the design of the A Series railcars there have been marked improvements in technology. This is particularly the case with modern electronics.

Modern electronics has provided the AC drive. It has only become available with modern electronics because the speed of a 3-phase AC motor is determined by the frequency of its voltage supply but, at the same time, the power varies. The frequency was difficult to control and that is why, until the advent of modern electronics, AC motors were unsuitable for railway operation. A modern railway 3-phase traction motor is controlled by feeding in three AC currents which interact to cause the machine to turn. The three phases are most easily provided by an inverter which supplies the three variable voltage, variable frequency (VVVF) motor inputs. The variations of the voltage and frequency are controlled electronically.

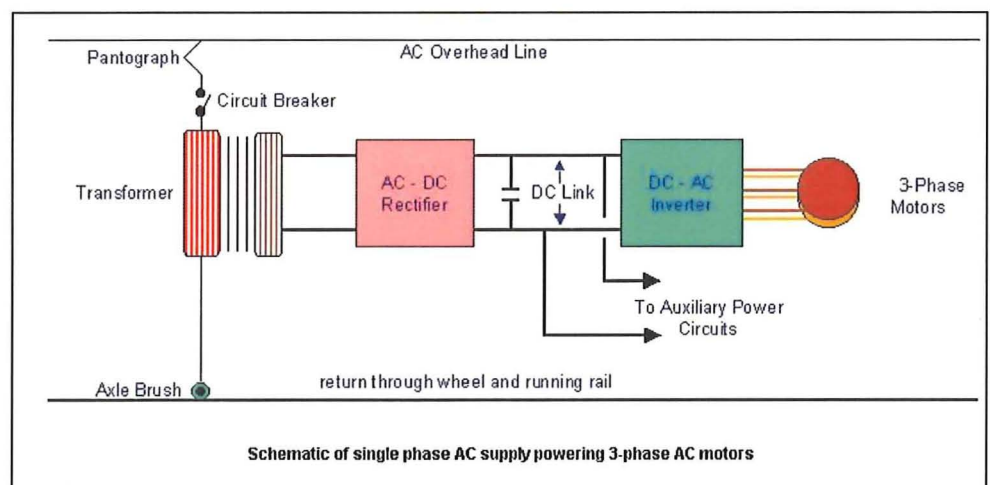


Figure 9: Example of AC traction.

The two big advantages of the 3 phase AC induction motor are that the motor has no brushes or commutator. This reduces the maintenance cost and time to undertake a service as well as improving reliability. The second advantage is the weight. AC motors are significantly lighter. This is the system employed on the B Series railcars.

The switching element employed in a modern traction converter is the Insulated Gate Bipolar Transistor (IGBT). This device has proved to be reliable and requires less complicated circuitry to drive it and is far more efficient.

An upgrade to an AC traction system is included in the cost calculations for life extension option 3 of the A Series railcars. It is expected that the existing transformer will be retained for the life extension option as the existing secondary voltages should be able to be accommodated by a new traction converter (indicated as a DC-AC inverter in the previous figure.)

Updating the traction system will have the added advantage of allowing for regenerative braking. Regenerative braking can save 20-25% of the electricity for traction. Assuming an annual electricity bill of \$10M and assuming that the A Series railcars consume 40-50% of this results in a saving of \$1M per annum.

11.4.2. AUXILIARY POWER CONVERTER

IGBTs have greatly improved the design of auxiliary power converters, making them simpler and more reliable. As part of a technology upgrade for a life extension option a new auxiliary converter should be considered. The battery charger could be built into the same enclosure.

11.4.3. TRAIN MANAGEMENT SYSTEM (TMS)

In order to control the new sub- system components for an AC traction upgrade it is recommended that a new Train Management System is also employed. It will be required to manage the additional inputs from the new equipment and should perform at a higher level of reliability than the old existing TMS. A budget estimate is included in the life extension option.

11.5. RELIABILITY DRIVERS

For the life extension option there are number of areas of the train where upgrades can be justified on the basis of reliability improvements. While the systems are currently functioning satisfactorily they will need replacement or major overhaul to ensure that they continue to 35 to 40 years. Further discussion regarding the following key systems and other systems on the A Series railcars is provided in Appendix 1 Condition of the Fleet.

Key systems to be considered include:

- Door systems – replacement of the pneumatic actuation with a new electric actuator system and control unit. It is felt that installing an electric sliding plug door such as on the B Series railcar would not realise any particular gain on a re-worked car. Replacement of the pneumatic sliding doors with electric sliding doors will eliminate inherent reliability issue that are inevitable in pneumatic equipment.
- Braking system – after 35 to 40 years it would be prudent to allow for new brake control units. Although the Faiveley EBC5 units are

used throughout the world and thus are very common, improvements in electronics will dictate that in the future a more reliable brake control unit (BCU) will be available and should be fitted if the 55 year life extension is being considered.

- Air-conditioning units – after 35 to 40 years it is expected that the reliability of the air-conditioning will fall unless a major re-build is undertaken. This would include replacement of electronic control equipment, heat exchanger coils on condition and a rebuild of the compressors.

11.6. OBSOLESCENCE AND ONGOING OEM SUPPORT

There is concern regarding the increasing risk of component obsolescence and discontinuation of original equipment manufacturer (OEM) support for the traction, traction control and braking systems.

As the demand for DC traction systems has reduced, the support and supply of components for them also reduced, particularly the power electronic components unique to DC traction systems. This does not apply to the A Series railcars as the power electronic components are not unique to DC traction. Thyristors are, and will be, used for the foreseeable future in AC to DC rectifiers in many different applications. Consequently for the options up to 40 year life it felt that the current major sub-systems can be retained. If the trains are to be pushed beyond this then it is felt appropriate to update these systems. After 40 years there will be a certain level of uncertainty regarding their reliability. Also it will be difficult to gain OEM support for problems that may be starting to surface which are beyond the skill of maintenance and engineering staff.

As a half-way measure between converting the A Series railcars to AC traction, Interfleet investigated procuring a replacement phase control DC traction system to replace that currently employed. This is discussed further in section 12.2.

12. TRACTION SYSTEM OPTIONS

Three different options for the Traction System have been reviewed and are discussed in the section below. These are as following:

1. Retain the existing equipment;
2. Replace the system to incorporate an IGBT traction control system whilst retaining the existing DC traction motors; and,
3. Fully replace the existing system with an IGBT drive system and modern three phase AC induction traction motors.

12.1. RETAIN THE EXISTING TRACTION SYSTEM

A review of the performance of the existing traction system reveals that the thyristor based control system and traction motors appear in the middle of the Pareto of Lost Time Incidents with 46 (3.5%) and 96 (7%) of the Lost Time Incidents being allocated to these systems respectively during the period of November 2007 to October 2009. It is noted that the percentages of total Lost Time Incidents has reversed for these two systems in the last year of the data but their approximate location on the Pareto is consistent.

Further analysis reveals that the components or subsystems that caused the majority of the traction control system failures are the contactors, the power factor correction and the main converter. To address failures with the main converter it is understood that a fleet change-out of the main thyristors and diodes is proposed within the next couple of years.

A similar review of the traction motor failures identify that the windings and flashovers were the main cause of Lost Time Incidents. It is noted that this has reduced to zero incidents during October 2009 with a significant reduction since July 2009. Interfleet understand that the cause of these failures was prolonged high speed running on the north / south lines by the A Series railcars and this has subsequently been reduced.

Failure rates and obsolescence are significant factors when considering whether to retain the existing traction system. Whilst failures occur on the A series railcars they are not currently a significant cause of Lost Time Incidents. Interfleet has also reviewed the risk of obsolescence and as with all electrical and electronic systems the risk will increase as the railcars get older. However, the traction system uses thyristor based technology and whilst some re-engineering may become necessary it should be possible to continue to procure thyristors because of their use in rectifiers and other similar equipment. This will reduce the likelihood of obsolescence significantly affecting availability of spares.

Advantages of retaining the existing traction system include the equipment performance and maintenance practices are known and are well established. With the exception of the replacement of the thyristors and modifications to improve the reliability of the power factor correction components and the contactors there are no major up front costs.

Disadvantages of retaining the existing traction system predominantly centre on the obsolescence of components. Whilst the availability of thyristors is not expected to be a significant issue the technology used for the A series railcars is two generations old and as a result availability of other major components within the control system may be difficult to source. Nevertheless Bombardier has indicated that it will continue to support its products in service.

It is understood that the commutators of the traction motors are monitored as part of the TMP and are ground in-situ to ensure that they remain round. Whilst the traction motors are 18 years old at the time of writing it is likely that, to continue to operate beyond the original service life of 30 to 35 years, it will be necessary to undertake a major overhaul on condition that may include new armature shafts, armature commutators and armature/field windings. This procedure is understood and is currently undertaken in the steady state maintenance budget.

Notwithstanding unforeseen circumstances, and based on experience with the Brisbane EMUs which employ a similar system, it is felt that well, maintained, this system should operate reasonably reliably for up to 40 years.

12.2. REPLACE THE DC TRACTION CONTROL AND RETAIN EXISTING DC MOTORS

This option is to replace the current thyristor phase control unit with a modern IGBT design but retain the existing DC motors.

During the risk assessment workshop, this option was recognised as being less technically risky than a complete change out to AC traction. While Interfleet was able to locate suppliers that would modernise a 1500VDC or 750VDC powered, DC traction railcar this is not the case with an AC powered railcar. Only one supplier has been located that would undertake this work on a railcar powered with AC.

Consequently Interfleet feel that while this option may be technically possible it could be somewhat risky due to the lack of commercial competition.

12.3. REPLACE PROPULSION SYSTEM WITH AC DRIVE

This option is to replace the complete propulsion system with an IGBT converter driving AC motors.

Prices have been obtained for such a system which includes two traction converters, associated AC induction traction motors, gearboxes and couplings. The traction motors should be mounted off the bogie frame, not axle hung as is currently the case. This is current railway practice with modern equipment designed in this manner to reduce un-sprung mass. To retain the existing traction motor mounting would mean especially designed components increasing the risk of reduced reliability and the cost of components. It is understood that the bogie frames can be modified to include the necessary brackets required to mount the traction motors as the same bogie is employed on the B Series railcars with the addition of brackets for mounting the motors.

This option will also allow regenerative braking to be employed. Savings are generally in the range of 20-25% of the electricity consumed and with the A Series being half of the fleet consuming \$10M pa of electricity it is estimated that savings will be in the order of \$1M pa.

For this option it is recommended that the Train Management System (TMS) also be renewed. This will allow a modern TMS to interface with the new systems and it is expected that reliability will also be improved when the old and outdated TMS is replaced.

While the current auxiliary converter has proved to be reasonably reliable an upgrade will be required as the existing converter will not last the longer service life envisaged for this option. Reliability will be enhanced by employing an IGBT based auxiliary converter and battery charger. Most likely it will be possible to house both components in the one enclosure.

While not included in the budget estimate, there is a development in railway technology beyond the AC induction motor. Suppliers are now promoting permanent magnet AC motors. These motors have a number of features that make them attractive. The motors are fully sealed which results in a greatly increased interval between major overhauls. The bearings are located outside this sealed region and can be accessed without opening the motor. One supplier has quoted 18 years before a major motor overhaul is required.

This technology is starting to be introduced for metro style EMUs and it is understood that adoption of this technology will accelerate. The increase in cost for this technology is approximately \$300,000 per set for the A Series railcar.

Another development in technology for AC traction is the direct drive permanent magnet AC motor. In this case the motor shaft is coupled to the railcar axle, negating the need for a gearbox. Operating experience with this technology is in its early stages but it is expected that it will be increasingly adopted over the coming years.

13. UPGRADE OPTIONS AND COSTS

In accordance with the brief, a set of upgrade options has been investigated.

Costs for each option were then estimated using either data from manufacturers and equipment suppliers or, where this wasn't available, an estimate based on Interfleet's experience and expertise. Discussion regarding the various sub-systems is provided in Appendix 1 and a spreadsheet showing the breakdown of estimated costs for each option is included in appendices 2, 3 and 4. Costs were compared between the suppliers and also with the Interfleet database for such equipment. Generally the costs were within a reasonable range.

It should be noted that the capital costs shown in this section, are in addition to PTA's steady-state maintenance costs. Costs do not include PTA's project management costs or the proposed ATP renewal. The costs outlined are budget estimates and are not the subject of formal quotations. They also do not include additional spare parts, for which Rolling Stock Engineering has put forward a request for funding.

The fleet options have been developed as follows:

- | | |
|----------|--|
| Option 1 | Replacement at the end of 35 years. |
| Option 2 | Service extension to 40 years. |
| Option 3 | Service extension through a re-engineering program to 50 years plus. Considering the good condition of the railcars, 55 years was chosen as an appropriate period. |

13.1. OPTION 1 – REPLACEMENT AT THE END OF 35 YEARS.

This option allows for engineering upgrades to address reliability issues for continued operation through to 35 years. It also offers some further minor upgrades in terms of safety features and passenger amenity. Depending on condition, some of the sets may need to have particular tasks undertaken earlier than the general program.

The scope for Option 1 includes the following key tasks:

1. Carry out verification work for life extension (over design life of 30 years) of body structure and bogies. It is recommended that this be undertaken as soon as possible.
2. Traction Converter – Fleet wide replacement of high power switching elements.
3. Auxiliary Converter – Although reliability is good at present it would be prudent to allow for similar work to that being undertaken on the traction converter.
4. Air conditioning – While reliable at present it would be prudent to allow for a refurbishment at mid-life. This would involve the following:
 - Overhauling compressors;

- Replacing condenser coils on an on-condition basis;
 - Replacing fan bearings; and,
 - Replacing control components such as the DC-DC converter, PLC relays and general high switching rate contactors.
5. Door actuating pneumatic cylinders – mid-life replacement on an on-condition basis
 6. Unit rebuild Master Controllers rebuild / overhaul.
 7. Vacuum circuit breakers – repair as required.
 8. Axle speed probes – replace.
 9. EBC5 brake control unit – rebuild.

Many railway operators experience a marked increase in the gradient of the steady state maintenance cost vs age curve for their rolling stock as it approaches the end of life. For undertaking an economic analysis of the various options outlined, excluding major overhauls and barring unforeseen events, a relatively flat steady state maintenance curve has been assumed. Only an incremental increase over time has been assumed. As outlined in section 7, Rolling Stock Engineering has a policy of pro-actively reviewing sub-system performance and acting to improve areas of sub-optimal design to reduce failures and increase maintenance cycle intervals. This is considered an investment that will deliver cost and performance benefits as the trains enter the second half of their operational life.

Nevertheless it is considered prudent to budget for incremental annual increases as increasingly there will be failures that are unforeseen. For example, QR operational staff indicate the Brisbane EMUs that entered service in 1979 are beginning to experience faults not seen before. These annual increases are estimated at 1% per annum net of inflation.

An outline of costs for these upgrades is provided in Appendix 2. Assuming 2010 dollars, the total for the upgrade work is \$7M.

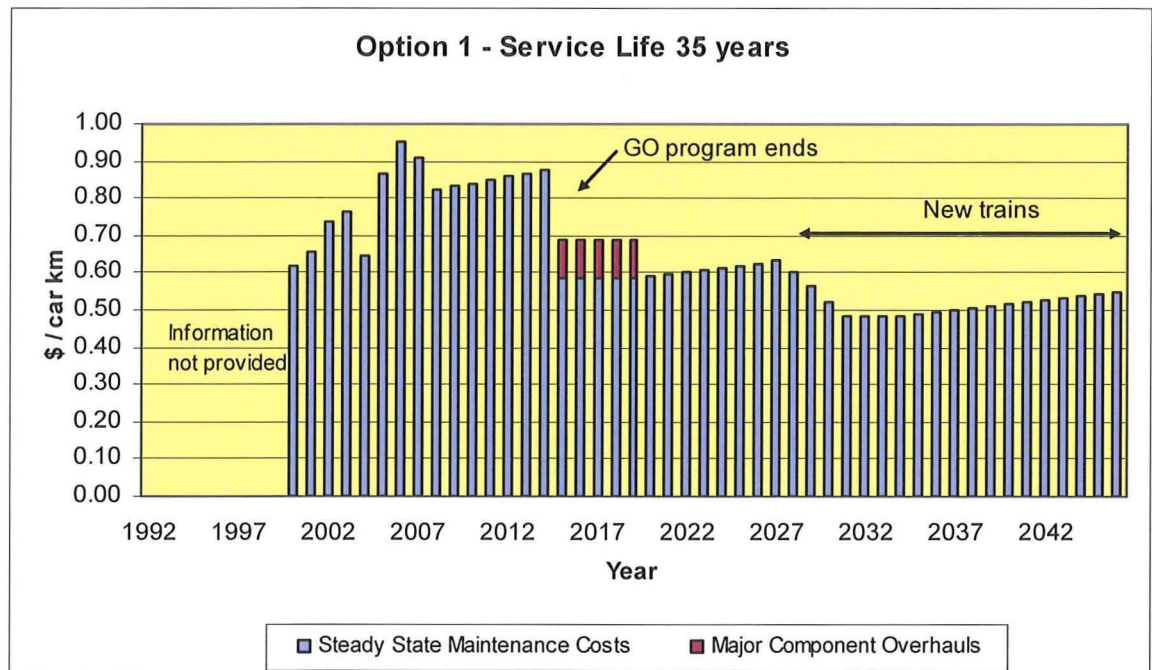


Figure 10: Option 1 Summary of maintenance costs

With this option it is assumed that new trains will replace the current A Series railcars after 35 years of operation in 2026.

The cost of the new trains are taken in to account in section 14 where life cycle costs are analysed using the net present value of future cash flows.

13.2. OPTION 2 – SERVICE EXTENSION TO 40 YEARS.

This option involves the modifications outlined for option 1 plus upgrades to address reliability issues, passenger amenity and DDA compliance.

In addition to option 1 this option includes the following key items:

1. Replace the brake control unit rather than rebuilding it.
2. Install hearing augmentation.
3. Re-position the internal door release to comply with DDA requirements.
4. Install smoke detection.

An outline of costs for these upgrades is provided in Appendix 3. Assuming 2010 dollars, the total for the upgrade work is \$9M.

A chart summarising maintenance and upgrade costs is provided below.

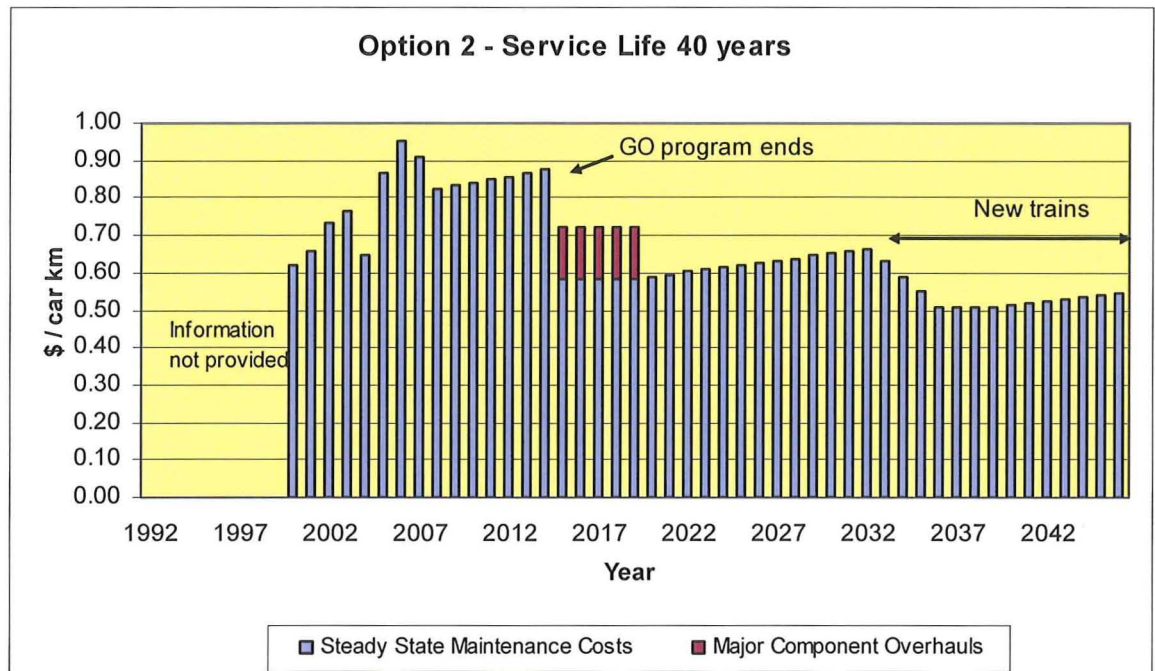


Figure 11: Option 2 - Summary of maintenance costs

13.3. OPTION 3 – SERVICE EXTENSION THROUGH A RE-ENGINEERING PROGRAM TO 55 YEARS

This option involves a major upgrade, the main part being the installation of AC traction. This will provide a more reliable traction system which should see improved performance through to a 55 year life.

An electricity saving of \$1M pa is also expected through the ability to employ regenerative braking.

The complete upgrade includes;

1. Carry out verification work for life extension (over design life of 30 years) of body structure and bogies. It is recommended that this be undertaken as soon as possible.
2. Installation of an AC traction package including new traction converter, traction motors, gearbox and couplings.
3. Modification to the bogies to accept mounting of the AC traction motors.
4. Installation of a new Train Management System.
5. Installation of anti climbers on the car ends to better transmit forces to the car structure in the event of a collision.
6. Installation of a new Auxiliary Converter.
7. Installation of new Intercar Jumpers.
8. Installation of hearing augmentation.
9. Replace the pneumatic actuators for the doors with electric actuators.
10. Install new door pushbuttons.

11. Re-position the internal door release.
12. Install smoke detection.
13. Install new brake control unit.
14. Install modern LED saloon lights.
15. Install LED Marker / red lights.
16. Renew Master Controller.
17. Renew pantograph.
18. Renew axle end speed probes.
19. Replace electrical coupler heads.
20. Replace headlights with HID type.
21. Rebuild air-conditioning units.

An outline of costs for these upgrades is provided in Appendix 4. Assuming 2010 dollars, foreign exchange rates of 1AUD = 0.6 Euro and 1AUD = 80 Yen, and a contingency of 15% the total for the upgrade work is \$115M.

A chart summarising maintenance and upgrade costs is provided below.

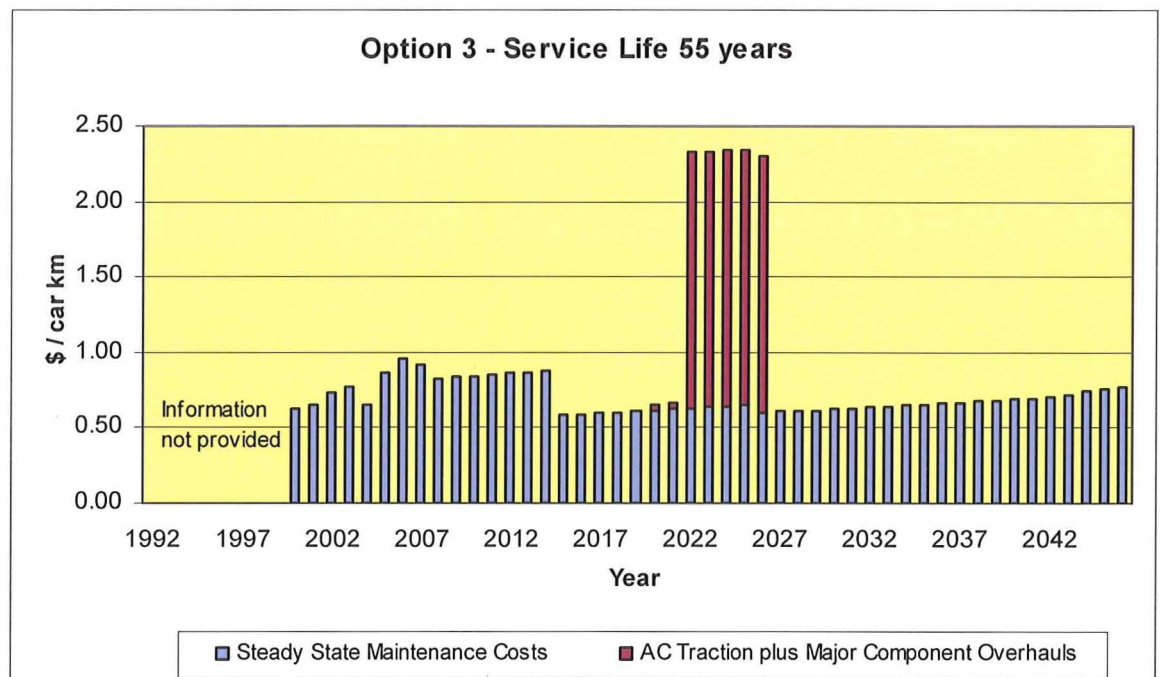


Figure 12: Option 3 - Summary of maintenance costs (including electricity saving)

It is anticipated that two to three sets will be out of service while this major upgrade is undertaken. To cover the timetable requirements for these sets, for the sake of this analysis, it is assumed that spare B Series railcars will be employed on the Heritage lines.

Consideration was given to purchasing three or four sets to cover the shortfall of trains during the upgrade program, however, this was considered an expensive option. Manufacturers will typically attach a significant cost penalty to small orders of especially built trains.

Another option worth considering while undertaking a major upgrade, is to amalgamate two sets into a single four car set. It is understood that this may better suit operations as patronage increases and the A Series railcars are no longer needed to cover services on the North - South lines. This option would involve removing the two centre drivers' cabs thus creating additional passenger space and allowing passengers to walk down the length of the train. This would enhance passenger security and amenity.

This option would allow for cost savings in equipment. For example, it is most likely that only half the axles would need to be powered, saving the cost of four traction motors for one four car set. Similarly this is true with a number of other systems. The equipment saving is estimated to be in the order of 15-20% for a fleet upgrade, however, it is estimated that this saving would be more than offset with the cost of removing the cabs, installing the inter-car connectors and renovating the former cab areas into passenger space.

14. UPGRADE OPTION LIFE CYCLE COSTS

An assessment to judge the three options on their merit from a financial point of view has been undertaken. The three main cash flows and their timings have been tabulated:

1. Steady state maintenance costs;
2. Estimates for the upgrade costs; and,
3. Capital costs for a new train.

These costs are summarised in the following table and assumes 2010 dollars. A cost for new trains is not included in option 3. This is because the 36 year period for undertaking the net present value (NPV) analysis coincides with a train life of 55 years for option 3.

For options 1 and 2 two alternatives are considered for the replacement new trains. Alternative 1 assumes that the new trains will be similar to the B Series railcars and will be 48 x 3 car sets. In this case the price of a new train is taken to be \$10.9M, which is the price recently offered to PTA by Bombardier.

Alternative 2 takes into account the concern regarding limited platform lengths on the heritage lines and assumes that 4 car sets will be purchased. Unlike the current situation, and as assumed in alternative 1, in peak time operations two sets will not be coupled together. In this case half the number of sets will be required. The price of a new four car train, based on the B series railcars, is taken to be \$14M.

	Option 1	Option 2	Option 3
1. Steady state maintenance	Varies see charts in section 13		
2. Upgrade costs	\$7M	\$9M	\$115M
Timing of majority of upgrade costs	2015-2019	2015-2019	2020-2026
3. New train cost Alternative 1 Replacement trains for Option 1 & 2 48 x 3 car sets	\$10.9M	\$10.9M	NA
4. New train cost Alternative 2 Replacement trains for Option 1 & 2 24 x 4 car sets	\$14M	\$14M	NA

Table 7: Summary of costs

A table which details cash flows and their respective timings was compiled and the NPV for each option was calculated. The cash flows that comprise this table are provided in Appendix 5.

The following assumptions were used in compiling the NPV table:

1. The NPV study was assumed to last from 2011 to 2046. This is because in 2046 the trains described in option 3 would have reached the end of their 55 year service life.
2. Maintenance costs are outlined graphically in the previous section.
3. New trains will be delivered over 4 years, from 2027 to 2030 for option 1 and 2032 to 2036 for option 2. Option 3 would require the purchase of new trains in 2047.
4. Depreciation of the new trains for options 1 and 2 was considered to be straight line with the value for the remaining life credited in year 2046.
5. Discount rate to take into account the time value of money of 6%.
6. The only positive cash flow is the crediting of remaining life of the new trains at the end of the 55th year for options 1 and 2. No account has been taken of revenue or changes in revenue associated with new, higher capacity trains.
7. All options include electricity saving of \$1M pa (20% of consumption) following either the delivery of new trains for options 1 and 2 or the AC upgrade for option 3.

The NPV for the three options are as follows:

	Alternative 1 Replacement trains for Option 1 & 2 48 x 3 car sets	Alternative 2 Replacement trains for Option 1 & 2 24 x 4 car sets
Option 1:	- \$270M	- \$210M
Option 2:	- \$221M	- \$184M
Option 3:	- \$168M	- \$168M

Table 8: NPV for the three options

Option 3 has the least negative NPV for both alternatives. Consequently from a financial point of view this option is the most attractive.

15. RISKS

A Strategic Risk Assessment on the future of the A Series railcars was held with PTA on Tuesday, February 16th and was continued on Friday, April 30th at the Perth Station Boardroom. A Risk Management approach consistent with the process defined in AS/NZS ISO 31000: 2009 was employed for the review. PAS 55 notes the importance of risk management in a strategic asset management framework:

"Risk identification, assessment and control are important foundations for proactive asset management. Their overall purpose is to understand the cause, effect, and likelihood of adverse events occurring, to optimally manage such risks to an acceptable level, and to provide an audit trail for the management of risks".

"Whenever possible, risk assessments should be carried out, and the control measures implemented, before changes are made to assets, or to the way in which they are managed."

The workshop participants, for each of the sessions, were as follows:

Participant Name & Position	February 16	April 30
William Wachsmann, Senior Consultant, Interfleet Technology	Yes	Yes
Evan Monkhouse, Consultant, Interfleet Technology	Yes	Yes
Pat Italiano, General Manager, Transperth Train Operations, PTA	Yes	Yes
Jeff Steedman, Business Manager, PTA	Yes	Yes
Elwyn Gearon, Assistant Operations Manager, PTA	Yes	No
Les Robinson, Mechanical Engineer, PTA	Yes	Yes
Rod Vermeulen, Rolling Stock Engineering Manager, PTA	Yes	Yes
Hugh Smith, Executive Director, Strategic Asset Management, PTA	Yes	Yes
Peter King, Chief Financial Officer, PTA	No	Yes
Graham Holden, Consultant	No	Yes

Table 9: Strategic Risk Workshop Participants

Prior to the first workshop date, Interfleet developed workshop slides and a workshop briefing paper with which to introduce the workshop to the participants. The briefing paper was circulated to the participants prior to the workshop and provided the participants with the necessary context and background information.

The briefing paper proposed that the workshop consider the following question:

"What are the foreseeable risks associated with each of the proposed options to the A Series fleet and what treatments could be employed to mitigate these risks?"

The risk assessment criteria and matrix used was that specified by PTA, as derived from PTA's Risk Management System Requirements. PTA's Risk Management System identifies different consequences classifications as Safety, Operations, Technical, Economic, Environment, Political & Public and Compliance. The workshop participants were

encouraged to consider all types of risks for each of the strategic objectives of the fleet. During the risk assessment, for each risk, the relevant consequence classification(s) was identified and the main consequence classification highlighted.

An overview of the level of risk for each of the options is shown in the graph below. In accordance with the PTA Risk Management System, all risks above a level of '10' require a treatment action plan. As such, the graph below shows the risk level for the initial risk evaluation and also the re-assessed risk evaluation (post treatment).

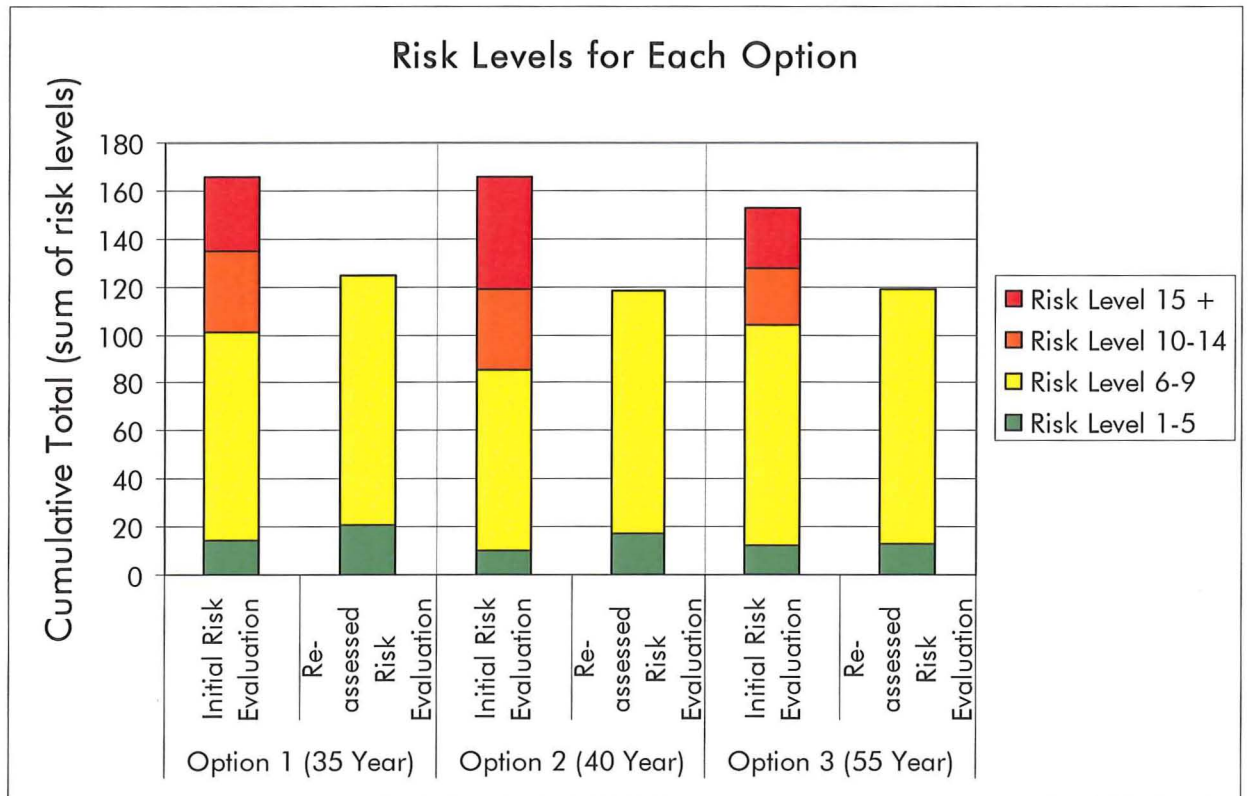


Figure 13: Risk Assessment Output Graph

The risk levels of all identified hazards for each option have been summed to provide the columns shown above. The height of each column indicates the relative risk of each option. From this analysis the risk level of all three options, post treatment, is relatively similar.

Appendix 6 provides the detailed analysis for each hazard identified.

15.1. DISCUSSION OF EXTREME AND HIGH RISKS IDENTIFIED

PTA Risk Management System requires for all risks that have a level of '10' or higher, a treatment action plan is required. Subsequently, the active participants proposed risk treatments for each of these risks identified during the workshop and are discussed in detail in this section.

It is noted that when each of these risks were re-evaluated (post treatment), the level of risk was thought by the participants to have reduced to a level of '9' or below.

15.1.1. 40 YEAR LIFE – IN SPITE OF 40 YEAR PLANNED WORKS TO TRAIN SYSTEM, RELIABILITY ISSUES WILL INCREASE

An operational risk with a level of '12' was identified by the participants where it was thought by increasing the life of the A Series railcars to 40 years, the railcars would see a reduction in their reliability due to new failure modes appearing in the equipment. It was not thought to be as high a risk for the 55 year option as it was assumed the fatigue life would have been reviewed and new equipment would have been fitted as part of the upgrade.

A treatment action plan of an additional budget to compensate for additional maintenance was proposed by the participants. It was also thought the PTA could learn from QR experiences with similar equipment fitted to their railcars. With this treatment action, the risk was re-assessed to a level of '9'.

15.1.2. 35 YEAR LIFE / 40 YEAR LIFE - MISSED OPPORTUNITY TO REDUCE OPERATING EXPENSES BECAUSE AC TRACTION IS NOT ADOPTED AND REGENERATIVE BRAKES ARE NOT FITTED

A risk was identified of a missed opportunity to reduce operating expenses on the A Series railcars due to the fact that unlike the B Series railcars, regenerative braking is not fitted. It was estimated the savings would be in the order to 10% of overall operating costs. This risk was not applicable to the 55 year life option as it was assumed that AC traction will be fitted in this scenario.

When formally evaluated as an Economic risk, the risk was evaluated as being '16'. The workshop decided that a financial study, to be undertaken by PTA, is needed to determine the benefits and costs associated with fitting AC traction and regenerative braking in order to reduce this risk.

15.1.3. 35 YEAR LIFE / 40 YEAR LIFE - CRACKS IN BOGIES

A '10' Safety risk of cracks in bogies was identified by the workshop participants. Although there have been no cracks identified in the A Series bogies to date, the design life is linked with an estimate of

minimum fatigue life. As such, it is reasonable to assume that fatigue damage may commence and will likely become an escalating issue with extended operating life of the vehicles. For the 55 year option, it was assumed by the participants that a full FEA analysis would have been complete prior to a decision being made to extend the life to 55 years.

As mitigation to this risk, it was decided by the workshop participants that a Finite Element Analysis (FEA) and strain gauge testing, together with monitoring through non-destructive testing should be undertaken by PTA in order to reduce this risk.

15.1.4. 35 YEAR LIFE / 40 YEAR LIFE – MISSED OPPORTUNITY TO REDUCE MAINTENANCE EXPENSES FOR BRAKING SYSTEMS WHILE CONTINUING WITH EXISTING TRACTION SYSTEM

The workshop participants recognised that DC traction will result in higher maintenance costs for the friction brakes. This was formally evaluated as an economic risk and was assessed to have a risk level of '15'. This risk was not applicable to the 55 year life option as it was assumed that AC traction will be fitted in this scenario.

Similarly to 16.1.1, the workshop decided that an economic study was needed to determine the benefits and costs associated with fitting AC traction in order to reduce this risk.

15.1.5. 35 YEAR LIFE / 40 YEAR LIFE – INCREASE IN MAINTENANCE COSTS

Typically fleet maintenance costs escalate with age, due to new failure modes occurring. Also, reliability tends to decrease resulting in a drop in on-time running performance and cancelled services. The risk of an increase in maintenance costs was assessed as an Economic risk with a level of '12' for the 35 year option and a level of '16' for the 40 year option. The risk level for the 55 year option was assessed as an Economic risk of '6'. This lower risk ranking was due to the fact that newer equipment will be fitted in this option.

The workshop participants suggested that mitigation to this risk would be to put a contingency in the funding. At the time of the risk assessment, with was not clear to PTA whether this contingency funding currently existed.

15.1.6. 35 YEAR LIFE / 40 YEAR / 55 YEAR LIFE – FUNDING CYCLE DOES NOT MATCH STRATEGIC VIEW OF ASSETS

A Political & Public risk was identified by the workshop participants where the WA Government forces PTA to keep their trains in service longer than had been original planned. This risk of 'funding cycle does not match strategic view of assets' was evaluated to have a risk level of

'16' by the participants. The impacts of this risk would be reliability issues and a decrease in public perception.

To mitigate this risk, the participants suggesting interacting with the WA Government in a different way via lobbying, demonstrate strong leadership and communicate to the Government early and often. With these risk mitigations in place, the risk was still thought by the participants to be reduced to a level of '8'.

15.1.7. 55 YEAR LIFE – RELEASING CARS FOR UPGRADE PROGRAM MEANS TRAIN SETS ARE NOT AVAILABLE FOR PASSENGERS

The Economic risk of not having enough train sets available to passengers due to cars going through an upgrade program was assessed by the participants as a '25'. This was the highest risk identified by the participants and also the highest ranking on PTA's risk matrix. This risk was only applicable to the 55 year option.

As a treatment action plan, several mitigations were proposed by the participants. It was thought that PTA could consider ordering more railcars in the next train order to compensate for sets that will be unavailable due to the upgrade program. Operational mitigations proposed included changing the timetable, running three car sets on heritage lines or increasing the frequencies of services. By planning and spending strategically, the participants believed that this risk would be reduced to a risk level of '1'.

15.1.8. 55 YEAR LIFE – TEETHING PROBLEMS WITH NEW EQUIPMENT (E.G. AC TRACTION)

By fitting AC traction to the A Series railcars in order to extend the life to 50 years, an Operational risk with a level of '12' was identified by the workshop participants. There is a risk that there will be 'teething' problems with the new AC equipment and these unexpected problems will lead to reliability issues.

The workshop participants agreed that mitigations to this risk would be extensive testing and commissioning of new equipment, prototype equipment and possibly reducing / limiting the scope. These mitigations would help reduce both the consequence and likelihood of this risk and would need to be built into any PTA project management plan associated with life extension work.

16. CONCLUSIONS

PTA is currently in the operation and maintenance phase of a strategic asset model. It was required that an examination of the enhancement vs disposal phase for the A Series railcars was undertaken. The condition of the A Series railcar fleet has been assessed and various options have been considered to account for different levels of upgrade work to support three life extension options.

Various aspects of life extension have been examined and the following points can be made.

1. The A Series railcars are viewed positively by passengers as indicated by annual surveys. They have a modern interior and are hardly discernable as different from the more modern B Series railcars. Also, disabled access features are excellent. Investment by PTA in a high level of presentation and modifications for DDA compliance has been successful. These are two areas that often require a large investment with other fleets and can cause life extension projects to fail a feasibility study. This is not the case for the A Series railcars.
2. The specified design life is an important factor with respect to the car-body and bogies. Usually the design life is linked with an estimate of minimum fatigue life. It is reasonable to assume that fatigue damage may commence and will likely become an escalating issue with extended operating life of the vehicles. Interfleet was unable to resolve this important issue as supporting documentation provided by PTA, from the manufacturer, was insufficient and did not provide an appropriate level of confidence that the structures could last 30-50 years without fatigue issues.

Consequently it is recommended that a structural finite element analysis (FEA) is undertaken of both the body and bogies prior to a decision being made regarding life extension.

3. The vehicles are fitted with some out of date technology, in particular the DC traction control system, auxiliary converter and Train Management System. Reliability and the sourcing of spare parts can become an issue with such equipment.

While the traction system and auxiliary converter is based on out-dated technology both systems are operating reasonably reliably. PTA has established a specific electronics workshop to repair and troubleshoot the control electronics for these systems and this facility seems to be coping well. Also in extreme cases it is understood that the manufacturer will continue to support the product although it will involve a long lead time and relatively high cost. The high power switching elements are also able to be obtained directly from semi-conductor manufacturers. Both systems are based on thyristors which are not an obsolete component. Consequently with a mid-life upgrade both systems can be maintained for the foreseeable future. Nevertheless, for the longer life extension option a change to an AC traction system and a new modern auxiliary converter is recommended.

The Train Management System is a high contributor to poor reliability. Rolling Stock Engineering has just installed a test rack within the electronic workshop to improve repair and testing of printed circuit board cards for this system and it is envisaged that this will address the reliability problem.

- Typically fleet maintenance costs escalate markedly with age. Also reliability tends to decrease resulting in a drop in on-time running performance and cancelled services. The pro-active maintenance system adopted by the Rolling Stock Engineering team at the Claisebrook depot will deliver benefits in this regard. Condition monitoring of sub systems and components has resulted in a better understanding of reliability and performance with modifications undertaken to not only replace faulty components but also improve on them. This investment in the early part of the railcar's life cycle will pay dividends in the second half of its life. It is envisaged that steady state maintenance costs will not increase at the rate normally expected.

Maintenance cash flows have been extrapolated from the existing data and future cash flows for upgrades have been estimated. Because of the current pro-active maintenance regime it is felt that maintenance costs will not increase markedly as the A Series railcars age. After upgrades, maintenance costs should decrease and this is most marked following the upgrade to AC traction which is included in option 3.

A Net Present Value (NPV) analysis has been undertaken assuming two alternatives. The first assumes that the replacement fleet for options 1 and 2 is 48 x 3 car sets similar to the B series. The second alternative assumes that the replacement fleet for options 1 and 2 is 24 x 4 car sets, a new type of train for Perth which takes into account the concern regarding limited platform lengths on the Heritage lines. For both alternatives, option 3, lengthening the service life of the A Series railcar to 55 years, is the most attractive option from a financial point of view.

Two risk workshops were undertaken with the management team of Transperth Train Operations. The outcome of these workshops indicates that the level of risk is relatively similar between the three options.

Contingent upon the bogie and body fatigue life, option 3, lengthening the service life of the A Series railcar to 55 years, is the recommended option. This is based on the risk profile being similar between the three options and option 3 having the best Net Present Value (NPV).

17. GLOSSARY OF TERMS

AC alternating current

ATP (Automatic Train Protection): a system for ensuring positive train separation.

Brake Blending: the method by which different braking systems on a train are combined into one braking sequence so that a smooth overall braking control is achieved.

Brake Valve Isolating Cock: an electro-mechanical device located within the Brake Controller which allows the driver to control the flow of compressed air to the braking system.

Car: Used when describing, or in reference to, rail vehicles of a specific type of group, e.g. freight cars, passenger cars, tank cars, flat cars etc (sometimes referred to as a 'wagon')

CCO (Component Change Out): a maintenance process that involves the replacement of components at a pre-determined time.

Chopper Drive: a type of semiconductor technology employing Gate Turn Off thyristors (GTOs) or IGBTs used to control DC traction motors.

DC: direct current.

DC Drive: A type of semiconductor technology which is used to control DC traction motors.

DDA: Disability Discrimination Act.

Disc Brake: A mechanical braking system where two brake pads are forced against each side of a disc attached to a wheel or axle to achieve braking.

EDR (Emergency Door Release): Facility to allow crew and/or passengers to override door locking mechanisms to open doors in an emergency situation.

ERTMS: European Rail Traffic Management System

Fatigue Crack: An undesirable crack in material as a result of repetitive movement.

GO: General Overhaul

GTO (Gate Turn Off thyristor): A relatively slow speed semiconductor device

Headstock: A tubular cross-member welded between the side frames at each end of the motor bogie for the purpose of mounting the brake equipment.

IGBT Insulated Gate Bipolar Transistor – modern, high speed semi-conductor switching device.

OEM: Original Equipment Manufacturer

Pantograph: an apparatus fixed to the roof of electric traction vehicles to draw current from the 25kV overhead power supply.

RAPID: Recording And Passenger Information Dissemination.

Regenerative Brake: an electrical braking system where, by electronic means, the driving motor is commanded to effectively go into reverse whilst moving forward. The electrical energy generated from this technique is put back into the overhead power system.

Risk: the combined likelihood and consequences of a hazard being realised.

Rollingstock: A collective term for rail vehicles of various types, including locomotives, freight, service and passenger vehicles.

Set: generally used when referring to a multiple-car set – two or more compatible and easily separable cars coupled together to form an operating consist. A multiple-car set may include all powered or a combination of power and trailer cars.

Side Frames: the two fabricated steel side members of the bogie, held apart by the transom.

Slip Slide protection: an electronic control device which monitors the rotation of the train wheels and controls the tractive and/or braking effort to prevent the wheels skidding on the track.

Spike: in electrical technology refers to a sudden short term rise in voltage which can have an undesirable result or cause component Failure.

Stable: to leave a train unattended and secured, usually in a siding.

Static Inverter (SIV): a semiconductor power supply used to generate AC power.

Strain Gauge: an electronic device which can detect strain on a surface.

Technical Maintenance Plan (TMP): Definition of maintenance activities and

VESDA System: an on-board smoke detection system that meets the specified requirements for a 'Very Early Smoke Detection Alarm'.

Vigilance Equipment: equipment installed in the driving console which requires the driver to regularly press a button to indicate their presence.

Wheelset: an assembly of two wheels on an axle.

18. APPENDIX 1 CONDITION OF THE FLEET

18.1. CAR BODY

18.1.1. STRUCTURAL

In summary, from our inspections and interviews, there is no corrosion visible nor are the maintenance staff aware of any. The body is in good condition and the stainless steel finish is attractive and appealing to passengers.

It was reported that cracks were discovered in floor support members in 2007. Two instances of these cracks were found and they were attributed to a combination of poor welding at the point of cracking, and stress due to sub-optimal installation of the floating floor during manufacture. In most of the cars the wooden floating floor has been replaced and this condition rectified.

Other than those mentioned above, no fatigue cracks have been identified at this stage. Nevertheless, fatigue is an issue that needs to be considered. It is important to come to a view regarding this as managing fatigue cracks can become an increasing expense until the train must be de-commissioned before the operator is ready to dispose of the asset. Typically design life is linked with an estimate of fatigue life for the body and bogie structures. Fatigue damage is a cumulative effect from operating load cycles which commences from day one in service, and exists even if no cracks are visible yet.

A number of documents have been provided to Interfleet which discuss structural issues. The one of most value is the Finite Element Analysis (FEA) undertaken by Bombardier on the B Series car body. The body is reported by PTA to be very similar to that of the A Series railcars.

On close examination of the report certain frailties appear. In summary the main aspects of concern to Interfleet are as follows:

- Only a "single pass" of the FEA process was undertaken. That is, the finite element model was not refined to alleviate visually obvious coarse mesh effects on the calculated results. Many stress "hotspots" occur in regions of coarse mesh relative to the underlying geometric feature. To fully understand the stress characteristics at these points the mesh could have been made finer. There are numerous instances where hotspots are singularities due to coarse mesh, i.e. the hotspot is one element away from where it would be intuitively expected to occur.
- Buckling analysis (particularly for the buff and collision load cases) was not considered in the reported scope of work.

- It would be useful to replace standard forces in the calculations with those actually being experienced in service by the vehicles for fatigue life assessment.

Crashworthiness as originally specified in the A Series railcars is on a par with contemporary specifications. Interfleet understand that during the early years of operation an A Series railcar collided with the Armadale dock and suffered structural damage to the front drag box, the cab doorway as well as some minor side wall crumple between the cab and #4 saloon door. An analysis of the damage indicated that the train behaved in a manner that was relatively close to that predicted by the designer. Nevertheless the FEA report provided to Interfleet is not of a standard that would enable Interfleet to verify the requirements of the A Series specification.

In summary the FEA report does not provide an appropriate level of confidence that the structure could last 30-50 years without fatigue issues, or behave predictably in non-frontal crash situations. Further engineering analysis and testing would need to be done to provide confidence regarding this.

In our discussion with Queensland Railways (QR) operations staff at the Mayne depot they reported that there have been no cracks found on their EMU car bodies. These trains are of a similar design from the same manufacturer and are 12 years older. While this provides a certain sense of comfort it needs to be highlighted that operational conditions are not the same and cannot be taken to act as a predictor of performance for the Perth trains.

18.1.2. UNDERFRAME EQUIPMENT

Generally the mounting of the underframe equipment is in good condition, however, there is a corrosion problem with enclosures manufactured from painted carbon steel. The lids are being replaced with stainless steel and some boxes are being replaced altogether due to high levels of corrosion.

Rolling Stock Engineering have been replacing these items for a period of time now and these costs are considered to be part of the General Overhaul (GO) maintenance cost base.

18.1.3. EXTERNAL FITTING BODY ENDS

The fibreglass ends are in good condition with the fibreglass polished at least once per year.

18.1.4. INTERNAL FITTINGS AND PANELS

Internal fibreglass is also polished and repaired if scratched. It is in good condition and contributes to the pleasant atmosphere for passengers.

18.1.5. WINDOWS

Corrosion has been identified on window frames. These frames are replaced or repaired during GO. Rolling Stock Engineering at the Claisebrook depot has improved the design of the window frames to overcome corrosion in the future. The aluminium frames are now separated from the stainless steel car body in order to reduce galvanic action. Also the frames incorporate improved anodising in comparison to the original specification.

Windows are replaced every year and returned to a glass supplier for replacement of the plastic protective film on the inside. This contributes to the amenity of the train for passengers as there are less scratched windows.

18.1.6. SEATS

The transverse seats have been progressively changed to longitudinal. Management approval for the final tranche being changed out has just been received. Similarly with updated seat fabric. The seats are in good condition and compare favourably with those in the B Series railcars.

18.1.7. FLOORS

Carpets are cleaned regularly and are in good condition. They are replaced approximately every seven years and this cost is included in the steady state maintenance base line.

There has been problems with the plywood sub-floor delaminating. It was during a floor replacement that the cracks in the floor support members were noticed and this triggered a fleet wide floor replacement and check.

18.2. BOGIES AND WHEELSETS

18.2.1. BOGIES FRAME

No structural design reports have been received for the bogie. While no cracks have been found in the bogie frames, the bogies only undergo non-destructive testing if cracks are seen through the paintwork during a bogie overhaul.

At this stage of the train life it is considered appropriate to take a more pro-active approach to ascertain the durability of the bogie frame structure. This would entail measuring strains on the bogie during operation to determine loads and use these as input into a fatigue life assessment. From this, areas of high stress can be identified and judged as to whether they will be of concern as the railcars become older. Also once high stress areas are identified, a scheduled campaign of non-destructive testing can be undertaken during bogie overhaul so that there can be assurance that any cracks that may be initiating under the paint are detected.

This bogie is not the same design as that supporting the Brisbane EMUs so no comparison can be gained from the Brisbane operation.

18.2.2. PRIMARY SUSPENSION

The condition of the springs and dampers are monitored and is good.

18.2.3. SECONDARY SUSPENSION

Air Springs are in good condition and pose no extra-ordinary problems.

18.2.4. WHEEL SETS

Wheel life can be as high as 10 years (or in some cases longer). This is at an annual average distance travelled of 140,000km. This is long wheel life by any standard. Bearing life then becomes the limiting factor. Claisebrook depot has formulated a monitoring system to check on bearing condition. This is important as the bearings are typically operating at a higher number of kilometres that that recommended by the bearing manufacturer. Rolling Stock Engineering report no backlog in wheelset overhauls thus these costs are reflected in the steady state maintenance costs.

18.2.5. TRACTION MOTORS AND GEARBOXES

Traction motors have been modified since the railcars entered service and their overhaul interval and reliability have improved. The current overhaul interval is 5-8 years.

The maintenance requirements of the DC traction motors have been incorporated into the maintenance schedules. The profile of the commutators are measured and recorded into maintenance history with trends being monitored to allow maintenance staff to prepare for further work. Commutator grinding is undertaken in situ under the train.

The gearboxes have been modified with the cast iron casing being replaced with an aluminium casing. This allows for better handling by maintenance so that re-assembly can be performed with higher quality and a reduction in oil leaks has been noted.

18.3. COUPLERS AND INTER-CAR CONNECTIONS

18.3.1. AUTOCOUPERS

The auto couplers have been the subject of investigation by Rolling Stock Engineering and a number of modifications have been undertaken. Interfleet understand that these modifications have resulted in improved, and now acceptable performance.

18.3.2. INTER CAR JUMPER CONNECTIONS

Inter-car jumpers are currently reported to be in a good condition with no particular issues being highlighted. Two suppliers have indicated that the design life of inter-car jumpers is approximately 15 – 20 years dependant on the amount of movement between vehicles, the physical construction and the environmental conditions. The inter-car jumpers are replaced during the GO.

It may be necessary to upgrade the inter-car jumpers to provide additional capacity and signal type enhancements. This is included for the life extension option to 55 years.

18.3.3. AUTO-COUPLER ELECTRICAL HEADS

The Auto-coupler electrical heads are reported to be in good condition with no particular issues being highlighted. Unlike flexible inter-car jumpers they are less susceptible to wear and degradation through inter vehicle movement. As such it is expected that the coupler electrical heads will only require overhaul / change out in line with the original manufacturer's recommendations. This should include

replacing rubber seals and other flexible components and replacing any damaged contacts.

It may be necessary to replace the electrical heads or provide an additional head to provide capacity and signal type enhancements. This requirement will be dependant upon future modifications and technology advances. The indicative cost for replacement electrical heads is \$106,000 per set (i.e. 4 electrical heads). This has been included in the budget for the life extension option to 55 years.

18.4. DOOR SYSTEMS

18.4.1. PASSENGER BODYSIDE DOORS

Passenger bodyside doors are a key passenger interface and are subject to frequent open and closing as well as abuse by passengers. Their functionality is critical to the safe and reliable operation of the railcars.

A review of performance data provided by PTA indicates that the current passenger bodyside doors system is a significant contributor to the Lost Time Incidents on the A series railcars.

It is understood from discussions with PTA staff that the main cause of passenger bodyside door system failures are the door controllers. PTA is developing a new door control unit (DCU) using solid state electronics. When implemented this should reduce DCU failures.

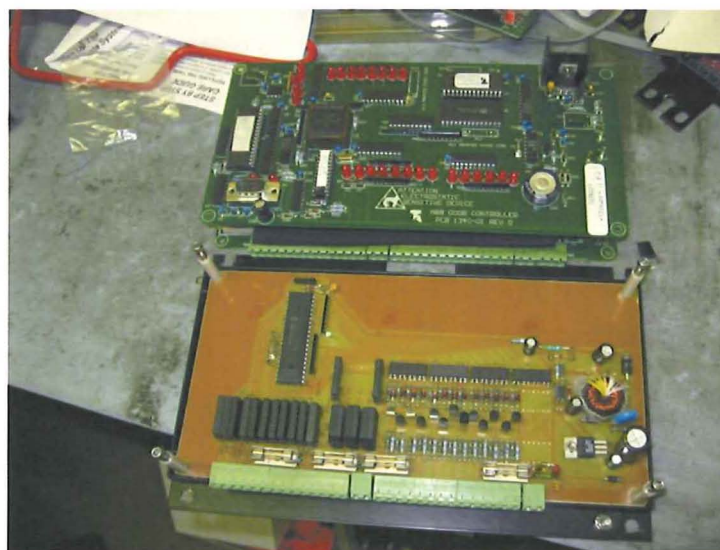


Figure 14: Visual comparison between the old door control unit (DCU) at the top and the new design being made in Claisebrook Depot.

The new design of DCU overcomes the issue of output relay life by employing solid state switches. The new design will be fully interchangeable with the *as delivered* DCU but with far higher reliability. This is an example of employing updated technology that has become more accessible since the train entered operation.

De-lamination of the door leaves has caused problems for the maintenance team. Doors are assessed and repaired or replaced if necessary during the GO for each car. A local supplier has been approved for supply of door leaves.

A number of the failures are understood to be caused by other components within the system. The A series railcars are fitted with air operated sliding pocket doors whilst the majority of modern EMUs, including the B series railcars use electrically operated sliding plug doors. Such doors, while more complex and difficult to set up, generally perform better in service than the air powered equivalent. When combined with electronic Door Control Units (DCU) they also provide enhanced functionality and control. Such enhancements include, but are not limited to, improved fault diagnostics and modern obstacle detection to improve passenger safety. It is also acknowledged that once set up correctly electrically operated sliding plug doors generally require less maintenance than their pneumatic equivalent.

A high level review of the technical risks and both engineering and material costs associated with changing the existing sliding pocket door system to a sliding plug system indicates that such a change would be prohibitively expensive and introduce technical risk that is likely to outweigh the benefits. Consequently it is recommended that consideration be given to replacing the existing door mechanism and control system with electrically operated actuators and new DCUs, whilst retaining the existing door leaves and the sliding pocket arrangement.

Interfleet recommends that replacement electrical mechanisms and new DCUs, with modern functionality, be introduced to extend the service life to 55 years.

18.4.2. INTER-CAR DOORS

Whilst inter-car doors are also a key passenger interface they are subject to less frequent operation and less abuse by passengers. Whilst some of their functionality affects passenger safety their operation is unlikely to affect reliable operation of the railcars.

From inspections carried out by Interfleet the inter-car doors do not appear to be affected by discolouration of the glass unlike other similar aged trains operating in Australia.

It is noted that the B series railcars are not fitted with inter-car doors providing a more open passenger saloon which assists in enhancing the perception of safety and security. Given that passenger perception of the vehicle age is a key consideration in what to replace during a refurbishment or life extension program, consideration should be given to modifying the door system to remain open during normal operation. This would be in conjunction with improving sound insulation in the gangways and interfacing the inter-car doors with a smoke detection system so that they automatically close if smoke is detected.

18.4.3. CAB DOORS

Cab doors on both the A and B series railcars are a hinged door with a traditional style of door handle and locking mechanism. As such the A series cab doors do not deflect from the image of a modern railcar, given that the same style is also fitted to the newer B series.

These doors have experienced de-lamination similar to the saloon doors and a similar action plan is carried out with these.

Interfleet does not, therefore, recommend any fundamental changes in this area although changes to the locking mechanism, possibly to an electronic version, may aid access from track level.

18.4.4. PASSENGER DOOR PUSHBUTTONS

The control push buttons fitted to the A series railcars for both the passenger bodyside and inter-car doors are compliant with the basic requirements of the Disability Standards for Accessible Public Transport 2002.

These buttons are a "soft touch" button specifically developed for the PTA so that people with motor function disabilities can operate the doors. They are common with those fitted on the B series railcars. As such no campaign replacement is recommended as part of any upgrade to increase the service life of the A series railcars.

18.4.5. INTERNAL EMERGENCY DOOR RELEASE

It is understood that the internal emergency door release is currently un-regulated. The trend is for modern trains to have regulated door releases where the doors only open if the driver does not over-ride a

door opening request and the train is stationary. This overcomes the risk of passengers moving into an unsafe area. This could be linked to the CCTV system in the train.

18.5. BRAKING SYSTEMS

The brakes were manufactured by Davies and Metcalf, now known as Faiveley. They are out-board mounted electro-pneumatic (EP) disc brakes.

18.5.1. BRAKE CONTROL UNITS (BCU)

Three Faiveley EBC5 brake control units are employed on each A Series railcar. Recently Faiveley has begun to compete with UGL for the overhaul of these components and have proved to be price competitive. Rolling Stock Engineering has been able to gain a price of \$9,000 for an overhaul rather than a total price of \$16,000 (parts and labour) from UGL.

The EBC5 is a commonly used system around Australia and the world and is considered to continue to be serviceable in the future.

There have been 19 brake system electronics failures during the 2 years covered by the data provided by PTA. This is less than 1.5% of the total Lost Time Incidents. As such the failure rate is not highlighting any particular issues that would need to be addressed in order to keep the railcars operating beyond their original service life. It is noted that the technology used within the BCU is at least 20 years old and due to advances in electronics technology it is foreseeable that obsolescence will become an issue, particularly when considering a service life of 40 to 55 years.

In order to overcome this Interfleet recommends that a new, current technology BCU be fitted for the 40 year + life extension options. Such an upgrade would also allow for improved fault diagnostics, updates to interfaces with the traction system and improvements to the WSP control system.

18.5.2. AXLE END SPEED PROBES

Axle end speed probes have caused approximately 2% of the Lost Time Incidents in the data supplied by PTA and appear within the top 10 failure modes (when vandalism, miscellaneous faults and those rectified by a shutdown are excluded). As such Interfleet recommend that consideration be given to replacing this equipment with newer, more reliable equipment for all options under consideration including the 35 year service life option.

18.5.3. WHEEL SLIDE SYSTEM

The current wheel slide system is serviced by Knorr Bremse and whilst occasional failures are reported they are repaired in PTA's electronics workshop.

In a similar manner to the brake system electronics, the wheel slide protection (WSP) control electronics are likely to be affected by obsolescence due to their age and the rapid development of electronics since their design and manufacture. As such Interfleet recommends that the control system for the WSP be included within the BCU upgrade recommended for the 40 and 55 year options.

18.5.4. BRAKE CYLINDERS

To overcome an increased maintenance and overhaul costs for this component a fleet wide replacement of the brake cylinders was undertaken recently. This should see this component lasting until the current life end at 35 years.

18.5.5. BRAKE RIGGING

After delivery a design problem with the brake rigging was identified and corrected. This item is now performing well.

18.5.6. BRAKE PIPING AND HOSES

These items are maintained so they exhibit no problems.

18.6. PNEUMATICS (OTHER THAN BRAKES)

18.6.1. MAIN AIR COMPRESSOR

The first 43 sets of the A series railcars are fitted with an Atlas Copco screw compressor, Model GAR 25B 150. The later five sets employ a Knorr Bremse compressor.

Whilst this equipment is 18 years old, the basic technology used within these compressors remains current and continues to be fitted to new rolling stock being manufactured today. These compressors have few moving parts - air is drawn into the chamber formed between the two mating screws. As the screws rotate the inlet is then blocked off by the rotating screw and the air is compressed by the decreasing volume of the chamber formed between the two screws. The two screws are driven by synchronising gears and whilst close fitting there is no physical contact between the screws. In compressors such as those fitted to the A series railcars, oil is injected into the compression cavities to aid sealing and to provide cooling for the air as it is compressed. The oil is then removed from the air and the air is further cooled.

Improvements to the air-compressor assembly have been undertaken by PTA to improve maintenance and performance. These include the following:

- Modifying the mounting frame to make it easier to remove the motor;
- Replacement of the drive coupling;
- Modifying the compressor to allow unloaded starts;
- Replacement of the motor with a 4 pole to 6 pole speed – for longer running and improved operation of oil separator.

Consequently the air-compressor generally operates and performs well.

It is noted, however, that the cited cause of failure of the park brake apply and release valves is oil contamination of the valve seals. Further improvements to reduce oil carry over may be appropriate.

Interfleet has discussed options for the compressor with the OEM of this equipment. The two main options discussed were to continue to operate the existing compressors and undertake overhauls at regular intervals or to fit a new screw compressor. The former would replace the main components, such as seals and bearings, which would degrade with time and use. The latter would introduce a more modern compressor with the developments in the design and technology that have occurred since the A series were built.

Atlas Copco has provided an indicative price for the necessary overhauls to extend the life of the compressor to 50 years. The cost quoted by Atlas Copco for overhauls is \$50,700. When the

magnitude of this quotation was questioned, Interfleet were advised that it covers the extreme of circumstances and compressor conditions that could occur. Atlas Copco has advised that a quote based on an actual A series compressor could be developed if required. It is understood that the compressors are currently being overhauled by a local supplier at a more competitive price.

The indicative cost for a replacement rotary screw compressor is \$27,500. Interfleet, however, considers a new compressor is unnecessary and given the limited number of moving parts and low levels of wear, due to there being no physical contact between the two rotors, that the compressor will be able to be operated for a further 36 years if necessary. A review of the performance data provided by PTA supports this – only 21 of the 1375 Lost Time Incidents (i.e. 1.5%) were caused by the air compressor.

18.6.2. PANTOGRAPH (AUXILIARY) COMPRESSOR

A review of the performance data revealed no Lost Time Incidents that were attributed to the pantograph compressor. Given the frequency of use, and when it is used, its lack of impact on service is not unexpected.

Based upon the performance data provided and Interfleet's knowledge of similar compressors, Interfleet recommends that the compressor continues to be used throughout the life of the vehicle

18.6.3. AIR DRYER FILTER SYSTEM

A desiccant system is used to extract water from the compressed air. This system has historically become overloaded with oil, although modifications upstream have allowed this system to work in an acceptable manner.

Since the A series railcars started operation, manufacturers of compressed air systems have introduced membrane driers as an alternative to desiccant based systems. Those fitted to rolling stock known to Interfleet are suffering from high rates of failure. As such Interfleet would not recommend fitting more modern technology unless PTA were able to satisfy themselves that the performance of membrane driers had improved to a satisfactory standard.

18.6.4. AIR RESERVOIRS

These are manufactured from painted galvanised steel. As required under legislation these are inspected at the required intervals and no corrosion has been reported.

18.6.5. AIR PRESSURE SWITCHES

The switches with the higher cycle rates are showing some problems. Nevertheless these switches can be easily replaced at relatively low cost.

18.7. AUXILIARY EQUIPMENT

18.7.1. WINDSCREEN WASH WIPER SYSTEM

The A series railcars have recently been retro-fitted with an electrically driven windscreen wiper system. As such the wiper system is aligned with current norms and best practice and no significant modification to the system is recommended for any life extension option.

18.7.2. AIR HORN

The horns both operate satisfactorily.

18.7.3. SMOKE DETECTION

Unlike the more modern B series railcars and other modern EMUs the A series railcars are not currently fitted with a smoke detection system. This was reviewed in the risk assessment workshop and referenced in section 15. The risk assessment determined that the risk of not installing a smoke detection system was low because of the fire and smoke retardant material in the railcars and a good track record with respect to this risk.

Whilst not currently required for continued operation through 55 years Interfleet recommends that further consideration be given to fitting a VESDA, or similar smoke detection system, to the A series railcars as part of a major life extension upgrade. This would equip the A series with a system that would align them with other modern EMUs and also be aligned with the principal of ALARP.

Fitting such a system would also allow modifications to the inter-car doors to enable them to be open during normal operation as discussed in section 18.4.2 above further aligning the appearance of the A series railcars with more modern EMUs including the B series railcars

18.8. CLIMATE CONTROL

The A Series railcars are equipped with two air-conditioning units per car. These have proved to be reliable and have performed well keeping the passengers comfortable.

Air-conditioning problems contribute to very few LTIs. The main reason for this is that there are two units per car. In case of failure, the remaining unit will generally keep the interior of the train reasonably comfortable. It is only with a full train, on a hot day, that a unit failure will cause serious problems

A major reason for the success of this sub-system is the air-conditioning contractor for PTA. He is a former employee of the manufacturer, Sigma Industries (now Sigma Coachair Group) and has proven to not only service the equipment well, but has also undertaken well considered modifications. Examples of these of these modifications include:

- Replacement of the mechanical type return air thermostat with an electronic thermostat (currently being undertaken);
- As required, replacement of the original R12 refrigerant with R413A a refrigerant with zero ozone depletion potential.

Continuing with the current maintenance regime this system will last to 35 years life and beyond. We see no reason for its replacement. The main structure comprising the unit case was manufactured from stainless steel and the heat exchanger coils were manufactured with copper fins and brass end-plates. Nevertheless certain components within the air-conditioning units will need replacement over time and these include:

- contactors and relays (including the output relays on the PLC);
- control circuit DC-DC converter; and
- some condenser coils will need replacement because of corrosion due to the mildly corrosive car wash.

The manufacturer recommended an overhaul schedule for the compressors but PTA has adopted a monitoring regime that has shown itself to be effective. To illustrate this, without a specific overhaul campaign, and from a fleet of almost 200 air-conditioning units operating for up to 18 years, only 31 compressors have failed needing to be rebuilt. The compressor is a Carrier 06D semi hermetic compressor that is particularly robust.

Nevertheless it would be prudent to allow for a mid-life overhaul. Consideration should be given to a compressor re-build as well as the other measures outlined above.

18.9. TRACTION SYSTEMS

18.9.1. TRACTION CONTROL SYSTEM

The traction control system on the A Series railcars is based on a well-known technique known as Phase Angle Control. This technique is used in many rail applications around the world and has proven to be reliable.

It employs a solid state device known as a thyristor. Thyristors are used to rectify the single phase AC voltage in the same way as a diode does in a bridge rectifier, however, thyristors have the advantage that they can be gated, or turned on. The gating or switching on point of the thyristor can be controlled to provide a continuously variable supply voltage to the DC traction motors from zero volts to full volts, as the following table shows:

Situation	Rectifier Output
Thyristor bridge switched off continuously	Nil output
Thyristor bridge switched on and off for equal periods	Average output is half supply voltage.
Thyristor bridge switched on continuously.	Fully rectified supply voltage

Table 10: Traction Control

With an AC supply, the thyristor will automatically turn itself off when the current turns to zero (every half cycle), ready to be switched on again at the appropriate point in the next half cycle.

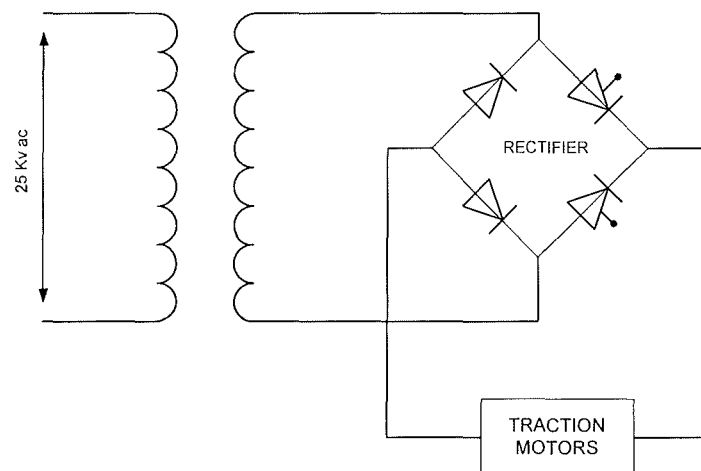


Figure 15: Typical Circuit for a Phase Angle Control Traction System.

The A Series railcars employ the above technique, however, in a double controlled bridge, with two voltage sources. That is, with two secondary tapplings out of the main transformer. This improves power factor and addresses interference problems.

The A Series railcars do not employ a state of the art traction control system. With developments in high power electronics DC traction has now been replaced with AC traction. AC traction will be discussed in a later section as one of the options for increasing the life of train.

The heart of the A Series railcars' traction control system comprises 4 thyristors and 4 diodes. Unlike other switching elements, such as Gate Turn Off (GTO) Thyristors, these solid state devices are expected to be available into the foreseeable future. The A Series railcars employ a MIL standard thyristor. Being of military standard this component is somewhat specialised and has a long lead time of 9 months, but nevertheless is still readily available. Currently the thyristors and diodes are beginning to become un-reliable due to age, and the relatively high temperatures that are experienced in Perth. Rolling Stock Engineering is investigating replacing these on a fleet wide basis – for a cost of approximately \$1.2M. Interfleet has included this cost into an upgrade program for all three options.

The control circuits for the traction control system are removable Printed Circuit Boards (PCBs) that experience failures from time to time. Rather than send these back to the manufacturer, and experience the long lead time to repair and return these cards from Sweden, a strategic decision was taken to establish a workshop dedicated to repairing electronic boards. Two technicians are employed. The majority of faults are able to be repaired by the electronics workshop with many faults being obvious, with a burnt area indicating a failed component. Function testing of these boards is possible without a test rack because the maintenance manuals, as originally written by ASEA, are of a high standard and so output and intermediate waveforms can be checked on the bench with an oscilloscope. In a situation where a fault cannot be found, it is understood that Bombardier will still support the repair of the ASEA components although it will involve a long lead time.

Consequently while the traction control system is outmoded both the power switching elements and the control boards will be able to be maintained into the foreseeable future.

18.9.2. RHEO-STATIC BRAKING

The A Series railcars incorporate a blended rheo-static and friction brake. The rheo-static brake incorporates a resistor grid and fan. The unit is reasonably reliable and should continue to provide good service, however, the nature of high temperature resistors is one that failures must be expected from time to time.

The A Series railcars do not incorporate regenerative braking. The additional cost could not be justified for an AC powered train when the trains were designed in the late 1980s.

More modern rolling stock, including the B series railcars, are fitted with regenerative braking. Regenerative braking normally recovers 20 – 25% of energy consumed by the rolling stock making it available for use by other rolling stock or returning it to the grid, dependant upon the infrastructure design. As such this technology reduces operating costs which in the case of the A Series railcars would be in order of \$1M per annum. It is recommended that this feature be incorporated into the AC traction upgrade for option 3. The cashflow analysis includes a \$1M positive cashflow compared with DC traction.

18.10. AUXILIARY POWER SUPPLY

18.10.1. AUXILIARY CONVERTER

The auxiliary converter is a solid state device which accepts a nominal 850VAC single phase from a separate winding on the main transformer.

The input phase of the converter rectifies the single phase AC voltage into a stable DC voltage employing a thyristor bridge rectifier. This is then filtered employing an LC filter with the inductor mounted in a separate enclosure. The capacitors that make up the other half of the filter are mounted within the auxiliary converter enclosure and are being replaced during the GO regime. This is not an unreasonable maintenance task.

The intermediate DC voltage is converted to 3 phase AC using a thyristor based inverter. As described in Section 18.9 it is relatively easy to trigger the thyristor into its 'on' state, equivalent to closing a switch, by applying a small pulse to its gate terminal. However turning it 'off' again has to be achieved by force-commutating it as the voltage being switched in this case is DC. The commutating circuit is relatively complicated. This design of inverter has been superseded by two or three generations of design. The latest designs employ Insulated Gate Bipolar Transistors (IGBTs) that are easily able to be turned on and off, in an efficient manner.

Maintenance history indicates that the auxiliary converter is relatively reliable. Once again the semi conductors should be available into the foreseeable future. In case reliability falls and maintenance costs increase it is far easier to replace the auxiliary converter than the traction converter. Auxiliary converters with the required input and output parameters are available from a number of suppliers. Budget estimates supplied to Interfleet indicate a price of \$100,000 per converter (which would include a new 6kW battery charger) for a quantity of 48.

18.10.2. BATTERIES

The batteries employed on the A Series railcars are Nickel Cadmium (NiCad). These have proven to provide the best service for Transperth. These are replaced at an acceptable schedule and present no specific problems.

18.10.3. BATTERY CHARGER

The battery charger is providing adequate service, however, to improve the charger characteristic, Rolling Stock Engineering through the electronics workshop is modifying the charging characteristic of the battery charger to better service the Ni Cad batteries.

If at some time in the future the auxiliary converter is to be replaced a battery charger can be incorporated in to the auxiliary converter as a package. According to budget estimates providing a 6kW, 110Vdc battery charger could be included in a price of \$100,000 for an auxiliary converter as noted above.

18.11. MAIN POWER SUPPLY

18.11.1. PANTOGRAPHS

The A series railcars are currently fitted with a single arm pantograph. Being predominantly mechanical in nature a scheduled overhaul in line with OEM recommendations or the result of condition monitoring should be sufficient to ensure that the pantograph can continue to operate for the full life of the vehicle. The pantograph should, however, be monitored for signs of metal fatigue during any life extension period.

Pantograph technology has evolved, leading to a number of other options for consideration. Modifications are available (as part of an OEM overhaul) to introduce design improvements which include maintenance free insulated bearings and braided tinned copper shunts. Interfleet has also reviewed the possibility of fitting autodrop and overheight protection to the existing pantographs. Whilst a detailed design review has not been conducted it is understood that such a modification is feasible. This would bring functionality into line with the pantographs fitted to the B series railcars.

More modern air cushion pantographs are also available as a complete unit which could be fitted as part of a major upgrade.



Figure 16: Air Cushion Pantograph

Cited features and advantages of the newer design of pantograph include :

- 8 to 10 year OEM recommended overhaul period;
- Maintenance free insulated bearings;
- No grease points;
- Braided tinned copper shunts;
- Mass : 128 kg;
- Carbons and copper shunts the same as the existing design of pantograph fitted to the A series railcars;
- Constant contact pressure right through entire operating range;
- Adjustable contact pressure from 50N – 160N;
- Pan head insulated from upper arm;
- Softer suspension on pan head which
 - Reduces wear on the carbons and contact wire.
 - Excellent contact behaviour between contact wire. and pan head even under basic catenary conditions
 - Minimise arcing throughout the operating range
- Minimum maintenance time at service intervals with low maintenance for the life of the pantograph

An upgrade to the more modern design of pantograph will introduce modern functionality in line with current industry norms and best practice which would provide protection for the pantograph and the catenary system. An indicative cost for a replacement pantograph is \$19,000 based on a quantity of 50 pantographs. A new pantograph has been included in the costings for option 3.

18.11.2. FORWARD / REVERSE CONTACTORS

It has been reported that the forward and reverse contactors are beginning to exhibit failures. It appears that it will be possible to replace certain wearing mechanical components that make up part of

the contactor. This would be far cheaper than replacing the whole contactor.

18.11.3. MAIN TRANSFORMER

The Main Transformer has been the cause of 5 Lost Time Incidents in the two years of failure data provided by PTA. As such it has caused less than 0.36% of the Lost Time Incidents and is therefore not a major cause of issues in service.

Main factors that would drive the replacement of the transformer are the failure rate and the choice of traction system. The technology of transformers has not evolved at a similar rate to other electrical and electronic systems. As such obsolescence is unlikely to be a major issue.

The input voltage of any alternative traction system should not be a major issue with the range of input voltages for the traction system being sufficiently broad to enable a suitable match to occur. Experience indicates that transformers are typically a long lasting component. Based upon their current and likely future performance for any of the life extension options, Interfleet do not envisage that a replacement will be required.

Interfleet has, however, noted that the interval between taking oil samples (which forms a major component of the transformer planned maintenance checks) is significantly longer than other 25kV railcars and locomotives operating elsewhere. In the UK some 25kV powered rolling stock on high profile routes, with significant penalty regimes, are checked every three months. Whilst Interfleet does not believe that this frequency is necessary for the A series railcars it recommends that a benchmarking study be undertaken to ensure that the frequency of sampling is aligned with industry norms and best practice and will detect and hence provide early warning of degradation within the transformer prior to causing significant failures.

18.11.4. EARTH RETURN BRUSHES

Whilst being used to return traction and auxiliary current to the infrastructure these items are basically a mechanical item. A review of the failure data provided by PTA reveals that no Lost Time Incidents have been attributed to this equipment. Interfleet does not believe that a component change-out program needs to be undertaken.

18.12. INTERIOR AND EXTERIOR LIGHTING

18.12.1. CAB AND SALOON LIGHTS

Interfleet has not carried out specific inspections of the cab and saloon lighting. However, from its visits and more general inspections of the railcars it is apparent that the lighting system performance is not significantly different to that fitted to the B series railcars. As with all

fluorescent lamps the lighting output will gradually reduce over time if the tubes are not replaced at regular intervals. The diffusers are also likely to degrade and discolour over time and further affect the lighting levels and ambience within the saloon. It may also be necessary to fit new ballasts in order to maintain the performance of the lights.

Interfleet has reviewed the main options for the cab and saloon lights with suppliers of this equipment. One option is to retain the existing lighting system and replace fluorescent tubes, the diffusers and the ballasts as required in order to maintain the current performance of the equipment. It may be appropriate to undertake such a change-out at the point of a major upgrade to extend the life of the vehicles.

A second option would be to fit LED based cab and saloon lights. This has been discussed with one of the equipment manufacturers who supply to the rail industry. Technology and performance of LED solutions continue to advance rapidly and are currently cited to be revolutionising the lighting industry. In the past decade LEDs have become a viable source of light for illumination. Because there is no fragile filament, the device is very robust and highly suited to high shock and vibration environments such as railway rolling stock interior lighting. Reliability is not the only benefit of LED based solutions. Low current consumption, low temperatures and higher luminous efficiency compared to fluorescent, tungsten or halogen based solutions are amongst the other benefits.

In summary the advantages of LED based technology include :

- Homogeneous light source.
- LED life expectancy 100,000hrs to 70% of initial light output.
- Ultra-high reliability design - 300,000 hours MTBF.
- Zero maintenance costs.
- Significantly reduced weight compared to fluorescent luminaries.
- Illumination levels exceed rail industry requirements (approx 430 – 690 lux).
- Energy savings compared to conventional light sources.
- Integrated power supply for direct connection to vehicle 110V DC systems
- Further energy reduction by incorporating dimming functionality whereby the lighting system measures the lighting levels within the saloon and increases or decreases the output of the LEDs dependant upon the ambient light levels entering the vehicle from outside.

In comparison a fluorescent tube has a life expectancy of 20,000 hours when operated optimally. The LED based lighting, when fitted with the associated diffuser has a more even light distribution as illustrated in the Figure below



Figure 17: LED Based Saloon Lighting

Such LED based lighting solutions are available as a flat panel or an LED strip. The latter solution is suitable to retrofitting to existing lighting modules in place of the fluorescent tubes whilst the former is more suited to new build.

This technology is currently being fitted to the Waratah EMUs being manufactured for RailCorp in NSW. It has also been used on the recently introduced Dubai Metro and the Virgin Pendolino tilting trains operating in the UK

18.12.2. HEADLIGHT

Interfleet expect that the existing headlights will continue to operate for the duration of any life extension with both maintenance and globe replacement requirements being unlikely to change from the current norms.

A number of developments in headlight technology have occurred in 18 years since the A series railcars were manufactured. A significant development has been the introduction of High Intensity Discharge (HID) headlights which provide a number of advantages over tungsten halogen based technologies. HID headlights have been fitted to new rolling stock worldwide since 2001, including the Waratah trains in New South Wales. HID headlights are also known to have been retrofitted to older rolling stock in the UK and elsewhere worldwide.

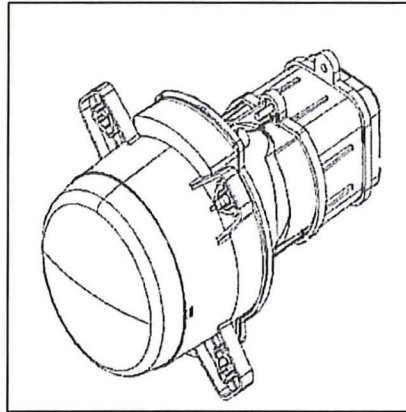


Figure 18: High Intensity Discharge Headlight

HID headlights offer higher reliability than tungsten halogen based solutions with the cited life of 100,000 hours being between three and five times longer than more traditional technologies. Light output is also significantly higher (approx 50,000 lux) providing better illumination of track, infrastructure and signage with lower power consumption and heat output. Photographs of comparison testing are provided in figures 21 and 22 below.



Figure 19: Tungsten Lamp Based Headlight



Figure 20: HID Headlight

Whilst an upgrade to HID headlights is not required in order to continue operation of the A series railcars for either the original service life or any proposed life extension options, an upgrade would provide external lighting of a level that is consistent with modern rolling stock. Indicative costs received are that the equipment necessary for such an upgrade would be approximately \$2,000 to 2,500 per cab, including the necessary power supplies. These costs are included as part of option 3.

18.12.3. MARKER AND TAIL LIGHTS

The current norm for marker and tail lights is to replace tungsten based technologies with LED based equipment.

A number of options are available. These include fitting a combined red tail / white marker light in a new housing, separate red and white tail and marker lights in the existing style of housing fitted to the A series railcars or to delete the white marker light and only fit a red tail light in either a new housing or the existing style of housing. (It is understood that PTA do not currently use the white marker lights relying upon the headlights to provide and indication of train presence).

An indicative cost for a combined tail and white marker light in a new housing is approximately \$200 per light or \$400 per cab. As per the headlight system and upgrade could also include the provision of status monitoring.

As per the headlights such an upgrade is not a pre-requisite to continued operation but we recommend that it be included at least in the overhaul for life extension to 55 years as it will improve visibility of the trains and reduce maintenance requirements.

18.13. INDICATORS, CONTROL & MONITORING SYSTEMS

18.13.1. RELAYS AND CONTACTORS

A review of the performance data provided by PTA revealed that none of the Lost Time Incidents in the period November 2007 to October 2009 were attributed to relays within the electrical control system.

Contactors within the electrical control system are performing to a similar standard with only 2 contactor failures being the cause of Lost Time Incidents in the same time period (0.15% of Lost Time Incidents).

This leads to the conclusion that the relays and contactors used on the A series railcars are of a robust design. However, when considering life extension to 40 and 55 years it would be necessary for these components to continue operating for another 22 and 36 years respectively.

Interfleet therefore recommends that replacement of high risk or critical relays and contactors (ie those with high switching loads / frequency of operation or those which form part of safety circuits) should be included in the budget for any life extension work.

18.13.2. CABLES AND WIRING

Interfleet has not carried out specific inspections of the cables and wiring on board the A Series railcars. However during its visits and inspections of other systems it is apparent that the cables and wiring are generally in good condition. This is supported by the performance data (5 Lost Time Incidents in 2 years which is less than 0.5% of Lost Time Incidents).

Two cable suppliers have independently advised that the design life for modern 4GKW type cable is approximately 30 years. That said this type of cable has not been available for sufficiently long to validate this advice which may be conservative. Interfleet does not believe that a full re-wire of the railcars will be required to extend the life of the vehicles beyond the original 30 year service life. Some re-wiring may be necessary where specific cables have been damaged or poorly terminated.

18.13.3. CIRCUIT BREAKERS

Interfleet understand that the A series railcars are currently fitted with Heinemann circuit breakers. These are considered to be a robust design and as such there would be no recommendation to undertake a fleet wide replacement program for any of the options under consideration.

18.13.4. CAB SWITCHES, PUSHBUTTONS AND INDICATORS

Interfleet has reviewed the switches, pushbuttons and indicators in the cab area and they appear to be a robust design with no indication that they will not last for the life of the vehicle including any life extension options. Interfleet do not, therefore, recommend any fleet wide retrofit of these items. In order to reduce the maintenance costs Interfleet would recommend replacing any non LED based indicators with LED illumination with the associated improvement in indicator life.

18.13.5. DRIVER'S INTERFACE

The driver interface is very similar to the B Series Railcars. It is a modern interface that Interfleet understand that driver's react positively to. It is not envisaged that any major modifications will be required unless the Train Management System is renewed.

18.13.6. TRAIN MANAGEMENT SYSTEM

Interfleet notes that the CPU hardware caused 211 Lost Time Incidents (15%) and as such is ranked second on the Pareto based upon the 2 years of data supplied by PTA. Whilst it is understood that PTA are currently investigating this issue it is not know whether a technical solution will be possible without significant re-engineering. In order to support operation of the fleet, repairs and investigatory work is being undertaken using a test rack in the electronics workshop.

The functionality and appearance of the current Train Management System is in line with 18 year old rolling stock. As such its functionality and appearance appear dated when compared to more modern rolling stock.

Interfleet recommend installation of a replacement TMS system as part of the upgrades for the 55 year life extension option. When combined with upgrades of other systems this will provide a modern system with increased functionality and a modern driver's interface. It will also eliminate the equipment that is currently causing significant Lost Time Incidents

18.13.7. DATA LOGGER

Interfleet understand that event recorders are being installed on the A series railcars as part of the RAPID project. They are being progressively fitted at the time of writing. As such the equipment is modern and is noted to be using current technology.

18.13.8. AUTOMATIC TRAIN PROTECTION

A review of the failure data provided by PTA identifies that the ATP system is the most significant cause of Lost Time Incidents on the A

series railcars. 225 Lost Time Incidents (16.4% of all Lost Time Incidents) were caused by this system during the 2 year period covered by the failure data supplied by PTA.

It is understood, however, that the current ATP system will be replaced by ERTMS in 2014 which it is envisaged will improve the reliability performance of the railcars. The cost for this upgrade is not included in the upgrade costs outlined in section 13 of this report as the ATP project is deemed to be outside the scope of this review.

18.14. COMMUNICATIONS

With the exception of a hearing aid loop, following completion of the installation of the RAPID system, the A series railcars will be fitted with communications equipment based on current technology. This includes:

- Digital Voice Announcements
- Passenger Information Displays
- Closed Circuit Television (CCTV)

The A Series railcars were delivered with help points.

18.14.1. HEARING AUGMENTATION

The A series railcars are not currently fitted with Hearing Augmentation (a hearing aid loop). In order to fully comply with the Disability Standards for Accessible Public Transport 2002 the railcars must comply with AS1428.2 (1992) Clause 21.1, Hearing augmentation. The Australian Standard requires hearing augmentation to cover at least 10% of the seated area. It is therefore recommended that audio frequency induction loop system be installed on at least one car of each A series set.

It is recommended that the system be installed on a full car rather than limiting its application to cover 10% of the seats as required by the standard. This will enable passengers to access the system by boarding the correct car rather than having to sit in specific seats which may be occupied by other passengers.

19. APPENDIX 2 OPTION 1 – UPGRADE COSTS – LIFE TO 35 YEARS.

			2015	2016	2017	2018	2019
Major Subsystem Overhauls	\$ for fleet		\$ / km				
Main Converter	1,290,000 over 5 years		\$0.019	\$0.019	\$0.019	\$0.019	\$0.019
Aux Converter	620,000 over 5 years		\$0.009	\$0.009	\$0.009	\$0.009	\$0.009
Air con	over 200 units 2,000,000 over 5 years		\$0.030	\$0.030	\$0.030	\$0.030	\$0.030
Doors	8 per set 400,000 over 5 years		\$0.006	\$0.006	\$0.006	\$0.006	\$0.006
Master Controllers (rebuild)	2 per set 700,000 over 5 years		\$0.010	\$0.010	\$0.010	\$0.010	\$0.010
Vacuum circuit breakers	200,000 over 5 years		\$0.003	\$0.003	\$0.003	\$0.003	\$0.003
Axle speed probes	\$6600 per set 316,800 over 5 years		\$0.005	\$0.005	\$0.005	\$0.005	\$0.005
EBC5 BCU rebuild	3 per set 1,350,000 over 5 years		\$0.020	\$0.020	\$0.020	\$0.020	\$0.020
	6,876,800		\$0.102	\$0.102	\$0.102	\$0.102	\$0.102

km/year 140,000

20. APPENDIX 3 OPTION 2 – UPGRADE COSTS LIFE TO 40 YEARS.

			2015	2016	2017	2018	2019
Major Subsystem Overhauls							
		\$ for fleet	\$ / km				
Main Converter	refurb	1,290,000 over 5 years	\$0.019	\$0.019	\$0.019	\$0.019	\$0.019
Aux Converter	refurb	620,000 over 5 years	\$0.009	\$0.009	\$0.009	\$0.009	\$0.009
Air con	over 200 units	2,000,000 over 5 years	\$0.030	\$0.030	\$0.030	\$0.030	\$0.030
Doors	8 per set	400,000 over 5 years	\$0.006	\$0.006	\$0.006	\$0.006	\$0.006
Master Controllers (rebuild)	2 per set	700,000 over 5 years	\$0.010	\$0.010	\$0.010	\$0.010	\$0.010
Vacuum circuit breakers		200,000 over 5 years	\$0.003	\$0.003	\$0.003	\$0.003	\$0.003
EBC5 BCUs new	2 per set	2,237,500 over 5 years	\$0.033	\$0.033	\$0.033	\$0.033	\$0.033
VESDA	\$13000 per set	624,000 over 5 years	\$0.009	\$0.009	\$0.009	\$0.009	\$0.009
Axle speed probes	\$6600 per set	316,800 over 5 years	\$0.005	\$0.005	\$0.005	\$0.005	\$0.005
Hearing aid loop		480,000 over 5 years	\$0.007	\$0.007	\$0.007	\$0.007	\$0.007
Re-position door release	4 per set	240,000 over 5 years	\$0.004	\$0.004	\$0.004	\$0.004	\$0.004
9,108,300			\$0.136	\$0.136	\$0.136	\$0.136	\$0.136

km/year 140,000

21. APPENDIX 4 OPTION 3 – UPGRADE COSTS AC FOR TRACTION AND INCREASE IN LIFE TO 55 YEARS.

AC Traction Upgrade	2019	2020	2021	2022	2023	2024	2025	2026
Project Engineering Costs		\$500,000	\$500,000	\$1,575,082	\$1,575,082	\$1,575,082	\$1,575,082	\$1,575,082
Equipment Costs				\$15,750,816	\$15,750,816	\$15,750,816	\$15,750,816	\$15,750,816
Installation Costs				\$2,553,600	\$2,553,600	\$2,553,600	\$2,553,600	\$2,553,600
Contingency 15%		\$75,000	\$75,000	\$2,981,925	\$2,981,925	\$2,981,925	\$2,981,925	\$2,981,925
Total Costs	\$115,457,111	\$0	\$575,000	\$575,000	\$22,861,422	\$22,861,422	\$22,861,422	\$22,861,422

km/year	140,000							
Additional Cost per car km	\$0.00	\$0.04	\$0.04	\$1.70	\$1.70	\$1.70	\$1.70	\$1.70

Equipment	per set
Traction System	
AC Induction	\$960,000
Modification to Bogie	\$40,000
TMS	\$163,000
Anti Climbers	\$12,000
Aux Converter	\$100,000
Intercar Jumpers	\$4,500
Hearing aid loop	\$20,000
Electric Doors	\$48,000
Re-position door release	\$5,000
Vesda	\$13,000
BCU	\$44,750
Saloon lights	\$5,000
Marker / red lights	\$800
Master Controller	\$48,500
Pantograph	\$19,000
Axle end speed probes	\$6,600
Electrical coupler heads	\$106,560
Headlights	\$4,000
Air Cond rebuild	\$40,000
	<u>\$1,640,710</u>

Installation per set	
8 people 6 weeks + 33% gross margin	
Labour	\$216,000
Consumables/wiring	\$50,000
	<u>\$266,000</u>

Note:

Assuming 2010 dollars and foreign exchange rates of 1AUD = 0.6 Euro and 1AUD = 80 Yen

22. APPENDIX 5 NPV TABLE

22.1. ALTERNATIVE 1 REPLACEMENT FLEET FOR OPTIONS 1 AND 2 IS 48 X 3 CAR SETS IDENTICAL TO THE B SERIES RAILCARS

NPV Analysis 2011 - 2022

Year of Analysis		1	2	3	4	5	6	7	8	9	10	11	12
Date Year		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	Sum (NPV)												
Option 1 - Run to 35 Years then buy new trains and credit remaining life of new trains back at 55 years													
sub total	-\$599	-\$11.4	-\$11.5	-\$11.6	-\$11.8	-\$9.2	-\$9.2	-\$9.2	-\$9.2	-\$9.2	-\$7.9	-\$8.0	-\$8.1
Discount rate factor		0.94	0.88	0.83	0.78	0.73	0.69	0.65	0.61	0.57	0.54	0.51	0.48
Discount rate applied	-\$270	-\$10.7	-\$10.2	-\$9.7	-\$9.2	-\$6.8	-\$6.4	-\$6.0	-\$5.6	-\$5.3	-\$4.3	-\$4.1	-\$3.8
Option 2 - Run to 40 Years then buy new trains and credit remaining life of new trains back at 55 years													
sub total	-\$539	-\$11.4	-\$11.5	-\$11.6	-\$11.8	-\$9.7	-\$9.7	-\$9.7	-\$9.7	-\$9.7	-\$7.9	-\$8.0	-\$8.1
Discount rate factor		0.94	0.88	0.83	0.78	0.73	0.69	0.65	0.61	0.57	0.54	0.51	0.48
Discount rate applied	-\$221	-\$10.7	-\$10.2	-\$9.7	-\$9.2	-\$7.1	-\$6.7	-\$6.3	-\$5.9	-\$5.5	-\$4.3	-\$4.1	-\$3.8
Option 3 - Run to 55 Years (Including Upgrade to AC Traction)													
sub total	-\$397	-\$11.4	-\$11.5	-\$11.6	-\$11.8	-\$7.8	-\$7.9	-\$8.0	-\$8.1	-\$8.2	-\$8.8	-\$8.9	-\$31.3
Discount rate factor		0.94	0.88	0.83	0.78	0.73	0.69	0.65	0.61	0.57	0.54	0.51	0.48
Discount rate applied	-\$168	-\$10.7	-\$10.2	-\$9.7	-\$9.2	-\$5.8	-\$5.5	-\$5.2	-\$4.9	-\$4.7	-\$4.8	-\$4.5	-\$14.9
Risk rate factor		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Including risk allowance	-\$168	-\$10.7	-\$10.2	-\$9.7	-\$9.2	-\$5.8	-\$5.5	-\$5.2	-\$4.9	-\$4.7	-\$4.8	-\$4.5	-\$14.9

NPV Analysis 2023 - 2034

Year of Analysis		13	14	15	16	17	18	19	20	21	22	23	24
Date Year		2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Option 1 - Run to 35 Years then buy new trains and credit remaining life of new trains back at 55 years													
sub total	-\$8.2	-\$8.3	-\$8.3	-\$8.4	-\$139.3	-\$139.9	-\$139.0	-\$139.1	-\$6.8	-\$6.8	-\$6.8	-\$6.8	-\$6.8
Discount rate factor	0.45	0.42	0.40	0.37	0.35	0.33	0.31	0.29	0.27	0.26	0.24	0.23	0.23
Discount rate applied	-\$3.7	-\$3.5	-\$3.3	-\$3.1	-\$48.7	-\$45.9	-\$42.9	-\$40.4	-\$1.9	-\$1.7	-\$1.6	-\$1.6	-\$1.5
Option 2 - Run to 40 Years then buy new trains and credit remaining life of new trains back at 55 years													
sub total	-\$8.2	-\$8.3	-\$8.3	-\$8.4	-\$8.5	-\$8.6	-\$8.7	-\$8.8	-\$8.8	-\$139.7	-\$140.3	-\$139.5	-\$139.5
Discount rate factor	0.45	0.42	0.40	0.37	0.35	0.33	0.31	0.29	0.27	0.26	0.24	0.23	0.23
Discount rate applied	-\$3.7	-\$3.5	-\$3.3	-\$3.1	-\$3.0	-\$2.8	-\$2.7	-\$2.5	-\$2.4	-\$35.8	-\$33.8	-\$31.6	-\$31.6
Option 3 - Run to 55 Years (Including Upgrade to AC Traction)													
sub total	-\$31.4	-\$30.4	-\$30.5	-\$28.9	-\$6.1	-\$6.2	-\$6.3	-\$6.4	-\$6.5	-\$6.6	-\$6.6	-\$6.6	-\$6.7
Discount rate factor	0.45	0.42	0.40	0.37	0.35	0.33	0.31	0.29	0.27	0.26	0.24	0.23	0.23
Discount rate applied	-\$14.0	-\$12.8	-\$12.1	-\$10.7	-\$2.1	-\$2.0	-\$1.9	-\$1.9	-\$1.8	-\$1.7	-\$1.6	-\$1.6	-\$1.5
Risk rate factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Including risk allowance	-\$14.0	-\$12.8	-\$12.1	-\$10.7	-\$2.1	-\$2.0	-\$1.9	-\$1.9	-\$1.8	-\$1.7	-\$1.6	-\$1.6	-\$1.5

Assumptions

Discount rate for time value of money pa	-6%
Allowance for risk pa	0%

Notes

1. \$ Figures are in Millions

NPV Analysis 2035 - 2046

Year of Analysis	25	26	27	28	29	30	31	32	33	34	35	36
Date Year	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046
Option 1 - Run to 35 Years then buy new trains and credit remaining life of new trains back at 55 years												
sub total	-\$6.9	-\$7.0	-\$7.1	-\$7.2	-\$7.3	-\$7.4	-\$7.5	-\$7.6	-\$7.7	-\$7.8	-\$7.9	\$216.2
Discount rate factor	0.21	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11
Discount rate applied	-\$1.5	-\$1.4	-\$1.3	-\$1.3	-\$1.2	-\$1.2	-\$1.1	-\$1.0	-\$1.0	-\$1.0	-\$0.9	\$23.3
Option 2 - Run to 40 Years then buy new trains and credit remaining life of new trains back at 55 years												
sub total	-\$139.6	-\$7.3	-\$7.3	-\$7.3	-\$7.3	-\$7.4	-\$7.5	-\$7.6	-\$7.7	-\$7.8	-\$7.9	\$290.9
Discount rate factor	0.21	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11
Discount rate applied	-\$29.7	-\$1.5	-\$1.4	-\$1.3	-\$1.2	-\$1.2	-\$1.1	-\$1.0	-\$1.0	-\$1.0	-\$0.9	\$31.4
Option 3 - Run to 55 Years (Including Upgrade to AC Traction)												
sub total	-\$6.8	-\$6.9	-\$7.0	-\$7.1	-\$7.2	-\$7.3	-\$7.4	-\$7.5	-\$7.7	-\$7.9	-\$8.1	-\$8.3
Discount rate factor	0.21	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11
Discount rate applied	-\$1.5	-\$1.4	-\$1.3	-\$1.3	-\$1.2	-\$1.1	-\$1.1	-\$1.0	-\$1.0	-\$1.0	-\$0.9	-\$0.9
Risk rate factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Including risk allowance	-\$1.5	-\$1.4	-\$1.3	-\$1.3	-\$1.2	-\$1.1	-\$1.1	-\$1.0	-\$1.0	-\$1.0	-\$0.9	-\$0.9

Assumptions

Discount rate for time value of money pa	-6%
Allowance for risk pa	0%

Notes

1. \$ Figures are in Millions

22.2. ALTERNATIVE 2 REPLACEMENT FLEET FOR OPTIONS 1 AND 2 IS 24 X 4 CAR SETS

NPV Analysis 2011 - 2022

Year of Analysis		1	2	3	4	5	6	7	8	9	10	11	12
Date Year		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
	Sum (NPV)												
Option 1 - Run to 35 Years then buy new trains and credit remaining life of new trains back at 55 years													
sub total	-\$449	-\$11.4	-\$11.5	-\$11.6	-\$11.8	-\$9.2	-\$9.2	-\$9.2	-\$9.2	-\$9.2	-\$7.9	-\$8.0	-\$8.1
Discount rate factor		0.94	0.88	0.83	0.78	0.73	0.69	0.65	0.61	0.57	0.54	0.51	0.48
Discount rate applied	-\$210	-\$10.7	-\$10.2	-\$9.7	-\$9.2	-\$6.8	-\$6.4	-\$6.0	-\$5.6	-\$5.3	-\$4.3	-\$4.1	-\$3.8
Option 2 - Run to 40 Years then buy new trains and credit remaining life of new trains back at 55 years													
sub total	-\$425	-\$11.4	-\$11.5	-\$11.6	-\$11.8	-\$9.7	-\$9.7	-\$9.7	-\$9.7	-\$9.7	-\$7.9	-\$8.0	-\$8.1
Discount rate factor		0.94	0.88	0.83	0.78	0.73	0.69	0.65	0.61	0.57	0.54	0.51	0.48
Discount rate applied	-\$184	-\$10.7	-\$10.2	-\$9.7	-\$9.2	-\$7.1	-\$6.7	-\$6.3	-\$5.9	-\$5.5	-\$4.3	-\$4.1	-\$3.8
Option 3 - Run to 55 Years (Including Upgrade to AC Traction)													
sub total	-\$397	-\$11.4	-\$11.5	-\$11.6	-\$11.8	-\$7.8	-\$7.9	-\$8.0	-\$8.1	-\$8.2	-\$8.8	-\$8.9	-\$31.3
Discount rate factor		0.94	0.88	0.83	0.78	0.73	0.69	0.65	0.61	0.57	0.54	0.51	0.48
Discount rate applied	-\$168	-\$10.7	-\$10.2	-\$9.7	-\$9.2	-\$5.8	-\$5.5	-\$5.2	-\$4.9	-\$4.7	-\$4.8	-\$4.5	-\$14.9
Risk rate factor		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Including risk allowance	-\$168	-\$10.7	-\$10.2	-\$9.7	-\$9.2	-\$5.8	-\$5.5	-\$5.2	-\$4.9	-\$4.7	-\$4.8	-\$4.5	-\$14.9

NPV Analysis 2023 - 2034

Year of Analysis		13	14	15	16	17	18	19	20	21	22	23	24
Date Year		2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Option 1 - Run to 35 Years then buy new trains and credit remaining life of new trains back at 55 years													
sub total	-\$8.2	-\$8.3	-\$8.3	-\$8.4	-\$92.5	-\$92.1	-\$90.6	-\$90.0	-\$4.5	-\$4.5	-\$4.5	-\$4.5	-\$4.5
Discount rate factor		0.45	0.42	0.40	0.37	0.35	0.33	0.31	0.29	0.27	0.26	0.24	0.23
Discount rate applied	-\$3.7	-\$3.5	-\$3.3	-\$3.1	-\$32.3	-\$30.2	-\$27.9	-\$26.1	-\$1.2	-\$1.2	-\$1.1	-\$1.1	-\$1.0
Option 2 - Run to 40 Years then buy new trains and credit remaining life of new trains back at 55 years													
sub total	-\$8.2	-\$8.3	-\$8.3	-\$8.4	-\$8.5	-\$8.6	-\$8.7	-\$8.8	-\$8.8	-\$8.8	-\$92.9	-\$92.5	-\$90.9
Discount rate factor		0.45	0.42	0.40	0.37	0.35	0.33	0.31	0.29	0.27	0.26	0.24	0.23
Discount rate applied	-\$3.7	-\$3.5	-\$3.3	-\$3.1	-\$3.0	-\$2.8	-\$2.7	-\$2.5	-\$2.4	-\$2.4	-\$23.8	-\$22.3	-\$20.6
Option 3 - Run to 55 Years (Including Upgrade to AC Traction)													
sub total	-\$31.4	-\$30.4	-\$30.5	-\$28.9	-\$6.1	-\$6.2	-\$6.3	-\$6.4	-\$6.5	-\$6.6	-\$6.6	-\$6.6	-\$6.7
Discount rate factor		0.45	0.42	0.40	0.37	0.35	0.33	0.31	0.29	0.27	0.26	0.24	0.23
Discount rate applied	-\$14.0	-\$12.8	-\$12.1	-\$10.7	-\$2.1	-\$2.0	-\$1.9	-\$1.9	-\$1.8	-\$1.7	-\$1.7	-\$1.6	-\$1.5
Risk rate factor		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Including risk allowance	-\$14.0	-\$12.8	-\$12.1	-\$10.7	-\$2.1	-\$2.0	-\$1.9	-\$1.9	-\$1.8	-\$1.7	-\$1.7	-\$1.6	-\$1.5

Assumptions

Discount rate for time value of money pa	-6%
Allowance for risk pa	0%

Notes

1. \$ Figures are in Millions

NPV Analysis 2035 - 2046

Year of Analysis	25	26	27	28	29	30	31	32	33	34	35	36
Date Year	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046
Option 1 - Run to 35 Years then buy new trains and credit remaining life of new trains back at 55 years												
sub total	-\$4.6	-\$4.7	-\$4.7	-\$4.8	-\$4.9	-\$4.9	-\$5.0	-\$5.1	-\$5.1	-\$5.2	-\$5.3	\$138.6
Discount rate factor	0.21	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11
Discount rate applied	-\$1.0	-\$0.9	-\$0.9	-\$0.8	-\$0.8	-\$0.8	-\$0.7	-\$0.7	-\$0.7	-\$0.6	-\$0.6	\$14.9
Option 2 - Run to 40 Years then buy new trains and credit remaining life of new trains back at 55 years												
sub total	-\$90.4	-\$4.9	-\$4.9	-\$4.9	-\$4.9	-\$4.9	-\$5.0	-\$5.1	-\$5.1	-\$5.2	-\$5.3	\$186.6
Discount rate factor	0.21	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11
Discount rate applied	-\$19.2	-\$1.0	-\$0.9	-\$0.9	-\$0.8	-\$0.8	-\$0.7	-\$0.7	-\$0.7	-\$0.6	-\$0.6	\$20.1
Option 3 - Run to 55 Years (Including Upgrade to AC Traction)												
sub total	-\$6.8	-\$6.9	-\$7.0	-\$7.1	-\$7.2	-\$7.3	-\$7.4	-\$7.5	-\$7.7	-\$7.9	-\$8.1	-\$8.3
Discount rate factor	0.21	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11
Discount rate applied	-\$1.5	-\$1.4	-\$1.3	-\$1.3	-\$1.2	-\$1.1	-\$1.1	-\$1.0	-\$1.0	-\$1.0	-\$0.9	-\$0.9
Risk rate factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Including risk allowance	-\$1.5	-\$1.4	-\$1.3	-\$1.3	-\$1.2	-\$1.1	-\$1.1	-\$1.0	-\$1.0	-\$1.0	-\$0.9	-\$0.9

Assumptions

Discount rate for time value of money pa	-6%
Allowance for risk pa	0%

Notes

1. \$ Figures are in Millions

23. APPENDIX 6 RISK REGISTER FOR A SERIES OPTIONS

QUESTION: "What are the foreseeable risks associated with each of the proposed options to the 'A' Series Fleet and what treatments could be employed to mitigate these risks?"																	
Note: Consequence Classification highlighted in blue means the main consequence classification																	
Hazard Information					Risk Assessment		Consequence Classification					Proposed Additional Risk Control		Residual Risk			
Hazard Ref	Strategic Objective	Description of Risk / Opportunity	Cause(s)	Impacts (leading to...)	Consequence Likelihood	Risk Rating	Safety	Operational	Technical	Economic	Environment	Political & Public	Compliance	Acceptable or Further Treatment	Consequence Likelihood	Risk	Comments
1	35 year life	In spite of 35 year planned works to train systems, reliability issues will increase	New failure modes appear	Reduced reliability	3	3	9	x	x	x					3	3	9
2	40 year life	In spite of 40 year planned works to train systems, reliability issues will increase	New failure modes appear	Reduced reliability	3	4	12	x	x	x				Additional budget to compensate for additional maintenance; Learn from QR experiences	3	3	9
3	55 year life	In spite of 55 year planned works to train systems, reliability issues will increase	New failure modes appear	Reduced reliability	3	2	6	x	x	x					3	2	6
4	35 year life	Missed opportunity to reduce operating expenses because AC traction is not adopted and regenerative brakes are not fitted	Functionality not available on 'A' Series	Missed opportunity to reduce electricity costs - approx 10% overall	4	4	16			x	x			Economic study needed - opportunity for savings	1	1	1
5	40 year life	Missed opportunity to reduce operating expenses because AC traction is not adopted and regenerative brakes are not fitted	Functionality not available on 'A' Series	Missed opportunity to reduce electricity costs - approx 10% overall	4	4	16			x	x			Economic study needed - opportunity for savings	1	1	1
6	55 year life	N/A															N/A due to the fact that AC traction is proposed to be fitted in the 55 year life extension option
7	35 year life	Cracks in bogies	Fatigue cracks may develop in bogies over time	Potential derailment; increased maintenance expense	5	2	10	x	x	x	x			Finite Element Analysis and strain gauge testing together with monitoring through non-destructive testing	5	1	5
8	40 year life	Cracks in bogies	Fatigue cracks may develop in bogies over time	Potential derailment; increased maintenance expense	5	2	10	x	x	x	x			Finite Element Analysis and strain gauge testing together with monitoring through non-destructive testing	5	1	5
9	55 year life	Cracks in bogies	Fatigue cracks may develop in bogies over time	Potential derailment; increased maintenance expense	5	1	5	x	x	x	x			Monitoring & review through NDT	5	1	5

Hazard Information					Risk Assessment		Consequence Classification						Proposed Additional Risk Control			Residual Risk			Comments	
Hazard Ref	Strategic Objective	Description of Risk / Opportunity	Cause(s)	Impacts (leading to...)	Consequence Likelihood	Risk Rating	Safety	Operational	Technical	Economic	Environment	Political & Public	Compliance	Acceptable or Further Treatment			Consequence Likelihood	Risk		
10	35 year life	Passenger complaints due to A Series not having an open intercar opening	A' Series do not have the walk through corridors that 'B' Series have	Perception of passenger amenity inferior in A series	2	1	2	x					x				2	1	2	
11	40 year life	Passenger complaints due to A Series not having an open intercar opening	A' Series do not have the walk through corridors that 'B' Series have	Perception of passenger amenity inferior in A series	2	1	2	x					x				2	1	2	
12	55 year life	Passenger complaints due to A Series not having an open intercar opening	A' Series do not have the walk through corridors that 'B' Series have	Perception of passenger amenity inferior in A series	2	1	2	x					x				2	1	2	
13	35 year life	PTA taken to tribunal due to position of EDR currently being at head height	Current configuration	Passenger amenity not met, DDA issue	2	2	4						x				2	2	4	
14	40 year life	PTA taken to tribunal due to position of EDR currently being at head height	Current configuration	Passenger amenity not met, DDA issue	2	2	4						x				2	2	4	
15	55 year life	N/A											x							Assume that this will be repositioned in the 55 year upgrade
16	35 year life	Over time decreasing support from OEM for DC traction control	OEMs discontinues spare parts due to equipment being out-dated	Increase in costs; trains unavailable	3	2	6	x	x	x							3	2	6	
17	40 year life	Over time decreasing support from OEM for DC traction control	OEMs discontinues spare parts due to equipment being out-dated	Increase in costs; trains unavailable	3	2	6	x	x	x							3	2	6	It is thought that the likelihood will increase, however not enough to change the ranking from 2
18	55 year life	N/A																		It is assumed that AC traction will be fitted in this option
19	35 year life	Missed opportunity to reduce maintenance expenses for braking systems while continuing with existing traction system	DC traction requires more friction braking than AC traction	Higher maintenance costs	3	5	15					x					1	1	1	The economic study will determine whether this is worth doing (costs vs. benefits)
20	40 year life	Missed opportunity to reduce maintenance expenses for braking systems while continuing with existing traction system	DC traction requires more friction braking than AC traction	Higher maintenance costs	3	5	15					x					1	1	1	The economic study will determine whether this is worth doing (costs vs. benefits)
21	55 year life	N/A																		It is assumed that AC traction will be fitted in this option

Hazard Information				Risk Assessment		Consequence Classification							Proposed Additional Risk Control	Residual Risk				
Hazard Ref	Strategic Objective	Description of Risk / Opportunity	Cause(s)	Impacts (leading to...)	Consequence Likelihood	Risk Rating	Safety	Operational	Technical	Economic	Environment	Political & Public	Compliance	Acceptable or Further Treatment	Consequence Likelihood	Risk	Comments	
																		22
23	40 year life	Complaints due to noisy brakes	Current configuration of discs and noise from brakes in DC traction	Environmental impact	1	3	3					x						
24	55 year life	N/A																It is assumed that AC traction will be fitted in this option
25	35 year life	TMS has increase in failure and cannot be maintained in the future	TMS old and outdated	Reduced train reliability	3	3	9		x									
26	40 year life	TMS has increase in failure and cannot be maintained in the future	TMS old and outdated	Reduced train reliability	3	3	9		x									In house support to keep at the same risk profile
27	55 year life	N/A																It is assumed that a new TMS will be fitted in this option
28	35 year life	Lack of VESDA system allowing fires to go undetected for longer	Vandals deliberately start fires	A fire is undetected for longer than with a Vesda system	3	2	6	x	x		x	x	x	x				Consider putting in the VESDA system in the 40 year life Existing controls include a help point that passengers can push
29	40 year life	N/A																It is assumed that a VESDA will be fitted in 40 year option
30	55 year life	N/A																It is assumed that a VESDA will be fitted in 55 year option
31	35 year life	Passengers avoid A Series trains as front of train looks dated and the train is considered inferior compared to 'B' Series	Increase in passenger expectations	Passenger complaints	1	1	1						x					
32	40 year life	Passengers avoid A Series trains as front of train looks dated and the train is considered inferior compared to 'B' Series	Increase in passenger expectations	Passenger complaints	1	1	1						x					



Hazard Information					Risk Assessment		Consequence Classification						Proposed Additional Risk Control			Residual Risk		Comments	
Hazard Ref	Strategic Objective	Description of Risk / Opportunity	Cause(s)	Impacts (leading to...)	Consequence Likelihood	Risk Rating	Safety	Operational	Technical	Economic	Environment	Political & Public	Compliance	Acceptable or Further Treatment	Consequence Likelihood	Risk			
33	55 year life	Passengers avoid A Series trains as front of train looks dated and the train is considered inferior compared to 'B' Series	Increase in passenger expectations	Passenger complaints	1	1							x			1	1	1	
34	35 year life	Lack of hearing loop	Not fitted	Does not meet with DDA requirements; passenger complaints	2	2								x	x	2	2	4	
35	40 year life	N/A																	It is assumed that a hearing loop will be fitted in the 40 year option
36	55 year life	N/A																	It is assumed that a hearing loop will be fitted in the 55 year option
37	35 year life	Increase in maintenance costs	New failure modes appear	Higher maintenance costs and reduced reliability	3	4		x				x				3	3	9	Having the funding means that the work can proceed
38	40 year life	Increase in maintenance costs	New failure modes appear	Higher maintenance costs and reduced reliability	4	4		x				x				3	3	9	Having the funding means that the work can proceed
39	55 year life	Increase in maintenance costs	New failure modes appear	Higher maintenance costs and reduced reliability	3	2		x				x				3	2	6	It is assumed that train upgrades will be done
40	35 year life	Structural issues with body	Fatigue cracking	Crashworthiness affected	4	2		x	x							4	2	8	It is noted that the specification as written is of a contemporary standard
41	40 year life	Structural issues with body	Fatigue cracking	Crashworthiness affected	4	2		x	x							4	2	8	It is noted that the specification as written is of a contemporary standard
42	55 year life	Structural issues with body	Fatigue cracking	Crashworthiness affected	4	1		x	x							4	1	4	It is assumed that FEA study will have been done prior to 55 year upgrade works
43	35 year life	Funding cycle does not match strategic view of assets	Government forces PTA to keep trains in service longer than planned	Reliability issues; public perception	4	3							x	x		4	2	8	High risk that requires constant attention
44	40 year life	Funding cycle does not match strategic view of assets	Government forces PTA to keep trains in service longer than planned	Reliability issues; public perception	4	3							x			4	2	8	High risk that requires constant attention

Hazard Information					Risk Assessment			Consequence Classification					Proposed Additional Risk Control	Residual Risk					
Hazard Ref	Strategic Objective	Description of Risk / Opportunity	Cause(s)	Impacts (leading to...)	Consequence	Likelihood	Risk Rating	Safety	Operational	Technical	Economic	Environment	Political & Public	Compliance	Acceptable or Further Treatment	Consequence	Likelihood	Risk	Comments
45	55 year life	Funding cycle does not match strategic view of assets	Government forces PTA to keep trains in service longer than planned	Reliability issues, public perception	4	3	12				x				Sell to the Government in a different way (lobbying) Strong leadership Communicate early and often	4	2	8	High risk that requires constant attention
46	35 year life	Funding cycle does not match internal planning cycle	Data unavailable to make decisions regarding the asset	Internal non compliance with QMS	4	2	8				x								
47	40 year life	Funding cycle does not match internal planning cycle	Data unavailable to make decisions regarding the asset	Internal non compliance with QMS	4	2	8				x								
48	55 year life	Funding cycle does not match internal planning cycle	Data unavailable to make decisions regarding the asset	Internal non compliance with QMS	4	2	8				x								
49	35 year life	Customer complaints due to running old train	Increase in passenger expectations	Patronage falls, Government loses faith in PTA ability to deliver a service	3	2	6				x		x						
50	40 year life	Customer complaints due to running old train	Increase in passenger expectations	Patronage falls, Government loses faith in PTA ability to deliver a service	3	2	6				x		x						
51	55 year life	Customer complaints due to running old train	Increase in passenger expectations	Patronage falls, Government loses faith in PTA ability to deliver a service	3	2	6				x		x						
52	35 year life	Overcrowding on the trains	Not enough sets / cars available due to increased maintenance requirements and poor reliability	Availability is poor; ministerial complaints	3	3	9		x										
53	40 year life	Overcrowding on the trains	Not enough sets / cars available due to increased maintenance requirements and poor reliability	Availability is poor; ministerial complaints	3	3	9		x										estimated that likelihood will increase, but not by an order of magnitude
54	55 year life	N/A																	It is assumed that new equipment will be fitted in the 55 year option



Hazard Ref	Strategic Objective	Hazard Information			Risk Assessment			Consequence Classification						Proposed Additional Risk Control Acceptable or Further Treatment	Residual Risk				
		Description of Risk / Opportunity	Cause(s)	Impacts (leading to...)	Consequence Likelihood	Risk Rating	Safety	Operational	Technical	Economic	Environment	Political & Public Compliance	Consequence Likelihood		Risk	Comments			
55	35 year life	Passenger loading on trains is not optimal	2 car sets of A Series does not meet business needs	Passenger complaints	3	2	6							X					
56	40 year life	Passenger loading on trains is not optimal	2 car sets of A Series does not meet business needs	Passenger complaints	3	2	6							X					
57	55 year life	Passenger loading on trains is not optimal	2 car sets of A Series does not meet business needs	Passenger complaints	3	3	9							X					Could consider running as permanent 4 car sets, thus reducing costs in re-engineering & maintenance, less powered axles, less capital costs
58	35 year life	Interdependency of the 'B' Series on the 'A' Series	'B' Series performance drops and 'A' Series can not be retired	'A' Series are required to keep required capacity	3	2	6	X											
59	40 year life	Interdependency of the 'B' Series on the 'A' Series	'B' Series performance drops	'A' Series are required to keep	3	2	6	X											
60	55 year life	Interdependency of the 'B' Series on the 'A' Series	'B' Series performance drops and 'A' Series can not be retired	'A' Series are required to keep required capacity	3	2	6	X											
61	35 year life	Maintenance quality decreases as PTA employees with good knowledge of 'A' Series leave and there is no succession planning (knowledge management)	Key staff close to retirement age and little OEM support for old equipment	Increase in failures; impact on reliability	3	2	6	X	X	X									
62	40 year life	Maintenance quality decreases as PTA employees with good knowledge of 'A' Series leave and there is no succession planning (knowledge management)	Key staff close to retirement age and little OEM support for old equipment	Increase in failures; impact on reliability	3	3	9	X	X	X									
63	55 year life	Maintenance quality decreases as PTA employees with good knowledge of 'A' Series leave and there is no succession planning (knowledge management)	Key staff close to retirement age and little OEM support for old equipment	Increase in failures; impact on reliability	3	2	6												It is assumed that new equipment will be fitted during the 55 year upgrades
64	35 year life	Releasing cars for upgrade program means train sets are not available for passengers. N/A - already covered in lower level overhaul program																	



Hazard Information					Risk Assessment		Consequence Classification						Proposed Additional Risk Control			Residual Risk				
Hazard Ref	Strategic Objective	Description of Risk / Opportunity	Cause(s)	Impacts (leading to...)	Consequence Likelihood	Risk Rating	Safety	Operational	Technical	Economic	Environment	Political & Public	Compliance	Acceptable or Further Treatment			Consequence Likelihood	Risk	Comments	
65	40 year life	Releasing cars for upgrade program means train sets are not available for passengers. N/A - already covered in lower level overhaul program																	This is already covered in existing overhaul program	
66	55 year life	Releasing cars for upgrade program means train sets are not available for passengers	Sets unavailable due to re-engineering	Impact on availability	5	5		x		x			x		Could potentially change timetable; Consider order more railcars on next train order; Order trains in advance of the refurbishment program Could run three car sets on heritage lines; Increase frequencies	1	1	1	This risk is rather covered in the cost of upgrading to the 55 year life extension	
67	35 year life	Market is at capacity and can't meet PTA requirements for re-engineering / refurbishment / new order	With a flood of rolling stock projects the market cannot meet demand and PTA have low priority with suppliers because of the offer of small projects	Delays in work being done; increase in costs (supply vs. demand)	4	2				x			x				4	2	8	
68	40 year life	Market is at capacity and can't meet PTA requirements for re-engineering / refurbishment / new order	With a flood of rolling stock projects the market cannot meet demand and PTA have low priority with suppliers because of the offer of small projects	Delays in work being done; increase in costs (supply vs. demand)	4	2				x			x				4	2	8	
69	55 year life	Market is at capacity and can't meet PTA requirements for re-engineering / refurbishment / new order	With a flood of rolling stock projects the market cannot meet demand and PTA have low priority with suppliers because of the offer of small projects	Delays in work being done; increase in costs (supply vs. demand)	4	2				x			x				4	2	8	

Hazard Information					Risk Assessment		Consequence Classification							Proposed Additional Risk Control	Residual Risk			
Hazard Ref	Strategic Objective	Description of Risk / Opportunity	Cause(s)	Impacts (leading to...)	Consequence Likelihood	Risk Rating	Safety	Operational	Technical	Economic	Environment	Political & Public	Compliance	Acceptable or Further Treatment	Consequence Likelihood	Risk	Comments	
70	55 year life	Teething problems with new equipment (e.g. AC traction)	Unexpected problems with new technology	Reliability issues	3	4	12	x	x				x	Testing and commissioning; prototyping equipment; possibly reducing / limiting the scope	2	3	6	Risk still exists One car only reduces the consequence and testing, commissioning and prototyping reduces the likelihood
71	55 year life	Lack of experience in re-engineering passenger rolling stock to AC traction in Australia causes failure of project	Large scale re-engineering being done elsewhere; lack of Australian experience in AC traction upgrade programs	Re-engineering project fails to deliver	3	2	6	x	x	x			x	Prototype the equipment; These are packages systems; Global equipment vendors; Locomotives in Queensland are currently having this modification done	3	2	6	
72	55 year life	Reliability of re-engineered train does not meet the current reliability levels	Endemic design problem	Political pressures; public complaints	3	2	6	x	x	x		x	Tender process	3	2	6		
73	55 year life	Re-engineering program is late, maintenance program falls behind	Money is not spent	Non-upgraded 'A' Series are now giving poor reliability and passenger perception of service is low	3	3	9	x					x		3	3	9	
74	55 year life	Significant failure or major interface issues of 'A' Series during the re-engineering program	Unexpected technical problem since not done before in Australia	Impacts confidence in the re-engineering program	4	2	8	x	x	x			x		4	2	8	
75	55 year life	Major OEMs (e.g. Mitsubishi, Bombardier) do not want to tender for small complex projects	2nd tier' or smaller company OEMs do the work	2nd tier' or smaller company OEMs have less financial strength PTA commercial terms are not accepted by OEM and commercial risks increase	4	2	8	x	x	x			x		4	2	8	

AMENDMENT RECORD

ISSUE	DATE	COMMENTS	NAME
A	24 May, 2010	Following review of draft versions, report issued to PTA of WA.	W Wachsmann