Modelling Train & Passenger Capacity

Report to

Transport for NSW

By

DOUGLAS Economics

July 2012

for distribution

Modelling Train & Station Demand & Capacity

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Foreword: Douglas Economics was engaged by TfNSW in October 2011 to assist in (1) the specification of a model to assess the interaction of train and station passenger capacity on train dwell times for the Redfern to Chatswood rail corridor; and (2) review the available computational packages worldwide to determine the degree to which they fit TfNSW's requirements. This report has been modified for external distribution to consultants and academics who volunteered advice and information to the study. These modifications are limited to areas of internal TfNSW decision making, and no amendments have been made to the information provided by the external parties.

Acknowledgments: Douglas Economics would like to acknowledge the help and study guidance of Gary Davey and Scott De Martino of TfNSW; Ian Kearns of TfNSW who provided statistics on-time running and Michael Doggett of TfNSW for providing dwell time survey data.

Douglas Economics would also like to acknowledge the following experts for providing information and advice: Paul Stanley and Marc Caplan of Arup for information on station pedestrian simulation; Malcolm Bradley and Pascal Suisse of Parsons Brinckerhoff for views on station and train simulation respectively; Professor Keith Still, Professor of Crowd Dynamics, Bucks New University UK and Professor Luis Ferreira of the University of Queensland for views on crowd modelling; Peter Howarth (Interfleet) and John Rosser (Institute of Electrical Engineers UK) for information on the train and passenger capacity modelling undertaken for the Thameslink and CrossRail projects in London; Peter Thornton and Alex Wardrop for information on static capacity modelling; Andrew Mein for information on AureAlis simulation and Uli Mohr Managing Director Rail Management Consultants Australia Pty Ltd for views on integrating dwell time into rail simulation.

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Executive Summary

Transport for New South Wales (TfNSW) engaged Douglas Economics to review alternative ways of calculating train dwell time as part of an assessment of line and station capacity for the existing Redfern to Chatswood layout, proposed new CBD stations and alternative train operating patterns including single deck trains.

Static and dynamic approaches were reviewed. Static models relate to a particular time period and usually allow for variability by introducing 'diversity' or 'utilisation' factors. Dynamic models track processes through time, 'feeding' results from one period into the next thereby allowing for queues, delays and other temporal interactions to be modelled.

Static approaches, such as the framework developed by the US Transport Research Board, are established ways of determining train and station capacity to meet target customer levels of service. For Sydney, Wardrop has developed a consolidated model to assess rolling stock and signalling.

Static dwell time algorithms based on statistical analysis of observed data were reviewed. An algorithm was also estimated, using data collected by RailCorp in 2006-07, that predicted dwell times with reasonable accuracy. All the algorithms relate to specific rolling stock however and apart from adjusting for the number and width of doors, they were not intended to model differences in train types such as single versus double deck. In this regard, a dwell time survey of Melbourne or Brisbane single deck trains could complement Sydney double deck data to provide a more general dwell time algorithm. A second limitation is that platform crowding has so far not been modelled explicitly in dwell time algorithms. A third limitation is that the predictions are for individual station stops. To assess the impact on a rail service, the algorithm needs to be incorporated into a dynamic model that allows for passenger build-up at following stations to amplify dwell times – the 'snowball' effect.

Simulation attempts to model the impact of demand variability and operational perturbations by repeat calculations. 'Off-the shelf' rail simulation models either address train operations or pedestrian activity at stations. The two processes are quite different and the review did not find an 'off-the shelf' package able to simulate both processes simultaneously. Moreover, the simulation is only as good as the statistical profiles describing the passengers and how these profiles are used in the simulation.

Simulations of train operations have typically incorporated station dwell time times as a set of average values plus or minus a range. Parsons Brinckerhoff, Cox, Hassell and Aecom (PB-CHA) used this approach to model the Redfern to Chatswood corridor for TfNSW with busier stations such as Town Hall having a longer average dwell and a wider range. The dwells at successive stations were not dynamically linked however by allowing for a build-up of boarding passengers.

Station pedestrian simulations model the impact of passenger volume on station crowding and circulation. Little or no attention is given to train operations. Indeed, dwell time may be 'fixed' by the timetable with the simulation determining boarding capacity rather than train service capacity. The number of passengers 'left on the platform' may be used as an evaluation criterion.

Station pedestrian models have been applied to simulating the board/alight process to evaluate different rolling stock designs. Instead of focussing on the platform, simulation focus on train layout and instead of a timetable of services only an example 'dwell' is simulated. Therefore, for a dynamic simulation, the board/alight process would need to be linked into a train operation simulation.

Some simulations have been undertaken of Bus Rapid Transit lines that have involved multiple bus stops using VISSIM. However modeling the complexity of peak period rail and station operations over the Redfern – North Sydney corridor including interchange from other rail lines would be a highly ambitious undertaking. Continued development of software simulation packages could make this task more achievable in the next few years.

Currently, simulating train and station performance using "off the shelf" packages would require linking a train simulation model such as OpenTrack or Railsys with multi-station pedestrian simulations using Legion or SimWalk. For dynamic simulation, results would need to be transferred at the end of time slice (Legion updates at 0.6 second intervals). The volume of data and the implication for run times would be the main implementation issue especially if repeat runs are undertaken to develop a statistical distribution of train and station performance.

Before embarking on such a detailed train and station simulation exercise, the adequacy of the patronage forecasts, representation of rolling stock and stations and the accuracy of the passenger behaviour algorithms should be assessed in terms of their likely predictive accuracy.

In this regard, a multi station dwell time survey covering train and platform crowding would be useful in providing estimation and validation data. As an initial modelling step, the results could be integrated within a simplified dynamic train-station simulation model built in Excel, Arena or other simulation software building package.

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1. Introduction

1.1 Study Aim

Douglas Economics was engaged by Transport for New South Wales (TfNSW) in October 2011 to (i) assist in specifying a model to assess the interaction of rail passenger demand and train and station capacity for the Redfern to Chatswood rail corridor and (ii) review available computational packages worldwide to determine the degree to which they fit TfNSW's requirements.

1.2 Background

The CBD Rail Capacity Program is supporting the Long Term Rail Plan (LTRP) by identifying engineering works at key stations, and upgrades to rail systems.

One of the constraints on rail capacity is the dwell time at each of the main stations. Whilst capacity modelling has been done for individual stations, the interaction of the stations when combined with line/train capacity has not been fully understood at a network level. The cumulative impacts of how delays on the network, including how interchanging passengers impact station/operational capacity, needs to be understood in more detail. Such an understanding of capacity limitations will assist with the development of infrastructure upgrades for the CBD stations and lines.

1.3 Train Dwell Time

Parsons Brinckerhoff estimated an average dwell time on the North Shore line of 69 seconds at Town Hall, 61 seconds at Central and 55 seconds at Wynyard in November 2011. The Town Hall dwell time was similar to that observed a decade earlier by TMG-International whereas the times at Central and Wynyard times were 9 and 5 minutes lower respectively.

Table 1.3: Train Dwell Times at Town Hall, Central & Wynyard 2001-2011

Observed stop-start dwell times AM Peak

Station & Platform	2001	2011
Town Hall Platform 3	70	69
Central Platform 16	70	61
Wynyard Platform 3	60	55

Source: 2001 TMG 2001 , PBCHA 2011

1.4 Evaluation Model

TfNSW is interested in developing a train and station demand and capacity model capable of assessing passenger movement, train and station design, layout and spacing.

The intention is to use the model to assess a range of future train and station options such as applying different rolling stock design parameters (e.g. number of door numbers, seating capacity) changing signalling systems; and new CBD alignments.

1.5 Overview

Section 2 provides the study brief issued by TfNSW.

Section 3 looks at the main factors that determine rail passenger carrying capacity.

Section 4 presents the alternative approaches to model the interaction between rail passenger demand and train and station capacity.

Section 5 presents a typology of static and dynamic approaches to model rail demand and capacity interactions

Section 6 looks at static approaches based on observation and statistical analysis to predict train dwell times, platform clearance times and hence train and passenger capacity.

Section 7 reviews statistical approaches to estimate train dwell times.

Section 8 estimates a dwell time algorithm for Sydney based on 2006-07 survey data.

Section 9 looks at train simulations packages which usually exclude patronage and model train dwell times as average times with an associated statistical distribution.

Section 10 looks at rail station pedestrian simulation models which have usually assumed the train timetable and station dwell time to be fixed.

Section 11 looks at the how train and station models can be brought together.

2. Study Brief

Douglas Economics received a study brief from the Transport Projects Division of TfNSW on 21st October 2011. The brief is provided below:

2.1 Study Aims

- Detail TfNSW's, requirements for a computational train and passenger capacity model covering the interaction of train capacity and passengers using the main Redfern to Chatswood stations
- Undertake a global market survey of the available computational packages to determine the degree to which they fit DOT's requirements.

2.2 History

The CBD Rail Capacity Program is supporting the LTRP by identifying engineering works at key stations, and upgrades to rail systems. One of the key constraints is the dwell time at each of the main stations. Whilst capacity modelling has been done for individual stations, the interaction of the stations when combined with line/train capacity has not been fully understood at a network level. The cumulative impacts of how delays on the network, including how interchanging passengers impact station/operational capacity, needs to be understood in more detail. Such an understanding of capacity limitations will assist with the development of infrastructure upgrades for the CBD stations and lines.

It has been identified so far that RailCorp and TfNSW have information on:

- Operational modelling for the North Shore
- Dwell time measurements on the North Shore and CBD stations.
- Pedestrian modelling
- Architectural and operational station capacity studies, in particular for Town Hall, Wynyard and Central
- Fire & life safety studies for the main stations
- Passenger Allocation models for the CBD stations.

2.3 Scope

In order to review the cost effectiveness of operational or infrastructure options that have been proposed to increase capacity it is proposed to develop a simulation-based line/train loading and station performance evaluation tool capable of predicting network performance in 'real time'.

Once developed the model could be run to consider the impacts on the capacity of CBD stations for options such as:

- Introducing new CBD relief line(s)
- Changing CBD station spatial configurations
- Modifying the timetable
- Applying different rolling stock design parameters (door numbers, seating capacity)
- Changing signalling systems
- Changes to other modes interchanging to/from heavy rail, such as bus and light rail

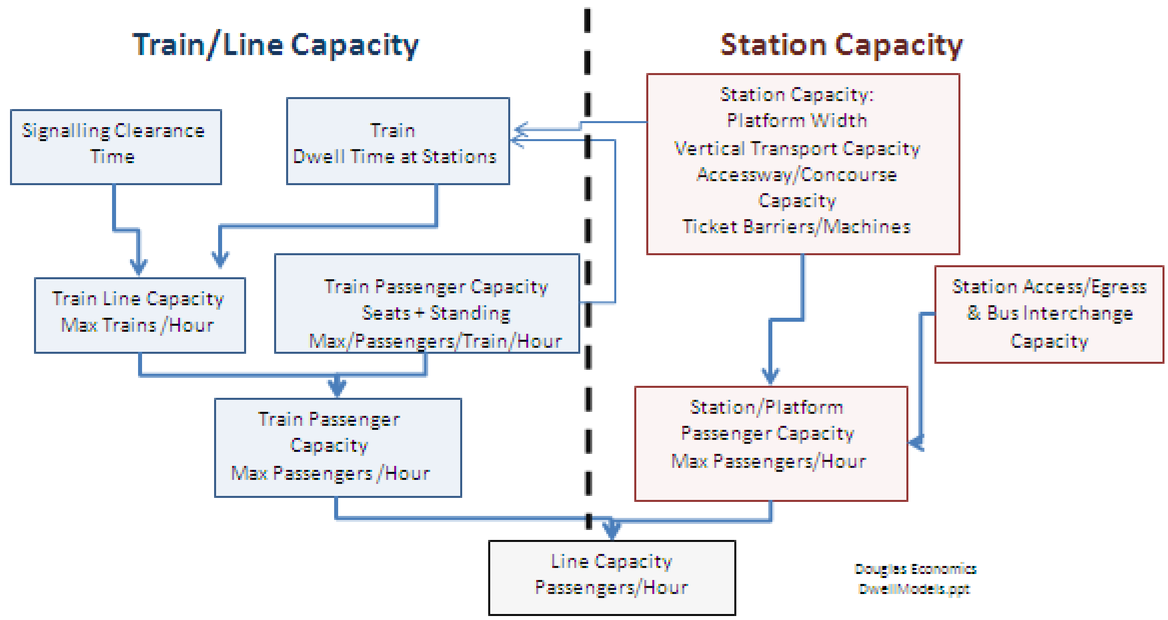
The model needs to dynamically simulate the three linked parameters of passenger movement, train timetabling and station spacing and layout.

3. Factors Determining Passenger Carrying Capacity

3.1 Introduction

Figure 3.1 sets out the main factors determining passenger carrying capacity of a rail line.

Figure 3.1: Factors Determining Rail Capacity



Passenger train capacity is the maximum number of passengers able to be carried per train (seated plus standing). For example, the "commonly accepted" capacity for an eight car double-deck train (e.g. Tangara or Waratah) for design purposes is 1,200 passengers (PB-CHA, 2011).[1]

Train line capacity is determined by the minimum headway between services. In Sydney, the planned headway is three minutes which is based on a signalling clearance time of two minutes plus a station dwell time of one minute.[2] This gives a figure of 20 trains per hour as the train line capacity.

[1] The crush laden capacity is around 2,100 passengers, which represents a theoretical maximum occupancy. The maximum practical load is around 1750 passengers. This occupancy value was derived from real loading tests undertaken by RailCorp in 2007, representing how many people can actually fit into the train and is commonly used in evacuation analysis. At this occupancy movement within the carriage is almost impossible, the only time actual services would be laden to this level without impact would be for terminating services at Olympic Park, where the whole train load alights (PB-CHA, 2011). BY way of comparison, TMG adopted a lower figure of 1,050 passengers for a standard 8 car train with 956 seats as a practical carrying capacity, (TMG International, 2004).

[2] Wardrop derived a different figure based on observations of the North Shore. He estimated an intrinsic signalling clearance time of 100 seconds and a station dwell time of 80 seconds.

PB-CHA (op cit) considered that 20 trains per hour was the “practical train capacity”. They calculated a higher “theoretical” capacity of 22 trains per hour which implies a minimum headway of 2 mins 43 secs. In their simulations, running 22 trains per hour ‘passed’ their simulation tests.

Dividing 20 by 22 trains (practical/theoretical) gives an ‘utilisation rate’ of 91%. PB-CHA noted that at 91%, the utilisation rate was above the recommended figure of 85% given in UIC 406 guidelines for peak hour suburban train operations (UIC, 2004).[3] In fact, practical train capacity would need to reduce to 19 trains per hour if limited to an 85% utilisation rate.

Train service capacity is defined as the maximum number of passengers that can be carried per hour. It is computed by multiplying the train carrying capacity by the number of trains that can be run per hour. With 20 trains per hour and 1,200 passengers per train, the carrying capacity is 24,000 passengers per hour.

Station capacity places an upper limit on the number of passengers that can be handled per hour. Capacity may be measured as a stock or as a flow. Stock refers to the maximum number of passengers who can ‘occupy’ a station or an area of a station such as a platform at any one time. Occupancy can be estimated by observation surveys.

Flow refers to how many passengers the station or an area of a station can process per time period.

Passenger safety and evacuation times set an upper limit on station occupancy and handling capacity. In this respect, much of the station congestion modelling work by London Underground in the mid-late 1980s was prompted by the need to test whether tube stations could meet an evacuated time of three minutes.

There are several elements to determining station passenger handling rates: ticker barrier throughput, corridor and access-way widths, vertical transport capacity (stairs, escalators, and lifts) and platform capacity for waiting and passengers alighting trains.

In the morning peak, the time taken to ‘clear the platform’ is a passenger handling limiting factor. Clearance time is determined by platform width and the maximum flow that vertical transport facilities (stairs, escalators, lifts) can handle.

TMG has suggested a practical maximum of 8,400 passengers per hour per platform for Sydney CBD stations. This was based on a theoretical maximum of 12,000 which was then factored down by 0.7 to 8,400 to allow for that *“passengers do not distribute themselves evenly down the lengths of platforms, nor do they depart in equal numbers on successive Trains”* (TMG, op cit).

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[3] In leaflet 406, UIC considered “railway capacity” as “a combination of the capacity consumption and how the capacity is utilized”. They divided capacity utilization into 4 elements: the number of trains, the average speed, the heterogeneity of the operation, and the stability. The leaflet describes how capacity consumption for railways can be worked out, and how capacity utilisation can be measured. UIC argued unused railway capacity may not allow more trains to be operated due to network effects and lower punctuality.

Given there are three CBD stations, the total CBD platform capacity would be 25,200 per hour (8,400x3). This exceeds the train carrying capacity of 24,000 per hour.

Another way of assessing platform capacity is ‘platform clearance time’. Arup adopted a one minute clearance time for Town Hall in a 2006 evaluation of redevelopment options (Arup, 2006). To calculate the clearance time, Arup adopted maximum flow rates for escalators of 100 passengers per minute and stairs capacities to 52 passengers per minute (per metre width).

In the PM peak, the number of passengers waiting for trains on the platform becomes important. Arup used a target of 2 passengers per square metre as a target maximum density in the evaluation of Town Hall station (Arup, op cit). With a platform 160 metres long and 3 metres wide, the area of 480 square metres provides a maximum carrying capacity of 960 passengers. If each passenger occupies the platform for an average of three minutes, the platform can accommodate 19,200 passengers an hour.

Finally, rail passenger carrying capacity may be limited by bus interchange, car park and taxi capacity and pedestrian access/egress capacities ‘outside’ the station.

3.2 Train Service Capacity Parameters

The current CityRail timetable is planned around a train dwell time of up to one minute. Therefore, up to one minute, variations in dwell time can be accommodated within the existing timetable. Of course, if the maximum observed dwell time was consistently reduced, there would be an opportunity to reduce the planned headway. Conversely, if a significant proportion of trains exceeded one minute, the headway would need to be raised unless increased service unreliability was tolerated.

As a guide to the ability of trains to keep to the one minute threshold, a 2006/7 peak time survey at Town Hall, Central and Wynyard found 6% of sampled trains exceeded one minute (RailCorp, 2007a).

Train dwell times are influenced by the number of passengers boarding and alighting. Future patronage growth, by increasing dwell times, will increase the proportion of trains that exceed the one minute threshold thereby compromising the reliability of the timetable.

Signalling clearance time is the second parameter determining service headway. PB-CHA (op cit) has looked at the impact of replacing the existing block signalling system with a more advanced European signalling system European Train Control System 2 (ETCS2). Simulations by PB-CHA have showed that ETCS2 could reduce the headway between train services.

The complexity of modelling the interaction of signalling and train operations means that simulation is now the accepted way of evaluating different systems.

3.3 Single Deck Rolling Stock

PB-CHA operation simulation evaluated a hypothetical single deck with nominal capacity of 900 based on 400 seats and 500 standing, Table 3.3. This compares with a nominal capacity of 900 seats and 300 standing for a Waratah double deck train.

Table 3.3: Rolling Stock Capacity

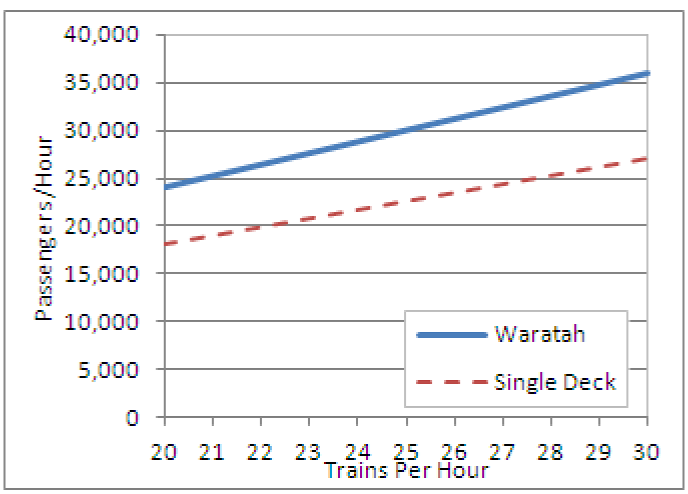
Capacity	Waratah	Single Deck	Comment
Seated Capacity	900	400	Rounded figures (Waratah has 896 seats)
Nominal Capacity	1200	900	Standing in double deck vestibules (19/vestibule) only and at approximately $2P/M^2$ for single deck
Peak Capacity	1400	1120	Double deck maximum load observed on Western Line; $3P/M^2$ for single deck
Max Capacity	1750	1350	Standing at $4P/M^2$. Only observed at special events

Source: PB-CHA (2011)

PB-CHA assumed that the train would have three doors per side per car: the extra set of doors per car offering the potential to speed up boarding and alighting, reduce dwell times and allow more trains per hour. PB-CHA considered that the capacity of existing stations would limit the reduction in dwell time. For Town Hall, the critical station, PB-CHA assumed a 10 second reduction in dwell time. Dwell times were assumed to reduce from 70 seconds with double deck trains to 60 seconds with single deck trains.

The small reduction in dwell time would be offset by a reduction in carrying capacity however. With the passenger assumptions in Table 3.3, the 25% lower single deck capacity would require 28 trains per hour to match the current capacity provided by 20 double deck trains per hour as shown in Figure 3.3.

Figure 3.3: Nominal Train Line Passenger Capacity

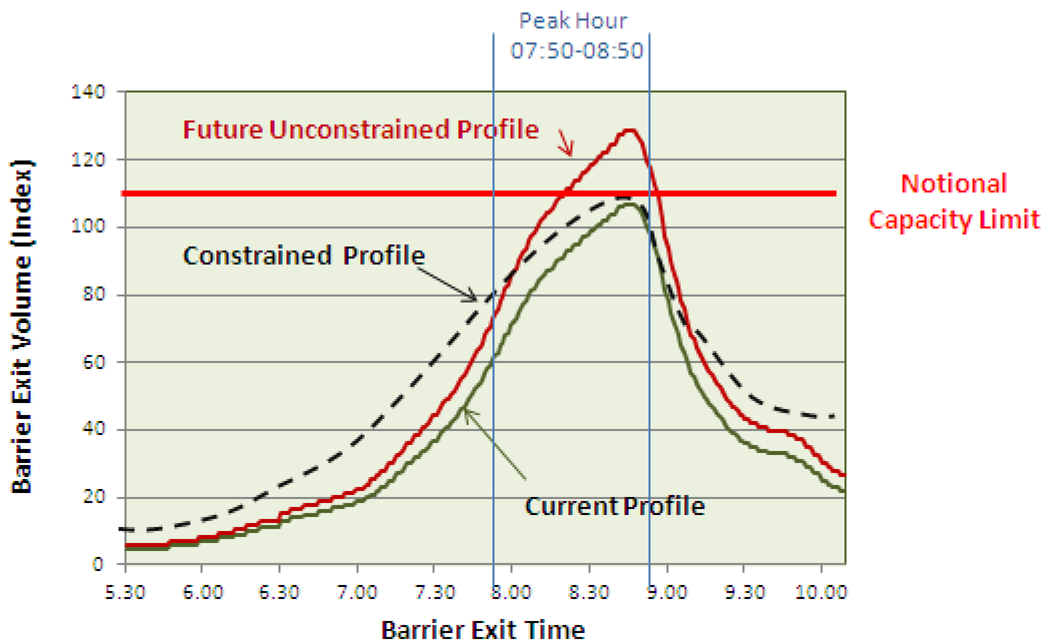


3.4 Peaked Demand

Peak demand determines the track, station and rolling stock requirements. Outside the peak, demand levels fall away and with that the utilisation of infrastructure. Catering for the peak therefore largely determines the capital cost of urban railways and thereby the overall economics of rail provision. Figure

3.4 shows the profile of Sydney AM peak rail demand based on CBD station barrier exits (Douglas et al, 2011).[4]

Figure 3.4: Constrained and Unconstrained Temporal Patronage Profiles



Peak hour demand is between 07:50 and 08:50 AM. Even within this hour, demand is still noticeably peaked with exits 75% higher at 08:40 than at 07:50. Moreover, there is the likelihood that demand would be higher at 8:40 with more capacity provided.

A notional capacity limit has been superimposed at a level of 110 to demonstrate the impact of a further 20% growth in patronage. Many demand and operational studies proceed by applying a uniform increase of 20% across the time period. This is shown by the dark red line. However, as can be seen for just over half the peak hour, demand would then exceed capacity. An alternative profile is shown using the dotted line in which demand is spread outwards into the shoulder peak periods.

The issue raised by this graph concerns the basis of the patronage forecasts that would 'interact' with the rail timetable thereby determining assess train dwell times and whether it is constrained by capacity in any respect.

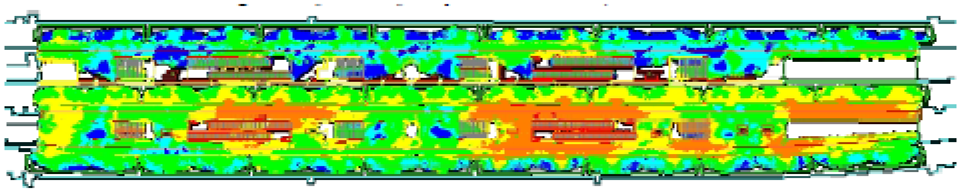
It should also be noted that the graph in Figure 3.5 is a smoothed profile. Train loadings can vary markedly by train service according to stopping pattern and also day-to-day variation.

[4] *The profile was estimated by Douglas, Henn and Sloan (2011) "Forecasting the Effect of Fare Changes on Train Loads using Rooftops", Paper presented at the 34th Australasian Transport Research Forum, Adelaide, 2011.*

3.5 Spatial Clustering

Passengers tend to cluster rather than distributed equally over a train or a platform and in this regard, passengers do not behave as a fluid. Observations of on-train loads show passengers tend to use the middle rather than the end carriages. Platform surveys show waiting passengers to congregate around the bottom of stairs or escalators as can be seen from Figure 2.5 which shows a passenger density graph produced by Arup for Town Hall platforms 1-3 with warmer colours indicating a greater density of passengers.

Figure 3.5: Passenger Platform Clustering



Source: Arup (2006) Town Hall evaluation

Rising patronage levels will ultimately encourage passengers to spread out and utilize more of the available capacity in a similar fashion to Figure 3.4.

However, it is likely that the spatial distribution of patronage will remain unequal which will tend to increase train dwell times and reduce practical train and platform capacity.

3.6 Capacity & Customer Service Level

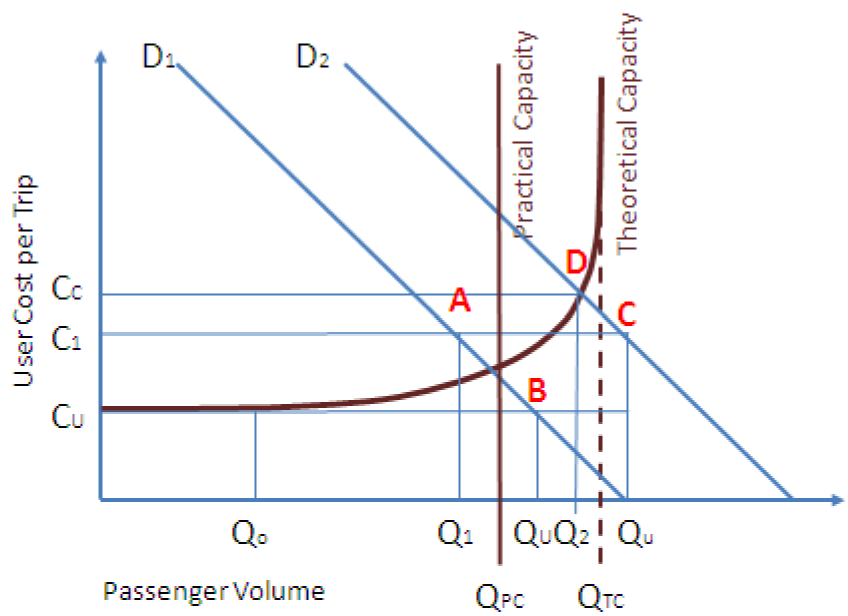
Upper limits can be placed on the passenger carrying capacity of rail based on crush passenger loads and minimum train headway. Clearly, before these upper limits are reached, customer service level will deteriorate as a result of on-train crowding, platform crowding, longer board and alight times, queuing for escalators and stairs, slow barrier exits and reduced service reliability.

Figure 3.6 helps illustrates the interaction between demand and supply. Up to Qo, passengers can be carried under 'free-flow' conditions. There is no crowding on trains and stations, train boarding and alighting is 'free – flow' and there are no queues for the escalators, ticket barriers and ticket machines. As peak hour demand rises past Q_0 however, queuing and crowding begins to reduce the customer service level by increases the user cost. The user cost function is shown as the upward sloping curve denoted S. Crush load capacity limits the maximum passenger volume to Q_{TC} and at this point, the user cost curve becomes vertical. Practical capacity is shown as the vertical line to the left of theoretical capacity.

Rail demand for travel in the peak hour is shown as the downward sloping line D_1. The number of passengers to travelling by rail in the peak hour falls as user cost rises. With current infrastructure, equilibrium rail demand would be at point A with Q1 patronage and C1 user cost. This is a typical 'base case' option that has some capacity related costs that dampen rail patronage.

Future growth in population and employment increases rail demand to D2. With no increase in rail infrastructure, rail peak hour patronage would be constrained to Qc. Equilibrium would be at point D with user cost per trip increasing to Cc. Had user cost remained at C1, demand would increase to Qu which is beyond the theoretical carrying capacity of the rail line.[5]

Figure 3.6: Capacity & Service Level



3.7 The Snowball Effect

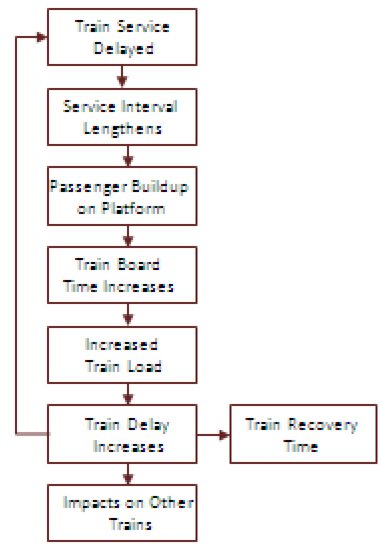
Train delays can compound at subsequent stations by passing the delay downstream through increased train dwell time. This is because the interval between services lengthens at the next station and as a result, more passengers arrive onto the platform.

When the delayed train arrives, the large number of waiting passengers increases the station dwell time. This will be especially so if the platform becomes congested since the time taken for alighting passenger will increase as well as the extra time required for the additional passengers to board.

[5] In many demand models, for instance the Sydney Travel Model, patronage level Qu is forecast. This patronage level is 'unconstrained' and has no crowding or capacity related costs other than those implicit in the 'base case' situation. In fact, demand would reduce to Q2 in response to increase in user cost.

The effects of the incident therefore 'snowball' down the rail line. Delayed trains can 'recover' once away from highly patronized stations. Therefore, the "snowball" effect will not necessarily permeate throughout the line.

Figure 3.6: The 'Snowball' Effect



A study of Tokyo Metro operations also found train run times to slow. Hibino (2010) used Centralized Traffic Control data on the departure and arrival times of train for a link of 15 stations. The service ran every three minutes with trains normally taking 20 minutes. Towards the end of the AM peak, the run time increased by up to 10 minutes. In the early AM peak, increases in station dwell time from platform congestion caused most of the increase in run time. These longer dwell times caused the following trains to reduce their speed. The delay was then propagated to other subsequent trains.

In Sydney, RailCorp keeps data on train delays and it is understood that where the delay increases due to patronage volumes, the 'cause' is partly recorded due to patronage, the remainder attributed to the original incident.

It is not common to include the snowball effect in operational simulations however. The PB-CHA (op cit) operational simulation study of the North Shore line included an assessment of three scenarios involving a single incident that increased dwell time by 300 seconds. The assessment did not lengthen the station dwell times at subsequent stations however. Instead they remained fixed. Nevertheless, for single-deck, 28tph operation with ECTS2 signalling, the delayed train caused many following trains to come to a full stop on the line. The frequent stop and go operation reduced train operating speed and reduced line capacity. PB-CHA considered that the large number of trains affected by the incident indicated that the system was "operating above its practical capacity". If dwell times had been increased, the assessment would have produced even greater dwell time delays to subsequent trains.

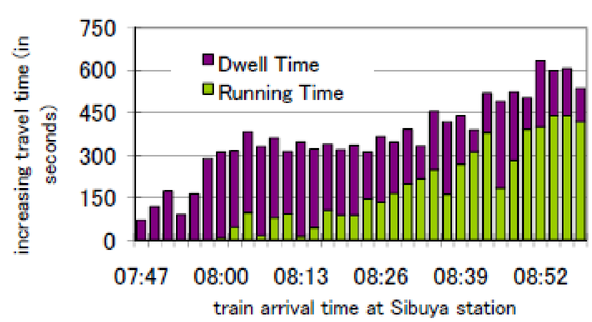


Figure 4 – increased amount of travel time

Train travel times were estimated to increase 50% by Hibino (2010) due to passenger crowding on Tokyo Metro as a result of increased station dwell times causing slower train run

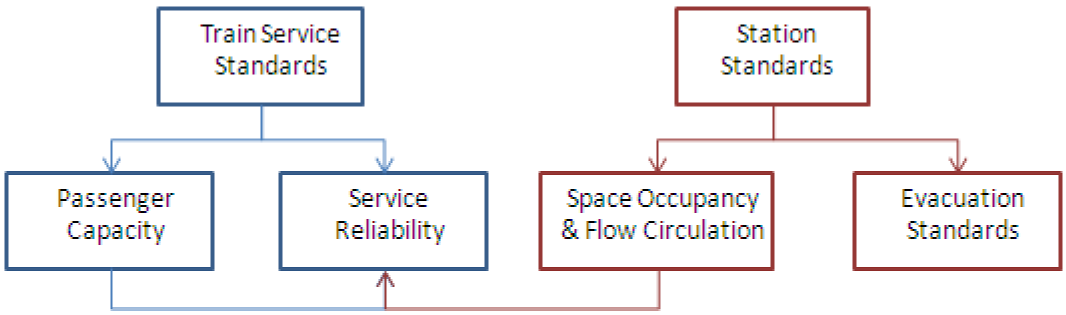
In summary, dwell time models will fail to pick the snowball effect unless train dwell time is expressed as a function of board and alight volume with the actual service interval determining the number boarding. Implementing the snowball effect would probably require an iterative procedure

4. Capacity & Level of Service Standards

4.1 Introduction

Section 3 ended by looking at the relationship between capacity and service level. In this section, capacity 'standards' for train services and stations used to assess the provision of urban rail services in Sydney are discussed. The nature of the standards helps specify the modelling output requirements.

Table 4.1: Demand & Capacity Standards



Section 4.2 looks at train capacity standards and section 4.3 train service reliability standards. Section 4.4 looks at station capacity, patronage and level of service.

There is no level of service standard for train dwell time. Train dwell time is both influenced by patronage volume and, by placing an upper limit on the number of services that can be reliably run per hour, helps determine passenger carrying capacity.

4.2 Train Capacity

CityRail surveys passenger loads on trains during the AM and PM peak periods twice a year. The survey results are used to assess average passenger density, train load versus seat capacity and length of stand. Three capacity standards are referenced in the NSW Auditor General's report.

Average Passenger density measures the number of passengers per square metre (PSM) of standing space for the peak hour. The observed densities are compared against an international benchmark of 4 PSM and an internal RailCorp threshold of 1.9 PSM. Between 2007 and 2011 (Figure 4.2.1), CityRail comfortably met both targets with a peak hour passenger density of 1 PSM in four five years only approaching the internal threshold in 2008 with a density of 1.8.

Individual Train Loads: The Rail Service Contract drawn up by the Minister of Transport sets a standard that no more than 5% of AM peak hour suburban trains (trains arriving Central 8-9am excluding intercity) exceeding passenger loads of 135% of seat capacity.[6] In fact, since September 2005 the target has been met only once in September 2011.[7]

Length of Stand: The third crowding standard is that passengers should not stand for more than 20 minutes. Definitive assessments would require monitoring of individual passengers although indicative assessments have been made from the loading surveys. For instance, the September 2011 Auditor General's report gave a figure of 47 morning trains with passengers standing for longer than 20 minutes.

Reviewing the three targets, the 135% train load implies a lower carrying capacity than the 1.9 PSM target whilst length of stand is the most difficult to measure. All three targets will depend on where the observations are taken.

4.3 Service Reliability

Reliability is a key consideration in developing the RailCorp timetable and passenger carrying capacity. RailCorp measures peak on-time running (OTR) for CityRail services in terms of the percentage of timetabled peak train services that reach their destinations with five minutes of scheduled arrival time for suburban services and six minutes for intercity services.[8] RailCorp aims for 92% of peak services to meet this OTR requirement. In the three years 2009-2011, on-time running exceeded the 92% target (averaging 95%-96%) although some individual lines such the Western Line failed to meet the standard.

The main cause(s) for late running is also recorded. Slow passenger boarding/alighting is one category. Over a two year financial period 2009/10 and 2010/11, slow boarding/alighting accounted for 8-10% of late running trains. However, in terms of the relationship between passenger dwell time and headway reliability, the five minute OTR threshold is too coarse to provide a useful target.

4.4 Station Capacity Standards

RailCorp has developed a set of Engineering Standards for stations and buildings (RailCorp, 2010). From a passenger capacity perspective, the relevant standards relate to (a) providing emergency evacuation and (b) providing safe circulation and sufficient waiting area.

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[6] The 135% target is an average for a train and does not allow for load variations between cars.

[7] The percentage has generally declined since March 2005 and reached a maximum in March 2007 with 16% of AM peak hour suburban trains exceeding passenger loads of 135%.

[8] In the AM Peak, Central station is the destination station and in the PM Central is the 'origin' station and the outer station is the destination station. When disruptions occur it is often necessary for trains to skip one or more stations in order to get the system back to normal as quickly as possible. CityRail's target is for less than 0.5 per cent of all scheduled stops to be skipped during peak periods.

4.4.1 Emergency Evacuation

RailCorp Engineering Standards for stations and buildings (RailCorp, 2010) reference the North American *'Standard for Fixed Guideway Transit and Passenger Rail Systems'* NFPA 130. NFPA 130 provides the basis for assessing railway station emergency evacuation. The principal is to establish the number of people in the station including those on trains at the station, then design sufficient means of egress so the population can leave the station platform within 4 minutes in the event of an emergency escape to a 'point of safety' within 6 minutes.

4.4.2 Passenger Capacity, Flow & Level of Service

Station capacity may be considered in terms of the maximum number of passengers that a platform, staircase or concourse can handle per hour. However, the physical maximum will necessarily require passengers to endure unpleasant levels of crowding waiting for trains and congestion moving around the station. Instead of using the maximum1, the conventional approach is to assess capacity that meets a desired level of service (LOS).

The concept of LOS dates to Fruin who developed a six category system for pedestrian walkways, stairs and queuing/waiting areas (Fruin, 1971). The system was based on crowding density measured in terms of the number of passengers per square metre (PSM)[9]. As passenger density increases, movement becomes more restricted and waiting becomes less pleasant.

Fruin labelled the six levels of service A to F with A the most pleasant and level F the least pleasant. The Fruin crowding levels are presented in Tables 4.4.1 to 4.4.3 for platform areas, walkways and staircases. As can be seen, the critical densities differ for each station area.

RailCorp's Engineering Standards for stations and buildings are designed around meeting a LOS of C. For platform areas, a LOS of C equates to a passenger density of between 1.1 and 1.4 PSM and is described as *"standing without touching is impossible; circulation is severely restricted with the queue/waiting area and forward movement is only possible as a group; long term waiting at this density discomforting".*

For a walkway, level C equates to a passenger density of between 0.4 and 0.7 PSM and is described as *"walking speeds freely selected; passing is possible in unidirectional streams; minor conflicts for reverse or cross movement"*

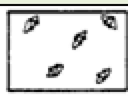
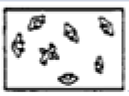
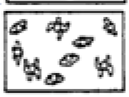
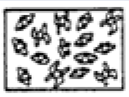
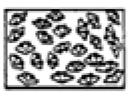
For a stairway, level C equates to a passenger density of 0.7-1.1 PSM and is described as *"speeds slightly restricted due to inability to pass slower moving pedestrians; reverse flow causes some conflicts".*

As was mentioned in section 3, the temporal and spatial distribution of passengers affects the calculation and interpretation of crowding density measures. Two density measures are space and entity density. Space density is the ratio of the number of passengers to total space for a given time period and may not reflect peaked or clustered demand well.

[9] Or the inverse, the amount of space provided to passengers.

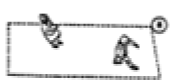
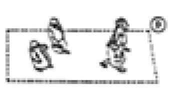
Entity density calculates density measures zones around each entity typically within a 1.5 metre radius. Areas without passengers record zero entity densities. Thus entity density will tend to be higher than space density. Indeed, LOS densities classified as D and E can be acceptable for short bursts of time such as when trains arrive and passengers alight.

Table 4.4.1: Level of Service for Waiting Areas

LOS	Illustration	M^2/P	P/M^2	Description
A		≥1.2	<0.8	Standing and free circulation through the queuing/waiting area possible without disturbing others
B		0.9-1.2	0.8-1.1	Standing and partially restricted circulation to avoid disturbing others possible
C		0.7-0.9	1.1-1.4	Standing and restricted circulation through queuing/waiting area possible; density within range of personal comfort
D		0.3-0.7	1.4-3.3	Standing without touching is impossible; circulation is severely restricted with the queue/waiting area and forward movement is only possible as a group; long term waiting at this density
E		0.2-0.3	3.3-5	Standing in physical contact with others unavoidable; circulation with queue/waiting area not possible; density sustainable for only short periods without serious discomfort
F		<0.2	>5	Virtually all persons within the queue standing in direct physical contact; density extremely discomforting; no movement possible within queue/waiting area; potential for pushing and panic exists

Based on Fruin 1971

Table 4.4.2: Level of Service for Walkways

LOS	Illustration	P/M^2	Speed m/sec	Flow P/M/min	Description
A		≤0.3	1.32	0-23	Walking speeds freely selected; conflicts with other pedestrians unlikely
B		0.3-0.4	1.27	23-33	Walking speeds freely selected; pedestrians response to presence of others
C		0.4-0.7	1.22	33-49	Walking speeds freely selected; passing is possible in unidirectional streams; minor conflicts for reverse or cross movement
D		0.7-1.1	1.2	49-66	Restricted freedom to select walking speed and pass others; high probability of conflicts for reverse of cross movements
E		1.1-2	0.8	66-82	Restricted walking speeds & passing ability; forward movement by shuffling; reverse/cross movement extremely difficult; volumes approach limit of walking capacity
F		>2	<0.8	Variable	Severely restricted walking speeds; frequent unavoidable contact with others; reverse/cross movements are virtually impossible; flow is sporadic and unstable

Based on Fruin 1971

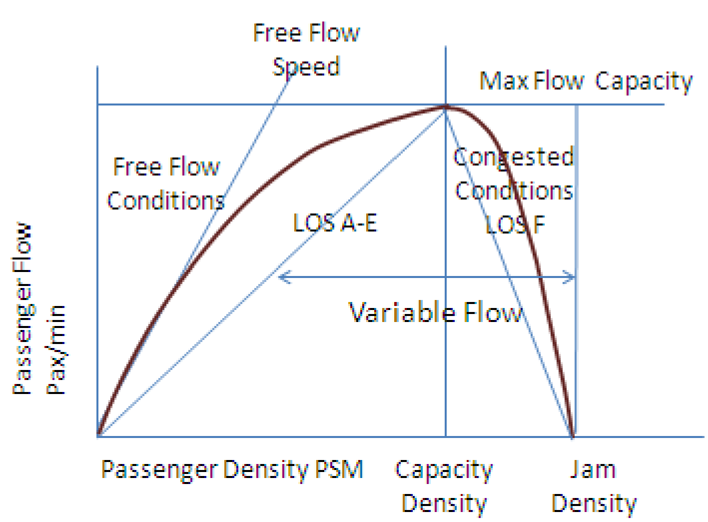
Table 4.4.3: Level of Service for Stairways

LOS	P/M²	Flow P/M/min	Description
A	<0.5	≤16	Sufficient area to select speed and pass slower moving pedestrians freely. Reverse flows causes limited conflicts
B	0.5-0.7	16-23	Sufficient area to freely select speed with some difficulty in passing slower moving pedestrians. Reverse flows cause minor conflicts
C	0.7-1.1	23-33	Speeds slightly restricted due to inability to pass slower moving pedestrians. Reverse flows cause some conflicts
D	1.1-1.4	33-43	Speeds restricted due to inability to pass slower moving pedestrians. Reverse flows cause significant conflicts
E	1.4-2.5	43-56	Speeds of all pedestrians reduced. Intermittent stoppages likely to occur. Reverse flows cause serious conflicts
F	>2.5	Variable	Completed breakdown in pedestrian flow with many stoppages. Forward progress dependent on slowest moving pedestrians

Source: Fruin 1971

For LOS A to E, the flow rate for accessways and passageways increases to a maximum. With further increases in crowding, the flow rate becomes unstable and complete breakdowns can occur. Figure 4.5, argues that the flow rate will actually likely down to zero decline at the jam density. The implication is that flow rates are likely to be variable and difficult to predict with a simple formula for densities exceeding 2.5 PSM (Crowd Dynamics, 2007).

Figure 4.4: Flow Rate & Passenger Crowding



Thus in terms of flow, the maximum passenger handling capacity is likely to be less the crush load capacity with level E rather than level F providing the maximum. Adopting level C as the required level of service implies a near halving in the flow rate for passageways and stairways.

4.5 Train Board/Alighting

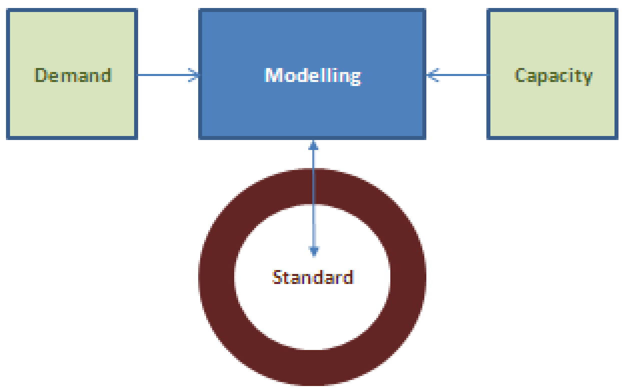
In terms of train dwell times, the current timetable for Sydney CBD train operations is designed around a maximum dwell of one minute. The one minute allowance needs to cover function time (door opening, door closing and train departure) and the time for passengers to board and alight.

There is no relevant train or station level of service since boarding and alighting is an interface between train and station. Given that train and station standards influence train loads and platform crowding, they will also influence alight and board times.

4.6 Summary

The capacity standards adopted by RailCorp are instrumental in assessing the adequacy of rail capacity to meet current and projected rail patronage, Figure 4.5.

Figure 4.5: Standards Demand and Rail Capacity

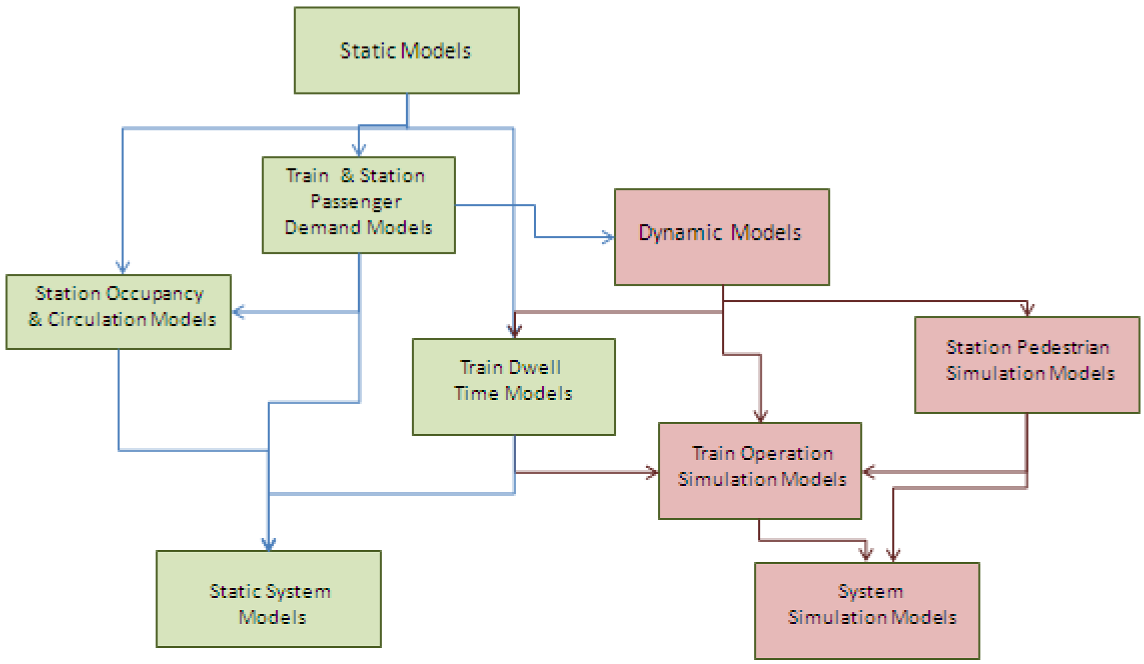


The RailCorp capacity standards are necessarily set below the physical maximum carrying capacity in order to achieve acceptable levels of passenger comfort and convenience. To some extent, the standards introduce arbitrariness into capacity determination. Moreover, the targets may or may not be met and in this regard it is the extent to which the targets are missed, both in duration and areal extent that becomes the assessment criteria.

5. Static and Dynamic Modelling of Rail Demand & Capacity

There are two approaches to demand-capacity modelling: static and dynamic as shown in Figure 5.

Figure 5: Static and Dynamic Modelling Approaches



A static model assesses demand and capacity for a particular time period; this might be an hour, quarter hour or minute for example. The defining characteristic is that the time periods are unlinked meaning that the results of one time period do not feed into the next time period and so on. By avoiding the time dimension, most static models can be built in a spreadsheet.

Static models include initial train and station passenger demand forecasting models that usually provide the inputs into capacity assessment models (either static or dynamic).

Static models are also used to assess the level of service or capacity of specific areas of a station such as a platform width or vertical transport circulatory capacity. Section 6 looks at the main steps involved.

Dynamic models are usually undertaken for short time periods typically of a minute or less. The defining characteristic of dynamic models is that the time periods are linked; the results of one time period feed into the following time period and so on. In this way, the build up and dissipation of queues for escalators, the alight/board process of trains and platform crowding can be modelled through time.

The key task of dynamic models it to simulate the train and passenger interactions. Due to the different response processes, simulation models have focussed on either modelling train operations or pedestrian activity.

Dynamic models, because of their complexity, usually require a proprietary simulation package or software language. Over the last decade there has been a rapid advance in 'microscopic' simulation modeling with several software packages available to model station crowding and train operations.

Their basic data requirements are effectively the same as static models however. Indeed a static model may provide the inputs for a dynamic model.

The key feature of dynamic modelling is the ability to show the operation of the train or station through time. Indeed some station-pedestrian models now offer 3D visualisation. For capacity determination however, the results will generally need to be summarised in tabular or graphic form and in doing so, static analysis may be undertaken.

Although, the time periods of dynamic models are linked, simulations rarely model demand-capacity feedback. Rail passenger volumes remain the same as input in total or per train service. Patronage does not respond to train or station crowding.

For rail, simulation packages have developed along two strands: simulation of train operations and pedestrian simulation of stations. There are some examples of simulation packages that model the interaction of vehicles and pedestrians but to date these packages have been road traffic based. No example could be found of a dynamic model that has attempted to simulate train operations and multi-station pedestrian activity for a through city rail link on the scale of Sydney CBD. A more practical 'system solution' would be to link station and train simulations together feeding the results of one model into the other. Section 7 looks at simulation approaches.

Both static and dynamic approaches have been used to model train dwell times. Static models have been based on surveys of passenger board and alight times. Dynamic pedestrian simulation models have also been used to assess the effectiveness of alternative rolling stock designs. In these applications, the emphasis has been on modelling the interior layout of trains such as seat configuration and door location rather than assessing platform layout and crowding. Section 7 looks at train dwell time modelling.

6. Static Models

6.1 Introduction

Static models provide a computationally manageable way of calculating train and station handling passenger capacity. Section 6.2 looks at the framework developed by Transit Research Board (TRB) to measure train and station passenger handling capacity.

Section 6.3 then reviews a consolidated model of train and station passenger capacity developed by Wardrop to assess the impact of changes in rolling stock, signalling and station dwell time for the Sydney rail system.

6.2 TRB Capacity and Quality of Service Manual

The North American Transit Research Board's Transit Cooperative Research Program (TCRP) Report 100: Transit Capacity and Quality of Service Manual, 2nd Edition provides a framework for measuring transit capacity (TRB, 2003).

The report contains quantitative techniques for calculating the capacity of train services and rail stations. The report is divided into parts. The two most relevant parts are:

- Part 5 which calculates train passenger carrying capacity and
- Part 7 station which calculates passenger handling capacity.

The techniques presented are static and can be calculated using an Excel spreadsheet. Some of the concepts were described in section 3. A brief review of the train and station techniques is provided below.

6.2.1 Train Passenger Carrying Capacity

TRB indentified station dwell time and the train signal control system as the key controlling factors of the number of trains that can be operated along a section of a line during an hour. The number of cars per train and the diversity of passenger demand control how many people those trains can carry. TRB introduced "diversity" factors to take account of the fact that passengers do not load evenly into cars and trains over the peak hour.

TRB considered station dwell time at the station with the highest passenger volumes to determine line capacity. The controlling station dwell time is the combination of dwell time and a reasonable operating margin—the dwell time during a normal peak hour that controls the minimum regular headway. Controlling dwell takes into account routine perturbations in operations—but not major or irregular disruptions.

Based on extensive surveys undertaken in 1995, TRB estimated average train door entry and exit times of 2 seconds per alighting passenger, 1.75 seconds per boarding passengers and 2.5 seconds for mixed flows (single stream width doors providing level to the platform).

TRB lists three methods to estimate planned dwell times. The first approach translates station passenger volumes and doorway flow rates into doorway flow times and then into dwell times. A similar approach using statistical analysis of observed dwell times is described in section 7. The second method is the "mean dwell time plus two standard deviations" estimated at busy stations or the mean plus an operating margin (15 and 25 second margins are suggested). The third method which TRB considered to be *"often the most practical"* is to select dwell times and operational allowances from comparable existing systems.

6.2.2 Station Passenger Handling Capacity - TRB

Part 7 of the TRB manual describes setting up a 'link-node network' to estimate the passenger handling capacity of a station in the absence of a transit station simulation model. As well as providing an initial assessment, TRB considered that the network data can "serve as typical inputs into computer simulation models".

The methodology includes the nine steps listed below:

Step 1: Define the station as a link-node network to describe the main paths passengers will take. Each link, representing a horizontal and/or vertical circulation element, is described in terms of (1) type — walkway, ramp, stairway, escalator, or elevator; (2) movements allowed—one-way or two-way (shared or not shared); (3) length—in feet or meters; and (4) minimum width—in feet or meters. Nodes are queuing points and/or decision points such as fare collection devices, doors, platform entrances or exits etc.

Step 2: Determine pedestrian volumes per period for each pedestrian origin-destination pair (typically the peak hour or the peak 15 minutes within the peak hour).

Step 3: Determine path choice that passenger can or take between a particular origin and destination pair

Step 4: Load inbound passengers onto the links and nodes.

Step 5: Load outbound passengers onto the links and nodes.

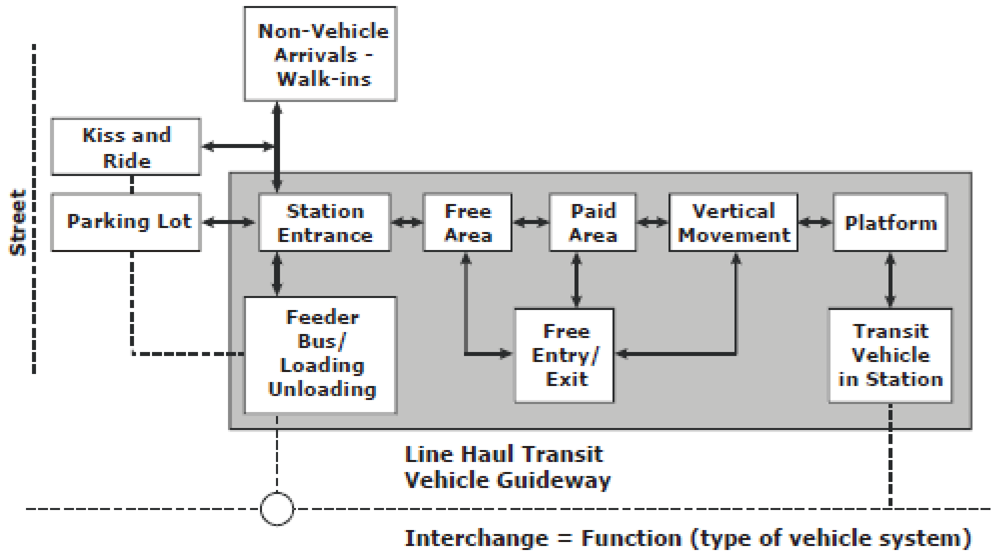
Step 6: Determine walk times and crowding on Links using flow/ density relationships.

Step 7: Determine queuing times and crowding at nodes by observation or analytical means

Step 8: Determine wait times for trains in order to determine platform occupancy

Step 9: Add travel time components and assess overall level of service for different origin-destination pairs to identify an average passenger processing time through a particular transit station which can then be translated into an overall passenger processing LOS.

Figure 6.2.2: Sample Pedestrian Flow Diagram



Element	Components
Train Arrival	On- or off-schedule; train length; number and locations of doors
Passengers	Number boarding and alighting; boarding and alighting rates, passenger characteristics; mobility device use, baggage or packages carried, bicycles and strollers, etc.
Platform	Length, width, and effective area; locations of columns and obstructions; system coherence: stair and escalator orientation, lines of sight, signs, maps, and other visual information
Pedestrians	Walking distance and time; numbers arriving and waiting; effective area per pedestrian; levels of service
Stairs	Location; width; riser height and tread; traffic volume and direction; queue size; possibility of escalator breakdown
Escalators	Location; width; direction and speed; traffic volume and queue size; maintainability
Elevators	Location; size and speed; traffic volume and queue size; maintainability; alternate provisions for disabled passengers when elevator is non-functioning

Source: TRB (2003) Part 7 Page 19

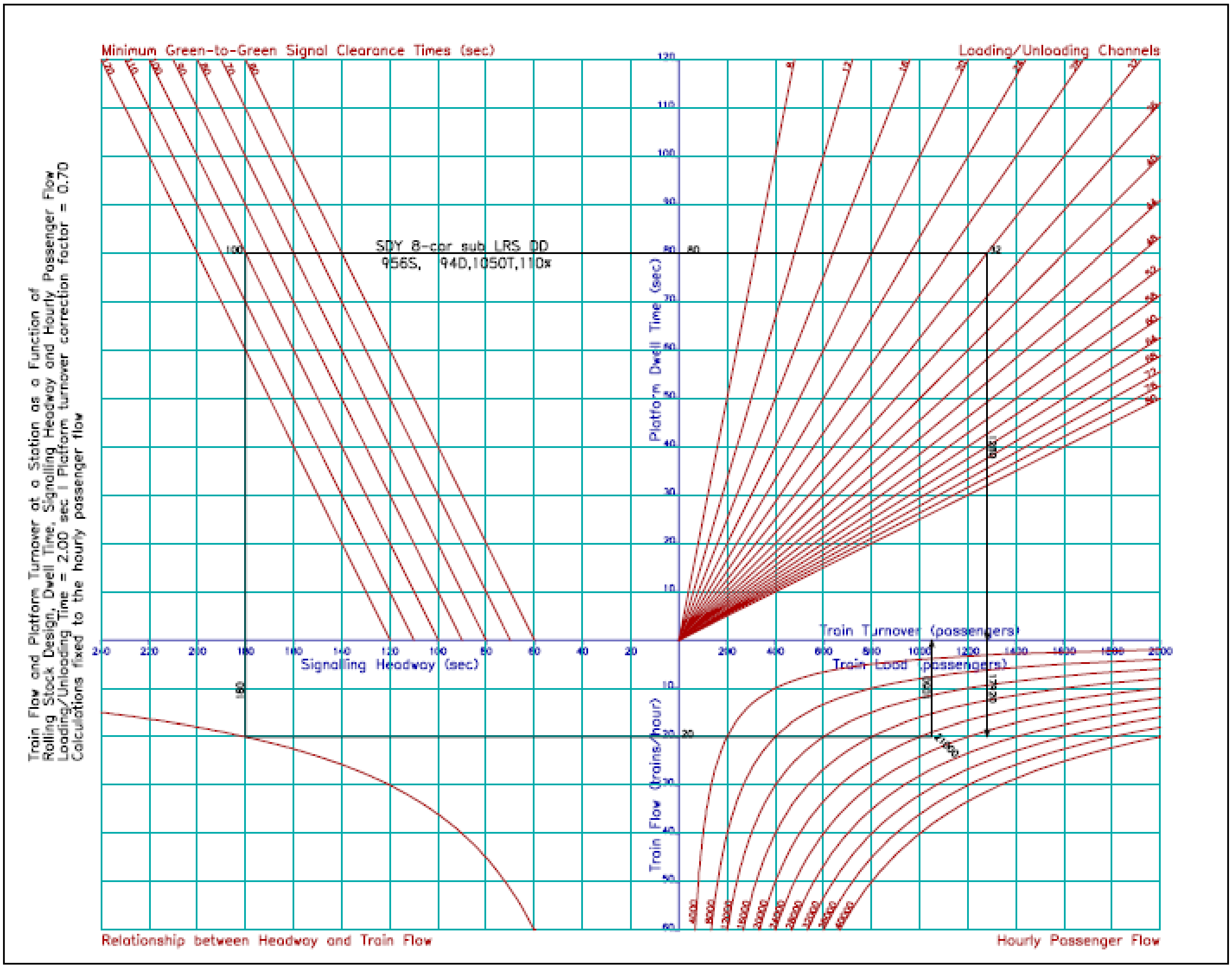
6.3 Wardrop Consolidated Train & Station Capacity Model

Alex Wardrop developed a static model (TRNFLW) that consolidated train and station capacity together. The model comprises five equations that describe the relationships between rolling stock, station dwell time, signaling, train flow, station platform turnover and passenger flow. The relationships are graphed using a 'nomagram' with the formulas provided in the Appendix. TRNFLW has been used to assess the impact of changes in rolling stock, signaling and station dwell time for the Sydney rail system.

The nomagram is presented in Figure 5.3 and displays four quadrants of information. By starting with train configuration shown in the top right hand quadrant, dwell time can be calculated in terms of the number of doors which are measured in terms of channels along the train length (a single door is 1 channel, a double door is 2 channels). Wardrop assumed that dwell time is proportional to patronage at two seconds per passenger per channel (i.e. one second per double door).

Figure 6.3: Wardrop Nomagram

Relationship between Train Configuration, Passenger Turnover, Station Dwell Time, Signalling System and Hourly Passenger Flow Based on Standard Sydney Double Deck Suburban Train



Source: TMG International (2004)

Moving to the top left quadrant, the dwell time is added to the intrinsic clearance time of the signaling system controlling the flow. This yields the headway in the bottom left quadrant between successive trains from which the train flow can be calculated. The product of the train flow and the train capacity (in turn the product of its seating capacity and load factor) determines the sustainable hourly passenger flow (in the bottom right hand quadrant). The average passenger turnover per station can be calculated, whence the hourly platform turnover can be calculated.

Figure 6.3 uses a standard 8-car Sydney double deck with 956 seats. Assuming a load factor of 110%, the train could carry 1,050 passengers. An 8-car train has 16 double doors, or 32 access/egress channels. Assuming an 80 second dwell time gives a practical turnover as high as 896 passengers per station stop. With an intrinsic signaling clearance time of 100 seconds, the headway is 180 seconds allowing a flow of 20 trains per hour. This yields a line flow of 21,000 passengers per hour and a maximum hourly platform turnover of 17,920 passengers.

TMG used the nomagram to evaluate how well twelve other rolling stock / signaling systems could carry 21,000 passengers per hour, that is: assuming what headway, at with what load factor; and with what platform turnover. TMG normalised comparisons by constraining the different system's trains to 160 metre platforms, although they have assumed that their cars could achieve their native dwell times and line capacities. Finally, they compared the suburban operations with selected metro operations to draw out the differences between suburban metro operations and the rolling stock. The results of the TMG analysis are presented in Table 6.3.

Table 6.3: Operational Comparison of Different Suburban Railways and Metro Systems

City	Rolling Stock	Number Of Cars	Number Of Channels	Dwell Time (sec)	Signal Time (sec)	Head Way (sec)	Train Flow (t/h)	Platform Turn Over (pax/h)	Train Capacity		Load Factor (%)	Pax Flow (pax/h)
									Seats	Stands		
Sydney	LRS	8 DD	32	80	100	180	20	17920	956	94	110	21000
	T								840	210	125	
	M								904	146	116	
Melbourne	CG	6 SD	18	50	100	150	24	7560	590	285	148	21000
	XP								528	347	166	
	NX		24					10080	528	347	166	
LIRR	M-1	6 SD	12	60	120	180	20	5040	720	330	146	21000
	M-7	6 SD							633	417	166	
	C-3	5 DD	10	60	120	180	20	4200	697	353	151	
London Liverpool Street	Cl 315	8 SD	32	60	120	180	20	13440	636	414	165	21000
	Cl 317	8 SD	16	60	120	180	20	6720	590	460	178	
	Cl 321	8 SD							624	426	168	
Glasgow	Cl 318	8 SD	16	60	120	180	20	6720	576	474	182	21000
Paris	Z6400	6 SD	36	50	100	150	24	15120	540	335	162	21000
	Z20500	6 DD	24					10080	900	Nil	97	
	Z22500	7 DD	42					17640	770	105	114	
Berlin	Cl 481	8 SD	32	60	120	180	20	13440	376	674	279	21000
Zurich	Cl 450	5 DD	20	60	120	180	20	8400	645	405	163	21000
Hong Kong	MTRC	7 SD	70	30	90	120	30	22050	315	385	222	21000
New York	R46	7 SD	56	30	90	120	30	17640	518	182	135	
Washington	B3000	7 SD	42	30	90	120	30	13230	476	224	147	
London	T73	9 SD	51	30	90	120	30	16095	396	304	177	
Paris	MF77	10 SD	60	30	90	120	30	18900	256	444	273	

Source: TMG International (2004)

TMG found that all the types of trains were capable of carrying the required numbers of passengers (i.e. 21,000 per hour) but most would require high numbers of standees to do so. The double deck Sydney fleet could carry the requisite number of passengers at load factors of 125% or less whereas none of the single deck fleets could carry the requisite passengers at less than 150% load factor. This means that high peak single deck train loads could reach crush loads with little reserve capacity. TMG considered that it would be far harder to also achieve the platform turnover requirements of 12,000 passengers per hour and only car designs with wide doorways in sufficient numbers would meet the platform turnover requirement.

In consideration, the consolidated model developed by Wardrop provides a quick and straightforward way of computing the capacity provided by different rolling stock/signalling systems.

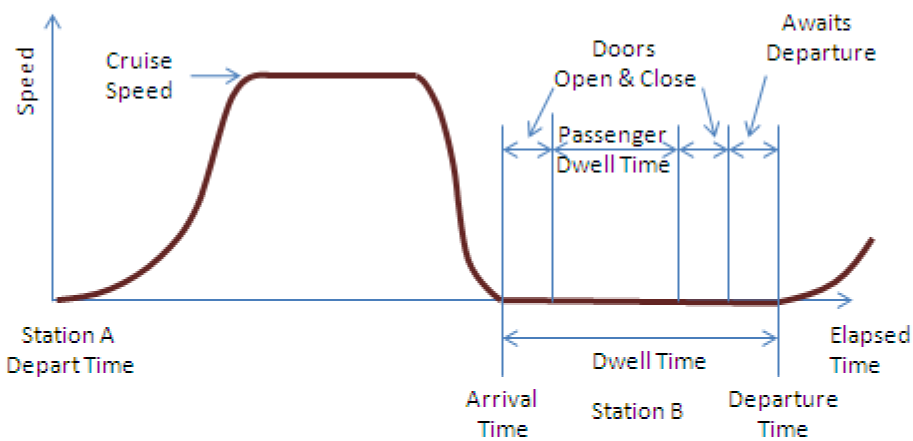
It is a static model in that it does not take account of variability in demand or operational factors via simulation but rather by introducing factors to reduce theoretical to practical capacity.

7. Statistical Models of Train Dwell Time

7.1 Introduction

Train dwell time is the time a train stands at the platform usually for the purpose of allowing passengers to board or alight. The diagram shows dwell time in context of the speed of the train between stations.

Figure 7.1: Train Dwell Time



Section 7.2 looks at the factors that influence dwell time. Then three dwell time algorithms based on observations of actual times are reviewed. The first was developed by Gerry Weston of London Underground and is described in section 7.3. The second algorithm was developed by John Rosser for Thameslink and CrossRail is presented in section 7.4. The third algorithm was developed by Puong using data for trains in Boston and is summarised in section 7.5.

7.2 Factors affecting Dwell Time

Figure 7.2 groups the main factors influencing dwell time under six headings: passenger volume; passenger composition; train design, station design, the timetable and operational factors.

Passenger dwell time is determined by (i) the number of passengers alighting and boarding and (ii) the speed at which they board and alight. The speed or rate of boarding and alighting is determined by a variety of factors. The boarding rate also tends to slow after the initial queue has embarked reflecting the arrival rate onto the platform rather than the speed of boarding itself. For this reason, empirical studies 'cut-off' the boarding time after the last person in the boarding queue has boarded.[10]

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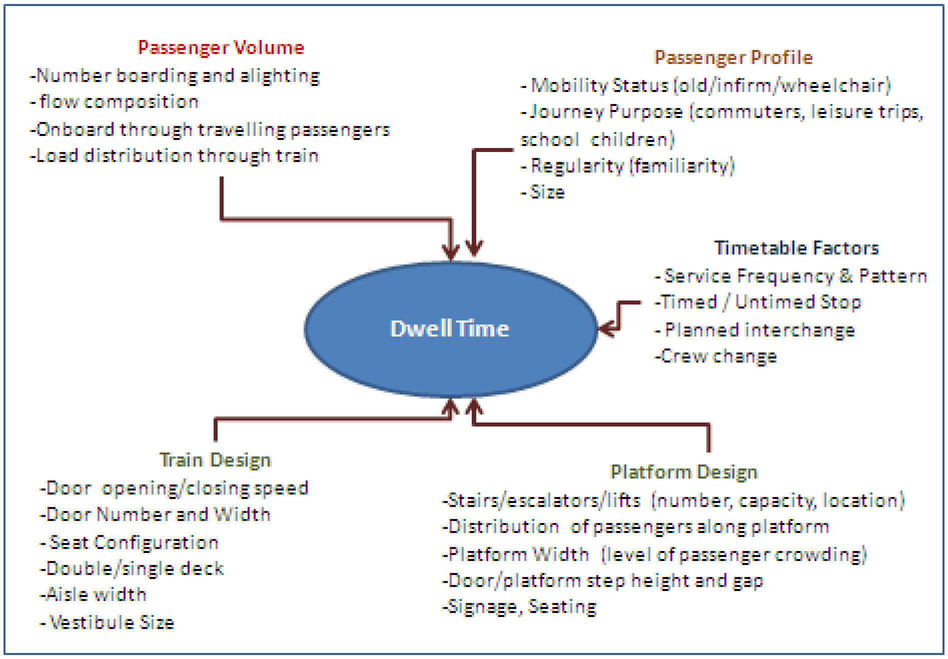
[10] This introduces some arbitrariness in disaggregating board time since the doors may stay open after the main boarding 'queue' has got on allowing later arriving passengers to board. For this reason, boarding time may be restricted to the last passenger in the boarding 'queue'.

Mixed board and alighting flows tend to lengthen dwell times compared to uni-directional flows: 40 passengers alighting will generally take less time than 20 alighting plus 20 boarding for example.

The number of through passengers on the train especially standing passengers (i.e. those passengers not alighting or boarding) in the vestibule and aisle is also likely to slow alight and board times.

The distribution of passengers through the train will affect the dwell time with the busiest car/door determining the dwell time.

Figure 7.2: Factors affecting Train Dwell Time



Passenger profile will influence the speed of boarding and alighting. Encumbered passengers with bags, strollers or bicycles tend to board and alight slower and take up more space thereby slowing others. Passengers in wheelchairs and older/infirm passengers may need assistance. Regular rail passengers such as commuters will be more familiar with the train and station layout and board faster than irregular passengers making leisure trips. Bunches of school children also tend to slow boarding and alighting.

Train design e.g. door width and station design e.g. stepping distance and platform gap. Most or all passengers alight before passengers start to board. Thus passenger dwell time may be broken down into alighting then boarding time. However, wide (double) doors may allow some passengers to board as others alight. Also when trains are heavily loaded, some passengers may have to get off to allow others to alight.

Train design also influence board and alight times. The number of doors and their width will affect the alighting and boarding speed. CityRail trains have two double doors per carriage and enable two passengers to alight at the same time. Single-metro deck trains usually have three doors per carriage per side. The time for the doors to open and close is influenced by train and door design. Wider doors take longer to open. It takes around two seconds for the double doors on CityRail trains to open or close. Whether the doors are passenger or guard operated or whether they are automatic will also influence door the opening and closing time. Plug doors take longer to open and close. The layout of the vestibule layout will also influence boarding/alighting rates. The newer Waratahs and refurbished Tangaras have greater standing room in the vestibule than the older CityRail cars.

Dwell times are also dependent upon platform design and demand. Town Hall and Wynyard have narrow platforms which become crowded at peak times. The number, capacity and location of stairs, escalators and lifts will influence the distribution of waiting passengers along the platform and hence the boarding time for trains. Likewise the location of platform signing and seating may affect the distribution of waiting passengers.

The timetable will also determine the dwell time especially if the station is a timed stop. Trains arriving early will have longer dwell times so they don't depart before the scheduled time. At interchange stations, longer dwell times may be required to allow for trains to connection.

7.3 London Underground Dwell Time Algorithm

Gerry Weston developed a dwell time model as part of a Train Service Model for London Underground. The formula is shown in equation 6.3:

$$SS = 15 + 1.4\left[1 + \frac{F}{35}\left(\frac{(T-S)}{D}\right)\right].\left[\left(\frac{FB}{D}\right)^{0.7} + \left(\frac{FA}{D}\right)^{0.7} + \left(0.027\left(\frac{FB}{D}\right)\left(\frac{FA}{D}\right)\right)\right] \quad .....(7.3)$$

Where:

SS = Station stop time (in seconds)
15 = Function time (secs) - train stop to doors open plus time for doors to close and train to start moving
A = Number of passengers alighting the train
B = Number of passengers boarding the train
D = Number of doors on train (double door width)
F = Peak door/average door factor
T = Number of through passengers
S = Number of seats on train

The LUL formula includes a constant 'function time' of 15 seconds to account for door opening and closing and the time for the train to start moving once doors are closed. This compares with estimates of between 10 and 21 seconds for CityRail (RailCorp 2007a&b).

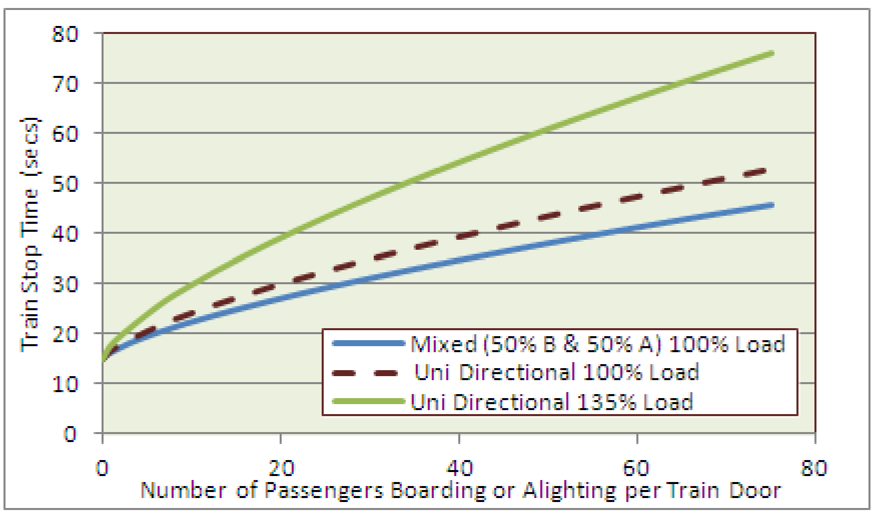
The formula is for an entire train rather than a carriage or door. The number of doors is included in the formula. The doors are double doors like CityRail trains. A factor F (the ratio of the peak door to the average door) is introduced to take account of unequal loading of passengers through the train.

It is possible to express the formula in terms of passengers per door. The 'door' could either be an average door with the peak/average door factor retained or the formula expressed in terms of the peak door with the factor removed.

The same exponential parameter of 0.7 is used for boarding and alight volumes.[11] Thus with uni-direction flow (i.e. either all 'offs' or all 'ons') the predicted stop time would be the same for 50 boarders as for 50 alighters.

In Figure 7.3, the LUL algorithm is used to predict the train dwell for a Waratah (896 seats) train. Three curves are shown to illustrate the predicted effect of ontrain loading: two for a 100% train loading i.e. when train throughput (T) equals the number of seats (S); and one for a 135% load.[12] As can be seen, ontrain crowding has a significant slowing effect on dwell time. For 20 alighters and 20 boarders per door, the dwell time increases from 40 seconds to 55 seconds.

Figure 7.3: Predicted Train Dwell using LUL Formula



The station stop time increases with the number of boarders/alighters. However the rate of increase declines. This is a result of the power function of 0.7 being less than 1. The LUL formula therefore does incorporate an 'alighting/boarding congestion effect'. An 'interaction term' is included that lengthens

[11] There is an element of doubt about this as an exponent of 0.9 was reported in the text for alighting.

[12] In producing the curves, it should be noted that the variable T was kept the same and not adjusted for the number of passengers boarding or alighting.

dwell times in mixed flow situations. With 40 alighters (or boarders) per door the predicted dwell time is 35 seconds. With 20 alighters and 20 boarders, the dwell time increases to 40 seconds.

A term is also included to take account of on-train passenger crowding slowing boarding and alighting. The term is calculated as the number of through passengers (presumed to be the arrival load minus alighters or the departure load minus boarders) minus the number of seats.

Harris and Anderson (2007) applied the LUL formula to station dwell data for thirty metros / suburban railways around the world. Sydney was not in the sample. There was a wide range in the observed board and alight times over the 30 railways investigated. Alight times varied between 0.56 seconds per passenger per metre door width to 5.55 seconds in highly crowded situations. Boarding speeds ranged between 0.63 seconds in situations of uni-direction flow to 2.7 seconds per passenger per metre of door width where trains were very full.

Harris and Anderson concluded that "although parameters have to be varied slightly, Weston's formula for estimating station stop time appears to have validity around the world, and the overall structure of the approach appears sound." Some adjustments were made to improve calibration. The alight and board parameters were adjusted. The alighting power was reduced to a value nearer 0.813 while the boarding power was found to 'vary more widely', across a range 0.45–0.9. There were also question marks about the interaction part of the formula at high levels of passenger flow (Harris, 2006).

7.4 Cross Rail & Thameslink Algorithm

The LUL model provided a basis for developing a dwell time model for the Thameslink and Crossrail projects in London. These projects involved building two new rail lines through London with four or more city stations. In this regard, there are parallels with the Sydney project.

John Rosser and Peter Howarth developed the algorithm and provided information for this study.[14]

The surveys and analytic work resulted in a much revised algorithms to that developed by Weston. Equation 6.3 presents one algorithm. The model has four multiplicative components: passenger volume; door width factor; step distance factor and a vestibule crowding factor.

Unlike the LUL model, the equation estimates passenger related dwell time and excludes door opening and closing time and other non-passenger related dwell time.

Surveys were conducted on the difference between passenger related dwell time and total dwell time. The difference was referred to as 'Dead Time'. Observations in London of both LUL and National Rail

[13] Harris and Anderson give a figure of 0.9 for the alight power in the text but in the formula it is given as 0.7 (the same as the board parameter).

[14] Peter Howarth (now of Interfleet) and John Rosser (now of the Institute of Electrical Engineers) provided details of the dwell time model (referred to as DSA8).

operations showed an average peak period Dead Time' for the core Thameslink section of around 28 seconds and 25 seconds for the seven LUL central area stations.

Dead Time was longest at London Bridge station at 38 seconds. Typically, two thirds of Dead Time was the time from the last boarder to doors close. Dead time was reduced to 20 seconds for forecasting future train frequency and route capacity calculations with Thameslink.[15]

$$TD = 0.49(A + 1.22B + .011AB)\left(\frac{1.702}{EDW}\right)(1 + .002SD)\left(1 + \frac{\left(\left(\frac{T}{3}\right) - 0.5\right)}{15}\right)\left(1 + \frac{T}{50}\right)$$

$$EDW = D + 0.7112\left(1 - e^{\left(\frac{V - D}{0.7112}\right)}\right) \quad ......(7.4)$$

where:

TD = Alighting and boarding time in seconds
A = Number of passengers alighting per door
B = Number of passengers boarding per door
T = Number of through standing passengers (i.e. neither alighting nor boarding) in the vestibule
D = is doorway opening in metres
EDW = Effective doorway width in metres
V = vestibule width along the train in metres
SD = diagonal platform to train stepping distance in millimetres

Rosser gave the following typical passenger values that were observed: 27 alighting passengers, 6 boarding and 4 standing in the peak doorway (vestibule). The diagonal stepping distance was 257 mm and the effective door width was 1.267 metres. With these values, the predicted passenger dwell time using equation 6.4 was 40 seconds.

The dwell times are per train, but the passenger numbers in the equation are for the doorway with the longest alighting and boarding time. In estimating the passenger flows at the busiest doorway, average passenger numbers were used for the whole train which was then multiplied by a Peak Doorway Factor (PDF).

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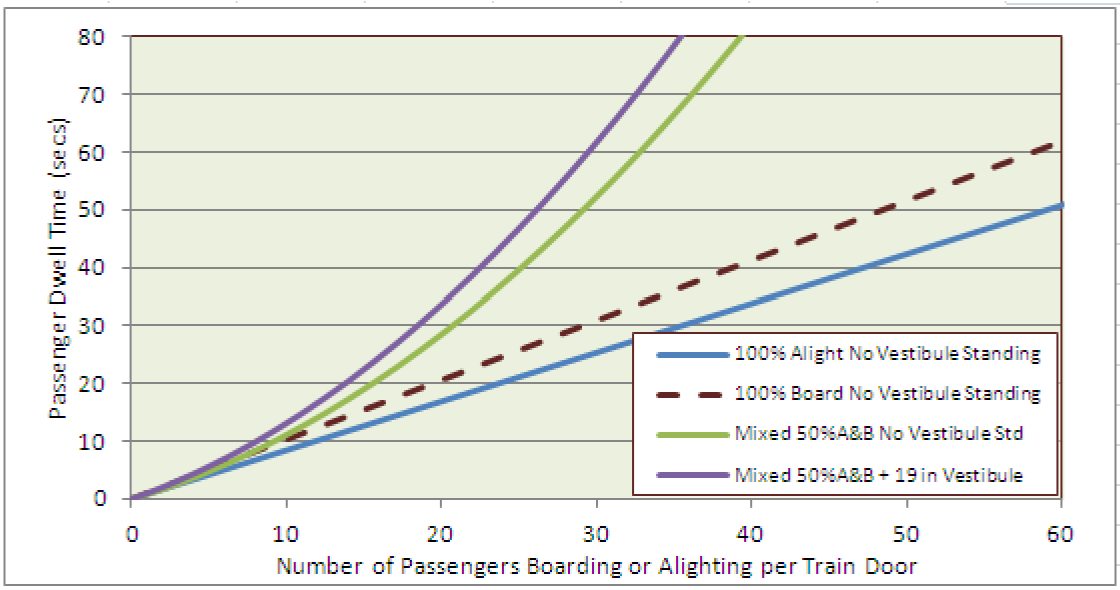
[15] Thameslink trains are 8 cars long whereas future trains (starting 2012) will increase to 12 cars long. The longer a train, the longer its dispatch from a station generally takes, particularly from a curved platform such as Farringdon.

Observations at a number of relevant London platforms produced a PDF of 1.3 which was considered representative of peak period conditions in the Thameslink core. However the surveys also showed that that the PDF fell as passenger loads increased due to crowding encouraging passengers to spread themselves out along the train.

Figure 7.4 presents the dwell time predictions for a CityRail carriage door. The equation has been standardised for a 1.7 metre wide door which is roughly equivalent to a CityRail double door. Single doors (at 750 mm wide) would double the board/alight time.

A zero step distance was used in drawing the graph since Central, Town Hall and Wynyard have level train-platform boarding.[16] A stepping distance of 100 mm (measured on the angle), would increase board/alight times by 20%.

Figure 7.4: Predicted Passenger Dwell Time using CrossRail/Thameslink Algorithm



Four 'curves' are shown, two of which are straight lines. These are for flows where everyone either boards or alights and there is no crowding in the vestibule area. Board times are slower at 1.22 seconds per passenger than alight times at 1 second. Alight times are constant with respect to passenger volume (rather than reducing as in the LUL model).

The other two curves are for mixed flow and these curves rise exponentially with passenger volume. Mixed flow (modeled as 50% alights and 50% boards) increases dwell time compared to uni-directional flow. The increase is non proportional.

The number of standing 'through' passengers (i.e. not boarding or alighting) in the vestibule increases board and alight times markedly although it should be noted that the graph uses the maximum

[16] There is a stepping gap at Redfern station on platforms 1-10.

observed for CityRail vestibules of 19 passengers(PBCHA figures) which are much higher than the numbers observed in the London study.

7.5 Boston Dwell Time Model

Puong developed a model to analyse dwell times for the Massachusetts Bay Transport Authority (MBTA). The model was based on 54 dwell time observations of trains that had either 3 or 4 single doors per carriage. All the observed dwell times were less than 90 seconds.

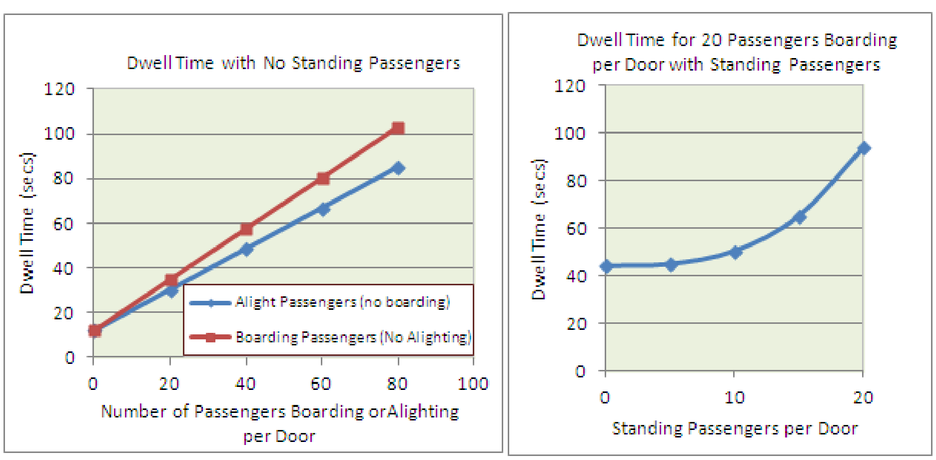
A constant of around 12 seconds was estimated for door opening/closing and train starting. Alight and board times were estimated to increase by 1.82 and 2.27 seconds respectively for each additional passenger. The single door widths increased the times above those of LUL which have double width doors. Onboard standing passengers slowed boarding times with the marginal boarding time increasing with standing patronage.

The fitted equation is shown below in equation 6.4 and a set of forecasts are graphed in Figure 7.4.The right hand graphs shows that at less than 5 standees per door, the effect on boarding times was negligible. Above 5, the dwell time increased at a cubed rate. Puong found that neither on-board standees nor the number of passengers on the platform significantly affected alighting times.

$$DT = 12.22 + 2.27B_d + 1.82A_d + 0.00062TS_d{}^3B_d \quad .....(7.5)$$

Where:
DT = Dwell time in seconds
Bd = Number of passengers boarding per door (single width door)
Ad = Number of passengers alighting per door (single width door)
TS_d = Number of standing passengers per door

Figure 7.5: Predicted Train Dwell (Station Stop Times) using Boston Formula



7.6 Comparison

The three studies show how dwell time data can be used to develop an algorithm to calculate dwell times according to passenger volumes.

The LUL model was non linear and the functional form forecasts that dwell times increased but at a decreasing rate as board/alight totals increased. By contrast, the Boston passenger dwell times increased proportionally (ignoring the constant 'function time'). It is considered that the LUL formulation is probably more realistic especially for boarding time.[17]

The LUL and Boston models allowed for dwell times to increase with onboard train crowding. In the LUL model, a factor for excess demand compared to seats was applied that increased boarding and alight times. In the Boston model, the number of onboard standing passengers was introduced as an interaction factor that increased slow boarding times after loads exceed 5 per door at an increasing rate.

A key distinction was that the LUL model related to an entire train whereas the Boston model was for an individual car and the Rosser model was for a train door. The LUL model included a peak to average train load factor to take account of unequally distributed passengers along the train.

[17] Some support for this is provided by Olympic Park which shows that boarding tends to slow after the immediate queue has embarked.

8. Development of a Dwell Time Algorithm for Sydney

8.1 Introduction

RailCorp carried out dwell time surveys in 2006-07. Two types of survey were undertaken: 'live' observations of train services at Central, Town Hall and Wynyard rail stations and 'simulated' passenger boardings and alightings experiments using a Millennium carriage at Sydney Terminal. The two surveys were described in two reports dated March 2007 (labeled draft) and May 2007 (updated).

The data obtained by these two surveys was provided to Douglas Economics to see whether dwell time algorithms similar to those described in section 6 by Weston, Rosser and Puong could be estimated.

Section 8.2 describes the 'live' survey data and section 8.3 uses regression to estimate passenger dwell time models. Section 8.4 re-estimates the model after adding in the 'simulated' observations. Section 8.5 adds in door opening and closing/depart time.

8.2 RailCorp 'Live' 2006-7 Dwell Time Surveys

The 'Live' surveys of actual dwell times were carried out during the AM and PM peaks in November and December 2006 and May 2007 at Central, Town Hall and Wynyard stations.

Observations were made of a single door. Carriages and door were randomly selected. Two field workers used hand held data capture devices (Psion) to record the times and passenger volumes. One fieldworker recorded alightings, the other recorded boardings. Three other fieldworkers recorded the arrival and departure passenger loads on the train by carriage.

RailCorp focussed on measuring passenger dwell time which was defined as the time from when the doors opened until the last person in the boarding queue boarded. Passengers who came onto the platform later were not included.

Table 8.2 presents a summary of the survey data. In total, 246 useable observations were obtained of which 102 were of Town Hall platform 2 in the PM peak. Around 30 observations were obtained at three other Town Hall platforms plus Central platform 17 and 16 observations were obtained at Wynyard platform 3.

The average passenger dwell time was 28 seconds and tended to be longer at Town Hall platforms 2 and 3 at 33 seconds compared to the other four locations (20-26 seconds). The average times correlated with alighting and boarding totals which were higher on Town Hall platforms 2 and 3 at 47 and 40 respectively than on the other platforms (31-35).

Figure 8.2 presents a scattergram of passenger dwell time against the number of passengers alighting plus boarding. A clear upward trend can be seen in passenger dwell time as passenger volume increases. The graph also shows the spread in passenger dwell times to widen as passenger volume increases.

Table 8.2: RailCorp Dwell Time Surveys

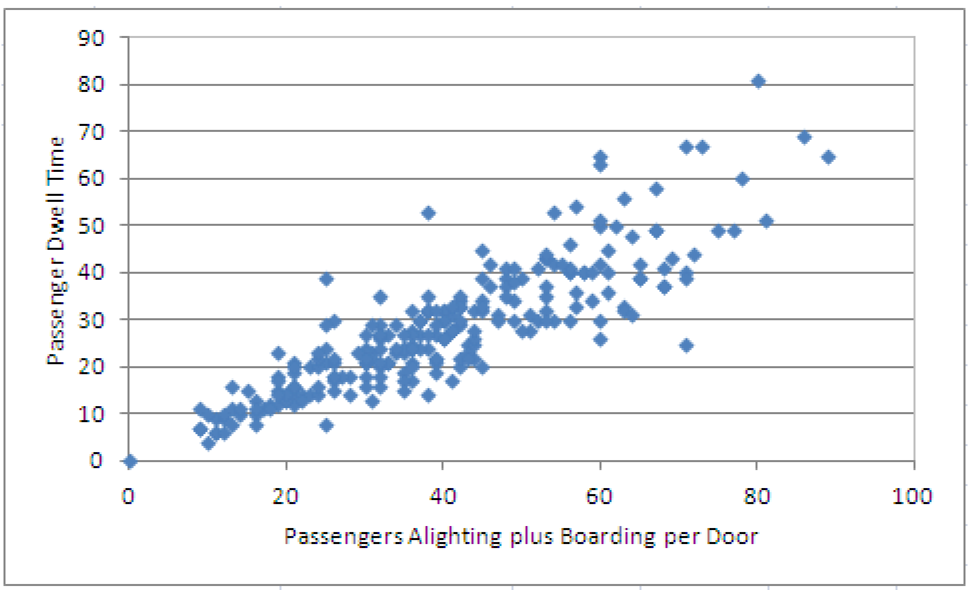
November 2006 and March 2007

	Plat	Time	Survey	Sample	Passenger Dwell (secs)			Alight + Board Passengers		
Station	Number	Period	Date	Size	Average	Min	Max	Average	Min	Max
Central	17	AM	9/11/2006	29	23	6	53	32	11	63
Town Hall	2	PM	8/11/2006	102	33	10	81	47	9	86
Town Hall	3	AM	16/11/2006	32	33	12	67	40	18	71
Town Hall	4	PM	10/4/2007	35	20	4	46	32	9	60
Town Hall	5	AM	10/4/2007	32	26	11	65	35	13	89
Wynyard	3	AM	15/11/2006	16	23	0	60	31	0	78
Total	na	na	Na	246	28	0	81	40	0	89

RCTables

Figure 8.2.: Passenger Dwell Time versus Alighting plus Boarding Volume

RailCorp Dwell Time Surveys at Town Hall, Central & Wynyard (Nov 2006 and April 2007)



8.3 Estimated 'Live' Survey Dwell Time Models

Six models were fitted to the data:

1. Combined Board + Alight Model
2. Separate Board & Alight Model
3. Board and Alight Model with allowance for standing through passengers
4. Model 3 but with a cubed function for standing through passengers
5. Model 3 with mixed board and alight variable

6. Model 3 with power function for boarding passengers

The estimated equations are presented below with t values in parenthesis.[18]

Model 1: Combined Board + Alight Model

$$DT = 1.48 + 0.67(A_d + B_d) \quad R^2=0.75 \qquad \text{....(8.3.1)}$$

(1.4) (27.0)

Where:
DT = Dwell time in seconds
Bd = Number of passengers boarding per door
Ad = Number of passengers alighting per door

Model 2: Separate Board & Alight Model

$$DT = 1.28 + 0.75A_d + 0.59B_d \quad R^2=0.76 \qquad \text{....(8.3.2)}$$

(1.2) (17.3) (22.3)

Model 3: Separate Board & Alight with Standing 'Through' Passengers

$$DT = 3.15 + 0.66A_d + 0.51B_d + 0.005(A_d + B_d)(Std_d) \quad R^2=0.78 \qquad \text{....(8.3.3)}$$

(2.9) (17.8) (13.6) (5.1)

Where:

Std_d = Estimated number of standing passengers travelling through station per door

Model 4: Separate Board & Alight with Standing 'Through' Passengers 'cubed'

$$DT = 2.26 + 0.71A_d + 0.55B_d + \frac{4.2}{1000{,}000}(A_d + B_d)(Std_d)^3 \quad R^2=0.78 \qquad \text{....(8.3.4)}$$

(2.2) (21.0) (15.8) (4.35)

Model 5: Model 3 with Mixed Flow Term

$$DT = 4.53 + 0.59A_d + 0.43_d + 0.0044(A_d + B_d)(Std_d) + 0.0042(A_d . B_d) \quad R^2=0.78 \qquad \text{....(8.3.5)}$$

(3.3) (10.3) (7.5) (4.3) (1.6)

Model 6: Model 3 with Power Function for Boarding

$$DT = 0.31 + 0.65A_d + 1.69{B_d}^{0.7} + 0.005(A_d + B_d)(Std_d) \quad R^2=0.79 \qquad \text{....(8.3.6)}$$

(0.3) (17.9) (14.0) (5.15)

[18] The t statistic is the ratio of the parameter mean to the standard error. A value greater than 1.96 indicates that the parameter is significant at the 95% confidence level.

A small positive constant was estimated in all models which varied from 0.31 seconds in model 6 to 4.53 seconds in model 5. In theory, the constant should be zero, since door opening time was excluded.

Predicted alight and board times averaged less than one second per person. Model 1 combined board and alight volumes and the average time was 0.67 seconds per passenger. This compares with the one second per passenger 'rule of thumb' guideline.

Alighting passengers tended to take longer than boarding passengers. In model 2, alighting passengers averaged 0.75 seconds and boarding passengers 0.57 seconds. It should be noted that the analysis did no use separate times for alighters and boarders. The faster speed for boarders therefore may have resulted from passengers boarding 'as a group' with the observation stopped when the last boarder 'in the queue' got on. Whereas, alighters may have got off over a longer period with some passengers alighting as boarders got on. The faster speed for boarders is contrary to the findings of Rosser and Puong however where boarding was slower than alighting.

Models 3-6 allow for standing through travelling passengers to slow alighting and boarding. Standing passengers were not recorded but were calculated from the train load observations. Fieldworkers estimated the load factor for each car (passengers / seat capacity). The arriving loads were used for the AM and the departing loads for the PM. Equation 8.3.7 shows the AM peak calculation.

$$Std_d = \left(PAX_d - SF(Seats_d)\right)\left[\frac{PAX_d - A_d}{PAX_d}\right] \quad ......(8.3.7)$$

Where:

$PAX_d = AVL\%(Seats_d)$

$AVL\%$ =observed average passenger load for surveyed car (Passengers/Seats)

$Seats_d$ = number of seats per car per door (900 seats per 8 car train divided by 2 doors)

SF = seat occupation factor which was assumed to be 85%

Each car was assumed to have 113 seats (900/8). The number of seats was then divided by 2 to get seats per door (i.e. 56.25). The observed arrival load factor for the carriage was then multiplied by the seats per door to get the arrival passenger load. Thus for a train with a load factor of 200%, the number of passengers per door would be 112.5.

The number of sitting passengers was then subtracted to get standing passengers. An allowance was made for some seats to be unoccupied using an assumed seat occupation factor of 85%. This factor produced 48 'effective' seats per door. Thus with a passenger load of 112.5 per door, 64.5 passengers would be standing. It was assumed that standing and sitting passengers would have an equal likelihood of alighting so the number of through standing passengers was calculated as the standing arrival load multiplied by the percentage of arriving passengers who alighted.

The highest number of through standing passengers calculated from the survey was 28 per door (i.e. 56 per carriage).

The best fit variable for standing through passengers was a linear function (model 3) that multiplied standing passengers by the combined total of boarding plus alighting passengers. A cubed function (model 4) as used by Puong for Boston did not fit the data as well. It should be noted that Puong only allowed boarding passengers to be affected by 'through travelling' standing passengers.

A variable for mixed boarding and alighting was introduced in model 5. The estimated parameter was positive implying that mixed flows tended to be slower than uni-directional flows. However the parameter was small and had low statistical insignificance (t value of 1.6).

Power functions for boarding and alighting as adopted by Weston in the London Underground model were tried. Model 6 presents the best fit functional form which was a linear alight function and a power function of 0.7 for boarding (the same as Weston used). The average board time therefore reduced as the number of passengers boarding increased.

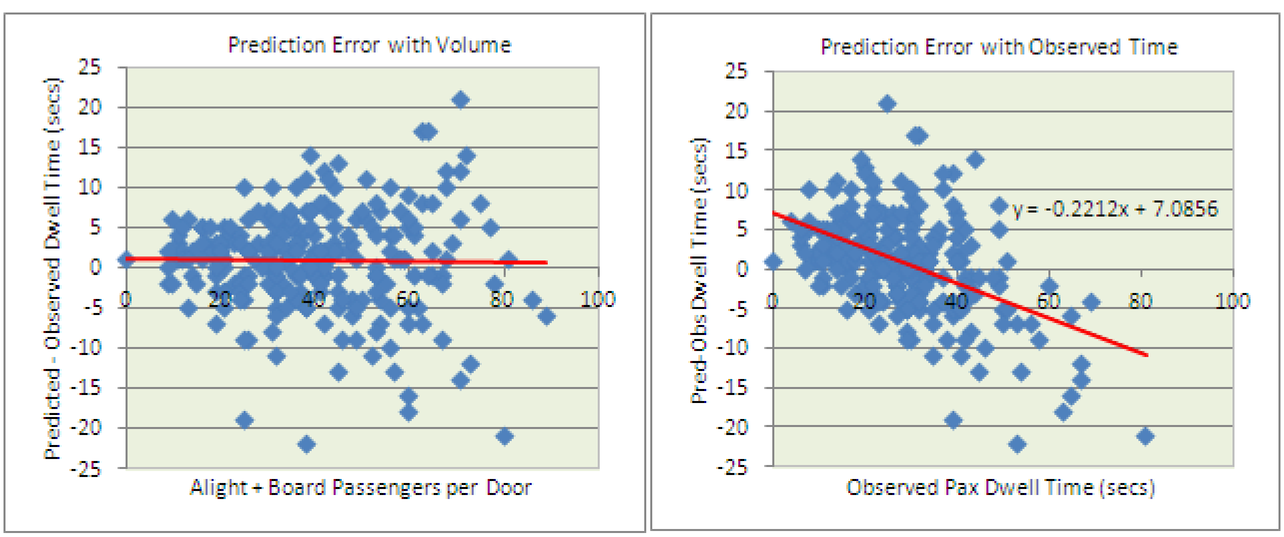
The models gave a reasonable fit to the data as measured by the coefficient of determination R^2. Model 1 explained three quarters of the variation in passenger dwell time with an R^2 of 0.75. Introducing additional variables improved the goodness of fit to 0.79 in model 6.

The predicted dwell times were compared with the observed dwell times. The average prediction error was ±4.7 seconds or ±20% of the observed time. Figure B3 plots the residual (Predicted – Observed) against the observed dwell times.

Two scattergrams are presented. The graph on the left plots the prediction error against the combined number of passengers alighting and boarding and shows a tendency for the prediction error to increase as volumes exceed 20 passengers but not for the model to under or over predict. However, when the prediction error was plotted against the observed dwell time, the model showed an increasing tendency to under predict high dwell times and over predict low dwell times.

Figure 8.3: Prediction Error for 'Live' Survey Sydney Dwell Time Model

Predicted– Observed Dwell for Model 6



8.4 RailCorp 'Simulated' Dwell Time Surveys

The 'simulation' surveys involved 300 fieldworkers boarding and alighting a Millennium carriage at Sydney Terminal. The surveys were undertaken in two phases: 21 experiments were undertaken on 6th December 2006 in which the number of passengers on the carriage was varied whilst keeping board and alighting numbers relatively constant; a further 34 experiments were undertaken in 11th May 2007 in which boardings and alightings were varied whilst keeping passenger load high and relatively constant.[19]

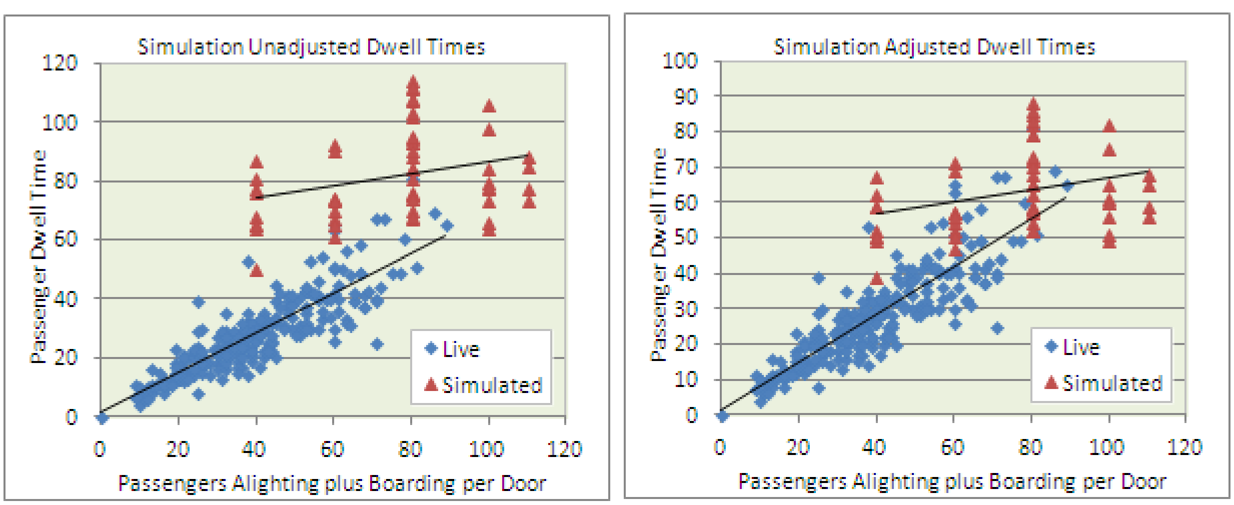
The simulation experiments tested dwell times under passenger loads and high board/alight turnovers that exceeded those in the live survey observations and as such enable the live survey models to be extended to cover more extreme situations. However, the simulation surveys were undertaken in the absence of platform crowding.

Unlike the live surveys where a single carriage door was monitored, the simulation surveys monitored both doors of the carriage. Thus, to place the two surveys on an equal basis, the numbers boarding and alighting were halved for the simulation surveys.

The left hand graph in Figure 8.4 superimposes the simulation surveys on to the live survey observations. Five vertical lines of data observations are shown for the simulation surveys which reflect the mix in boarding and alighting volumes and also the variation in onboard train loading. The scattergram also shows that the simulation surveys produced noticeably higher passenger dwell times than the live observations for a given passenger turnover (alight + board).

Figure 8.4: Live & Simulated Passenger Dwell Time

RailCorp 'Live' Surveys at Town Hall, Central & Wynyard & Simulated Surveys (2006 and 2007)



[19] There were a few experiments that were excluded from the statistical analysis data base because of survey administration problems.

RailCorp reviewed video footage of the experiments and considered that *"the fieldworkers in the experiment were boarding and alighting trains in a less aggressive manner than that observed in the live measurements"* (RailCorp 2007a). RailCorp calculated an adjustment factor based on a comparison of flow rates for comparable observations. The simulation surveyed produced a flow rate of 62 passengers per minute for experiments with around 160 alights/boards and an onboard load of 160%. This compared to observations of 81 passengers per minute in the live survey. Fieldworkers were therefore 30% slower than 'live' passengers.

The adjusted simulation survey observations were added to the live survey observations and regression models fitted to the data. The best fit model (Model 7) is presented below. The constant was close to zero and, for forecasting purposes, can be excluded, since the statistical significance was weak (t=0.5). A power function of 0.7 gave a better fit than a linear function for both alighting and boarding which is in agreement with the Weston model. Onboard standing slowed boarding and alighting with a linear function performing better than a cubed function as suggested by Puong. Mixed board and alighting also lengthened dwell times. Goodness of fit measured by R^2 was high at 0.83.

Model 7: Live + Simulated Observations:

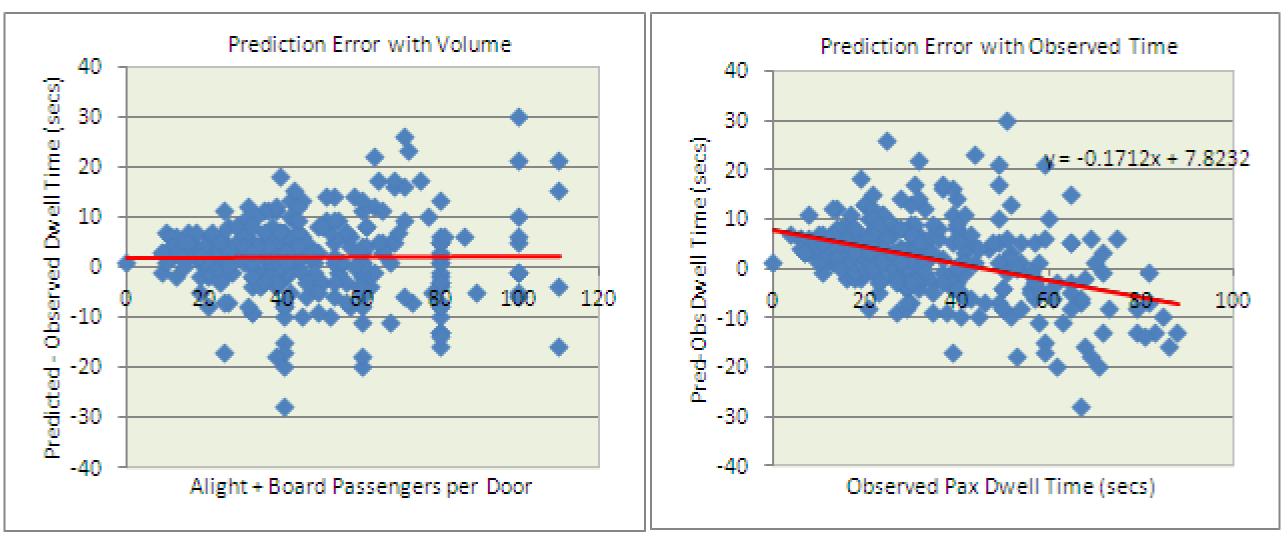
$$DT = -0.91 + 1.9{A_d}^{0.7} + 1.4{B_d}^{0.7} + 0.007(A_d + B_d)(Std_d) + 0.005(A_d . B_d) \quad R^2=0.83$$

(0.5) (10.7) (7.7) (10.5) (2.9)

The predicted dwell times were compared with the observed dwell times. The average prediction error was ±6 seconds or ±21% of the observed time. Figure 8.4 plots the residual (Predicted – Observed) against the observed dwell times.

Figure 8.4: Prediction Error Live & Adjusted Simulated Dwell Time Model

Predicted– Observed Dwell for Model 7



8.5 Total Dwell Time

So far, the analysis has assessed passenger dwell time. Door opening and door closing and train start times need to be added to get total dwell time. The April 2007 'live' survey provided 65 observations for platforms 4 and 5 at Town Hall (the data was not provided for the other locations).

Table 8.5: Components of Dwell Time

RailCorp Surveys of Dwell Time at Town Hall Platforms 4 & 5 April 2007

	Stop to Doors Opening	Doors Open to Last Boarder	Last Boarder to Doors Close	Doors Close to Train Depart	Total Dwell	Sample Size
Average	3	36	19	11	70	65
Max	8	78	70	60	104	65
Min	2	14	4	4	42	65

The graphs are similar to Figure 8.3 for the live survey data. Prediction error increases with volume and there was an increasing tendency to under predict high dwell times and over predict low dwell times.

Total dwell averaged 70 seconds and ranged from 42 to 104 seconds. Of this total, passenger dwell (doors open to last boarder in queue) accounted for 36 seconds or roughly one half of total dwell.

Door opening averaged 3 seconds with a range of from 2 to 8 seconds. 'Last boarder to doors close' and 'doors close to train depart' are influenced by the planned timetable dwell time of one minute as can be seen from Figure B5. The scattergram shows that as passenger dwell time increases, the time from the last boarding passenger to train departing reduces.

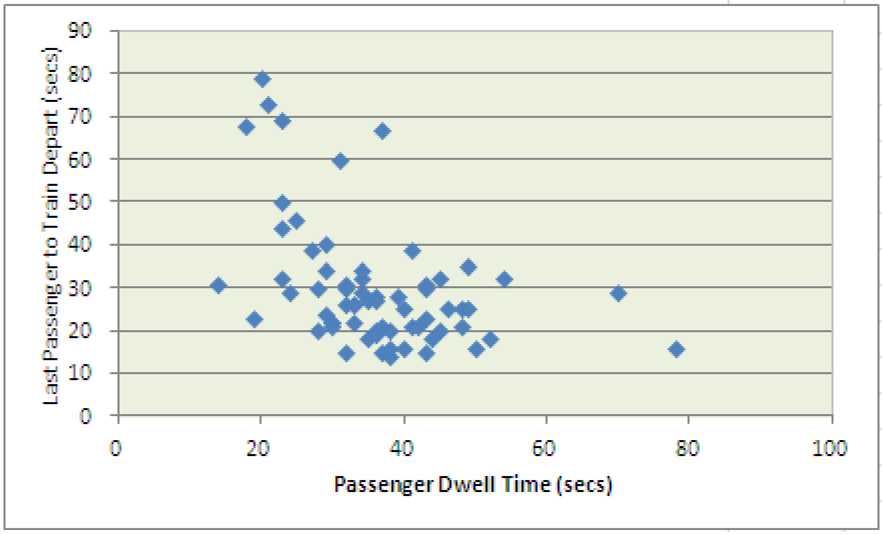
The average times for door closure and train departure in Table 8.5 cannot be used to develop a total dwell time function, uninfluenced by the planned timetable dwell time. Instead, the minimum times offer a better measure which would give a time of 8 seconds. Adding in the average door opening time of 3 seconds gives a function time of 11 seconds. Model 8 adds the function time to model 7 to give a constant of 10 seconds.

Model 8: Passenger plus Function Dwell Time:

$$PFD = 10 + 1.9{A_d}^{0.7} + 1.4{B_d}^{0.7} + 0.007(Ad + Bd)(Std_d) + 0.005(A_d . B_d) \qquad .....(8.5)$$

Figure 8.6: Relationship between 'Other' Dwell & Passenger Dwell

RailCorp Surveys of Dwell Time at Town Hall Platforms 4 & 5 April 2007

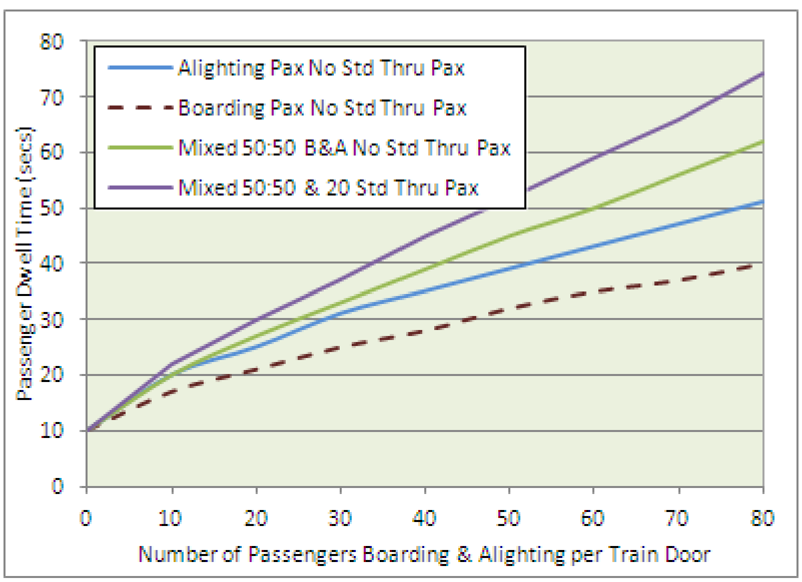


8.6 Predicted Dwell Time

The combined live and simulation model (Model 7) was used to predict passenger plus function dwell for different alighting and boarding passenger numbers. Figure 8.6 graphs the predictions.

Figure 8.6: Predicted Passenger Dwell Times

Predicted Dwell for Model 8



Four curves are presented. The fastest time is for boarding only with no onboard standing and for 60 passengers, the predicted passenger dwell time is 25 seconds. 60 alighting passengers would take nearly ten seconds longer. Mixed boarding/alighting was predicted to take longer. For 30 alighting and 30 boarding, the predicted dwell time was 40 seconds without standing and 49 seconds with 20 onboard standing passengers per door.

Table 8.6 (on the following page) presents three predicted passenger dwell time matrices. The predictions are an individual double deck carriage with two double doors (per side of train). The top matrix is for a carriage with no onboard standing through passengers travelling through the station. The middle matrix is for 10 standing through passengers per door and the bottom matrix is for 20 standing through passengers per door. The cells are shaded red when the predicted time exceeds one minute.

8.7 Train Service Model

The dwell time algorithm could be extended into a forecasting model for a particular line by feeding in initial timetable data and patronage forecasts. In essence, the model would repeat the dwell time calculations for successive train stations for a particular service.

A suggested approach is to add the algorithm into the Train Loading Model (PAS) developed by Douglas Economics in association with Trainbrain for the Independent Transport and Safety Reliability Regulator (ITSRR). During restructuring, the model was handed over to the TfNSW then to RailCorp.

The model was built to measure the impact on passenger loads of changes in the RailCorp timetable. The model can predict boardings, alightings and onboard passenger loads for each station along the route for an individual service. The loadings can then be compared with seating capacity of the train.

The geographic scope of the model covers both the AM 3.5 hr and PM 3.5 hr peaks for all CityRail suburban and intercity services. The model uses EXCEL to input patronage trip data and assign passengers to stations and ACCESS used to model passenger choice of trains. A simpler version for a single corridor was developed in EXCEL by Douglas Economics for the CRC for Rail Innovation in 2009 (Douglas, 2011).

The assignment of passengers to individual trains is the core of the model and is done on the basis of travel time and a desired travel time profile constructed on the basis of CBD barrier exits. The assignment algorithm uses a method called ‘roof-tops’ which was augmented to allow for passengers who turn up at random to the station without regard to the timetable.

It should be possible to incorporate a dwell time algorithm into the model perhaps with an additional algorithm to distribute passengers between the individual cars of the train for alighters and along the ‘platform’ for boarders. This might require surveys at stations.

Currently, the model is capacity unconstrained. Capacity constraints could be introduced that are based on excess demand to seats and onboard passenger density measures. A limit could be included to stop passengers boarding when loads exceed a certain density, for example 5 passengers per square metre.

However, unless detailed track and train performance data was built into the model, any revision of the timetable due to predicted excess dwell times could only be approximate. Moreover, the model as it currently stands is deterministic and has no facility to allow for unexpected delay.

Table 8.6: Predicted Dwell Times

Predicted Dwell Time in seconds for a Double Deck Train Carriage

Model 8 (Passenger Dwell + Function Time)

Standing Through Passengers per door = 0

	Boarding Passengers per Door										
Alighting Passengers per Door	0	10	20	30	40	50	60	70	80	90	100
0	10	17	21	25	28	32	35	37	40	43	45
10	18	25	30	35	38	42	46	49	52	55	58
20	23	31	36	41	46	50	54	58	61	65	69
30	27	36	42	47	52	57	61	66	70	74	78
40	31	40	46	52	58	63	68	73	78	83	87
50	34	44	51	57	63	69	75	80	86	91	96
60	38	48	55	62	69	75	81	87	93	99	105
70	41	51	60	67	74	81	88	94	101	107	113
80	44	55	64	72	79	87	94	101	108	115	121
90	47	58	68	76	84	92	100	108	115	122	130
100	49	62	71	80	89	98	106	114	122	130	138

Standing Through Passengers per door = 10

	Boarding Passengers per Door										
Alighting Passengers per Door	0	10	20	30	40	50	60	70	80	90	100
0	10	18	23	27	31	35	39	42	46	49	52
10	19	27	32	37	42	46	51	55	59	62	66
20	24	33	39	45	50	55	59	64	68	73	77
30	29	38	45	51	57	62	68	73	78	83	87
40	34	43	51	57	63	69	75	81	86	92	97
50	38	48	56	63	70	76	83	89	95	101	107
60	42	53	61	69	76	83	90	97	103	110	116
70	46	57	66	74	82	90	97	104	111	118	125
80	49	61	71	79	88	96	104	112	119	127	134
90	53	66	75	85	94	102	111	119	127	135	143
100	57	70	80	90	99	108	117	126	135	144	152

Standing Through Passengers per door = 20

	Boarding Passengers per Door										
Alighting Passengers per Door	0	10	20	30	40	50	60	70	80	90	100
0	10	18	24	29	34	39	43	47	51	55	59
10	19	28	35	40	46	51	56	60	65	70	74
20	26	35	42	48	54	60	65	70	76	81	86
30	31	41	49	55	62	68	74	80	85	91	97
40	36	47	55	62	69	76	82	89	95	101	107
50	41	52	61	69	76	83	91	97	104	111	117
60	46	58	67	75	83	91	98	106	113	120	128
70	51	63	72	81	90	98	106	114	122	130	137
80	55	68	78	87	96	105	114	122	131	139	147
90	59	73	83	93	103	112	121	130	139	148	157
100	64	77	89	99	109	119	129	138	148	157	166

An alternative to using Excel and Access is to build a model using a software package like Arena. Arena is a discrete event simulation tool used in manufacturing, logistics and transportation. The software's core strength is in modelling resource allocation, queuing, delay and storage so it lends itself to simulating station platforms.[20]

[20] Further information can be found at http://www.arenasimulation.com

9. Train Simulation Models

9.1 Simulation Packages

Train simulation models are established ways of testing and evaluating proposed rail timetables. The focus is on railway operations rather than rail patronage.

There are several rail software packages available including OpenTrack, RAILSYS, RailSIM, Simu++ and TRAKATTK. There are also transport simulation packages such as Paramics, AimSun that have been used to model bus and Light Rail that could be applied to model rail operations in particular station interchange facilities. Finally there are general simulation packages such as Arena that could be applied to modeling train operations.

Rail simulation software packages provide the editing facilities to enter track, signaling, stations, train performance data and timetables. The model then simulates the ability of train services to run to the selected timetable. Various simulations can be run allowing for variability in performance, day to day perturbations and specific incidents (usually entered by the modeler).

The aim is to provide an understanding of the operation and performance of a rail corridor or system visually and by reporting statistics on on-time running, track usage, train conflicts and train delay details.

9.2 PB-CHA CBD Simulation & Dwell Time

PB-CHA was engaged by TfNSW to look at the possibility of increasing the number of trains per hour on the North Shore Line between Redfern and Chatswood. PB-CHA used OpenTrack simulation to model timetables with improved signaling (ETCS 2) and single deck rolling stock.

A key variable were the station dwell times. PB-CHA developed a set of average, minimum and maximum times for double and single deck trains as set out in Table 9.2.

Table 9.2: PB-CHA Dwell Times (seconds)

	Double Deck		Single Deck	
Station	Average	Range	Average	Range
Redfern	50	40-60	40	30-50
Central	60	40-80	50	30-70
Town Hall	70	50-90	60	40-80
Wynyard	60	40-80	50	30-70
Milsons Pt	35	25-45	30	30-40
North Sydney	60	40-80	50	50-70
Waverton	25	25-45	30	20-40
Wollstonecraft	35	25-45	30	30-40
St Leonards	40	30-50	30	20-40
Artarmon	35	25-45	30	20-40
Chatswood	50	30-70	40	30-50

The times were based on surveys undertaken on three days during the AM peak at Town Hall, Central and Wynyard and consultant estimates regarding the likely impact of single deck trains with three doors per carriage. The average dwell at Town Hall was 68 seconds with a standard deviation of 14.5 seconds.

Adopting the TRB approach (2nd) of the 'mean plus two standard deviations' would give a planning dwell time of 97 seconds for Town Hall. This is higher than the upper range of 90 seconds used by PB-CHA in the simulation.

The dwell times for other stations were lower reflecting the survey results at Central and Wynyard and lower alighting and boarding at the small stations.

For single deck trains, PB-CHA reasoned that dwell times would be ten seconds less than for double deck times.

PB-CHA considered that *"refinement of the dwell times would require further observations, including single-deck trains, and pedestrian modeling. In particular for Town Hall Station, due its unique restricted platforms and interchange characteristics, pedestrian modelling is recommended to better understand the constraints and benefits of single-deck operation. However, given the very constrained situation at Town Hall Station and the absence of data, pedestrian modelling may not be capable of modeling passenger behaviour under these very congested conditions".*

PB-CHA did not increase dwell times for future patronage growth. On the other hand, dwell times were not reduced as a result of more services lowering average train loads. Finally, the PB-CHA approach forecast dwell times independently. Long dwell times at one station did not have a 'snow ball' effect on the next station.

9.3 RMCon Approach – Using German Platform & Station Capacity Standards

As part of the study, TfNSW contacted RMCon Australia Pty regarding the incorporation of dwell times and station crowding into RailSys, a train operating simulation package.

RMCon suggested using German Rail regulation Ril813 for the calculation of platform and station capacity. Like the TRB framework described in section 5.2, the use of the German regulation Ril813 would enable the times for emptying a platform, or dwell times to be calculated. The calculations determine the amount of passengers on the platforms at any one time. In this way it would be possible to determine at what time it would be required to limit additional passengers accessing a platform.

Platforms would be divided different functional areas, including waiting, walking towards an exit, cueing in front of an escalator, etc so as to a) model passenger behaviour b) look into ways to manage peoples' behaviour, or c) work out different alternatives, such as modifying the platform layout. The latter would also be good for scenario assessment.

RMCon would determine the train dwell times, platform clearance times, available platform capacity, and other parameters. RMCon would require forecasts from TfNSW on the number of passengers expected to that arrive at a platform from outside (as well as which train they'd catch and where they'd want to get off a train), and the number of passengers that are on a train and want to get off.

RMCon considers that the method would be quite accurate, although passenger movement simulation could be more accurate by about 1% to 2% but would take significantly more effort time and money.

Interactions with train movement would be assessed manually since there is no automatic link between passenger activity with the RailSys train operation simulation package that is used by RMCon. However, the number of trains and the number of stations to be evaluated would be limited, therefore a semi-manual process would not really slow down the analysis.

What we can do with RailSys later on though would be that we use the resulting specific delay values that are derived from the study to identify how this might impact on the rest of the network.

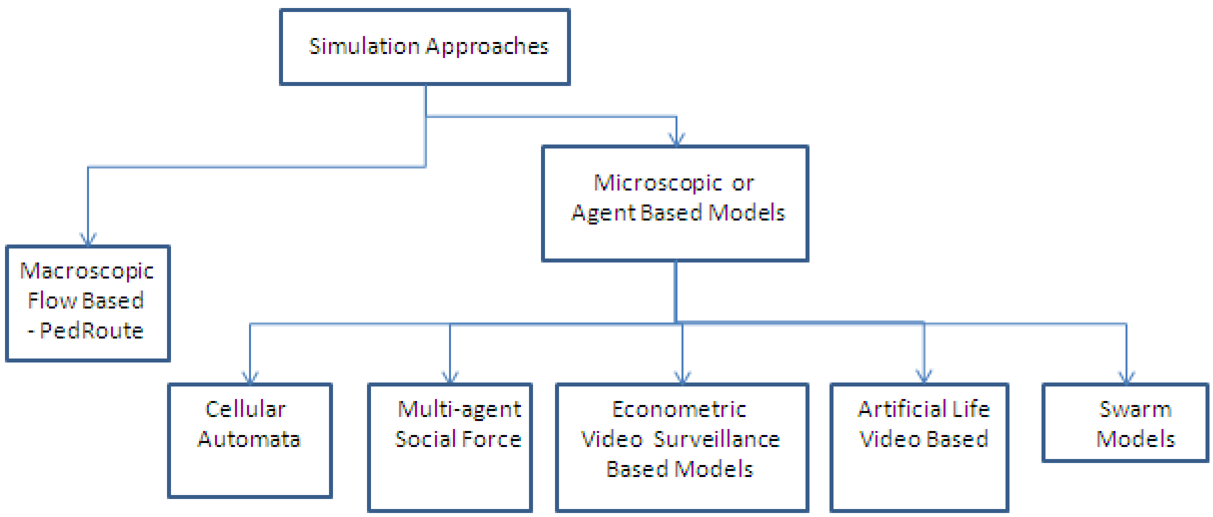
RMCon suggests that other additional regulations for the design and dimensioning of platforms could be used to evaluate the Sydney stations. The regulations are quite detailed (e.g. Hamburger Hochbahn AG, HHA) and are also used for creating action plans for special events, to indicate how passenger movements on a platform should be managed in order to achieve the required capacity while considering specific train service frequencies. The application of the various regulations would indicate possible ways to increase platform and station capacity to a desired level, or it would indicate where the achievable capacity limits are.

10. Station Pedestrian Simulation Models

10.1 Typology of Models

Several alternative simulation approaches have been developed that have applications to modeling pedestrian behavior in rail stations. Figure 10.1 presents a typology.

10.1: Typology of Station Pedestrian Models



In the 1980s/90s most station crowding models were 'macroscopic' in nature using aggregate speed-density-flow relationships to predict travel times and crowding in different station areas by time period given station entry and exit passenger volumes.

Over the last decade, advances in computing have led to a rapid development in 'microscopic' modeling in which the behavior of individual rail passengers and trains is simulated.

Most models are labeled 'agent based'. The label is a slippery one since however since according to Macall and North *"there is no universal agreement on the precise definition of the term 'agent'"* (Macall, 2009). Indeed agents don't need to be human. A train door can be an agent that makes 'decisions' about when to open and close and how many passengers will alight onto the platform. Agents generally have three properties: (i) they are autonomous and self-directed; (ii) they are modular or self-contained and (iii) they are social, that is, they interact with other agents.

The algorithms behind the simulations usually involve complicated mathematical formulas. For most packages only general descriptions are provided; the algorithms remaining confidential for commercial reasons.

Cellular automata models are based on small scale areal representations. The size of the areas may, for example, be drawn to fit the shoulder - body width of pedestrian. Cells generate 'fields' that represent the local effect of obstacles or of moving pedestrians. The algorithms include rules to resolve situations where more than one pedestrian wants to move onto the same cell. The Legion package originally used mobile cellular automata with simulated annealing which provides an approximate mathematical search routine to find a local rather than global optimum developed by Still (2000).

Probably the most widely used approach is the social force model developed by Helbing and Molnár, (1995). The basic idea is to model the elementary impetus for motion with forces analogously to Newtonian mechanics. The forces influencing a pedestrian's motion are caused by an intention to reach a destination as well as by other pedestrians and obstacles. Other pedestrians can have both an attractive and a repulsive influence. The driving force to the destination is deduced from the position of the agent and the shortest path to the destination. The repulsive forces produced by walls, obstacles and other pedestrians have been modeled in various ways.

There also three, lesser used, simulation approaches. Bierlaire (2003) suggested an econometric approach based on automatic surveillance data to model directions and speed. Recently, software developed in the cinematic industry to emulate human behaviour is now being used to model real life situations.

Swarm based models are based on the idea of applying the swarm intelligence of social insects like bees, ants Teodorovic (2003).

10.2 Pedestrian Simulation Packages

There are now many software alternatives available. The alternatives range from 'build your own' open sourced software to sophisticated packages that can track and store the movements of thousands of 'agents' and can show the operation of the station in either 2D or 3D in real or exponential up time. Some of the leading candidates are listed below:

LEGION uses a social force algorithm developed by the Maia Institute that models each pedestrian as a two-dimensional "entity" with a circular body that moves in 2D continuous space, in short (0.6 sec) time steps (Berrou et al, 2005). Each pedestrian moves towards its current target by selecting a step that minimises a cost function embracing: inconvenience (extra effort to reach a destination); frustration (violating preferred walking speed) and discomfort: (violating preferred clearance from neighbours and obstacles). Pedestrians learn as they progress changing the cost function weightings and can distinguish agents moving in the same direction from those in cross-flow. They can also interact with immediate neighbours to reduce blockages. Agents are sampled from profiles that vary by size (physical radius) and physical space (movement envelope around person, type (commuters, tourists, sport events), region, and preferred speed drawn from observed speeds. The resultant crowd behaviour 'emerges' out of the simulation.

NOMAD was developed by the Delft University of Technology Holland to describe pedestrian behaviour. It is activity based implying that the actions of pedestrians are determined by the different activities pedestrians have planned to perform. The model uses a social force algorithm in which routes are chosen to minimise the 'running cost' of walking which comprises: the cost of drifting from the planned trajectory; the cost of walking near other pedestrians/obstacles; and the cost of acceleration. The model allows for agents to replan their route based on flow behaviour – the adaptive controller framework (Hoogendoorn, 2004).

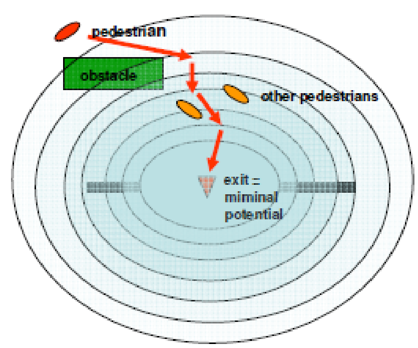
Paramics is offered by Quadstone and SIAS. It is a micro simulation package primarily aimed at modelling road vehicles but has a pedestrian modelling facility to simulate road junctions, bus stops and public transport interchanges.

PEDFLOW is a cellular automata simulation model that uses a set of rules to determine the speed by which pedestrians (modelled as squares) move around the grid. The rules originate from computer-aided analysis of video footage and are transformed into a form that can be efficiently processed by the agent.

PedGo was developed by TraffGo GmbH for testing cruise ship evacuation systems and processes. The program is a microscopic multi-agent simulation based on cellular automata.

PedRoute was developed by London Underground to model crowding and pedestrian flows at underground stations. It is considered a macroscopic rather than microscopic model because it uses aggregated flows, speed/flow/density curves and divides stations into blocks rather than small cells. The model was used to model many rail stations in the UK and abroad in the 1990s/2000s. It is now owned by the Legion Ltd.

Potential Field Model used in SimWalk



SimWalk is a multi-agent simulation package developed by Savannah Simulations a Swiss company. SimWalk uses a wave algorithm in which the walking direction and speed of the pedestrians depends on three forces. The first force leads the agent towards its destination, a second force regulates the interactions between agents ensuring that agents do not walk into other pedestrians and a third force keeps agents a certain distance from walls etc.

SimPed was developed by the Delft University of Technology Holland. It mixes microscopic modelling of pedestrians (they are treated as agents with specific characteristics) with macroscopic modelling of processes (e.g. movement down a set of stairs) using aggregate speed/flow/ density relationships. Discrete choice equations are used to model routes, walking trajectories and activity scheduling. Train boarding and alighting processes are modelled using service queuing models (Nakasuji, 2005).

VISSIM is a microscopic simulation tool developed by Visual Solutions, Boston USA. Pedestrians, trains and vehicles are simulated individually. Speed distributions are allocated by the modeller to pedestrian to define maximum walking speeds. The same company has also developed VISPED which offers 3D pedestrian and vehicle simulation (trains, buses or cars). The package offers simulation of a full passenger journey by bus or rail including network access and egress.

A recent development is a package called AureALIS. This package is an artificial intelligence based agent technology developed from the cinematic industry (emulating armies fighting each other in the Lord of the Rings Trilogy). Agents act independently using “simulated natural senses of sight and hearing”. It has been applied to real world modelling since 2009 and is being used to assess a multi-level Melbourne rail-bus interchange.

General simulation software packages such as Arena are available that provide the building blocks for users to build their own simulation model of passenger/ train interactions.

There are also programming languages and environments to build simulation models. Rindsfuser (op cit) used SeSAm to build a station simulation model of Bern Station. SeSam is a general modelling and simulation environment for agent-based simulations.

10.3 Rolling Stock Simulations

Simulation models are being increasingly used to model the train board and alight process. Video camera data of live and mock-up exercises is increasingly being used to improve accuracy and validate the simulations. Usually the models are restricted to simulating the train/platform interface. By not modelling the concourse and vertical transport, the models usually do not model the choice of train car or where passengers wait on the platform. The aim is to estimate the alight and board time sometimes for a single train carriage.

10.3.1 Beijing Metro Stations

Cellular automata-based micro-simulation has been used to model boarding and alighting at Beijing metro stations (Qi, 2008). The simulation program was developed in STARLOGO a programming language developed by Klopfer at MIT. Boarding passengers are distributed randomly near the edge of the ‘‘platform” on a 120 x 30 lattice of cells. When the train stops, boarding passengers gather around the doors and queue up. Alighting passengers are generated and alight from the doors. Train doors in the experiments stay open until the last passenger boards the train. The study found that larger groups of alighting passengers tended to alight faster than smaller groups but that larger groups of boarding passengers tend to slow alighting passengers and also presented greater opportunity for passengers to board before the end of alighting. The model did not allow for any ‘replanning’ whereby passengers change their choice of carriage.

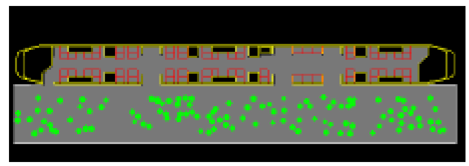
10.3.2 Thameslink Rolling Stock Simulation

Arup has used Legion to develop a simulation model of train alighting and boarding. The model was developed for Transport for London TfL to help evaluate rolling stock design for the Thameslink Program in which longer trains at up to 24 services per hour will run through the city of London. The model was calibrated to the results of board and alight tests on a mock-up train similar to the RailCorp simulation exercises described in section 7.

10.3.3 Melbourne Tram Simulation

A similar Legion based model was developed by Arup in conjunction with the Victorian Department of Transport to simulate the boarding and alighting process for a generic tram design. The model is being used to assist in the assessment of the boarding and alighting performance of short-listed tram designs.

Using Video Cameras to Develop a Board/Alight Model

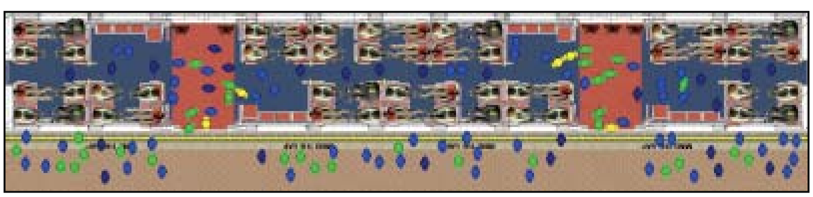


10.3.4 Toronto Rail Simulation

AECOM used the Legion simulation package in 2010 to model boarding and alighting and also the platform distribution of passengers at Bloor-Yonge, the busiest station in Toronto with 400,000 passengers per day. Bloor-Yonge is also a key interchange station with transfers contributing to congestion and slowing boarding and alighting. Future demand increases were forecast to require more trains which would reduce dwell times to 30 seconds. Legion was used to develop train dwell time models to ascertain the likelihood of achieving the target dwell time under various train boarding and alighting scenarios.

10.3.5 Bombardier Rolling Stock Simulation

Crowd Dynamics Limited was engaged in 2008 by Bombardier to analyse the dwell times of four train designs. An agent based simulation model was compared against linear and non-linear dwell time algorithms similar to the statistical models described in section 6. The agent based simulation allowed the boarding process for the new designs to be explored in the absence of observed board/alight data.



10.4 Platform Crowding & Train Dwell Time

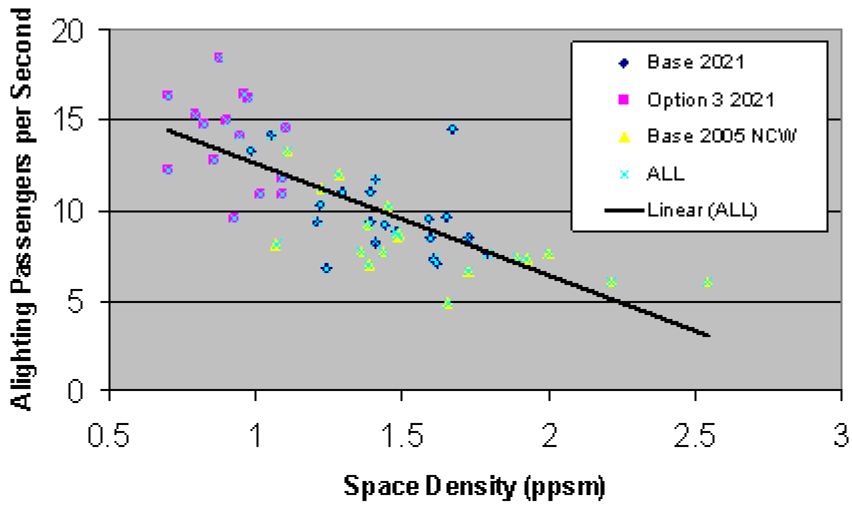
Arup used Legion simulation to quantify the extent to which train alight rates (the inverse of alight speeds) were reduced by waiting passenger crowding at Town Hall station during the PM peak.[21] Arup used the results of three different year/option simulations to graph a relationship between alight rate

[21] Train boarding times were considered to be unaffected by platform crowding with the boarding rate averaging 0.76 passengers per second.

and platform density (measured when the train doors opened) which is shown in Figure 9.4. [22] The alight rate declined as platform passenger density increased. Arup predicted a decline in alight rate of 0.4 passengers per second per door from increasing platform crowding density by 1PSM and with the linear relationship shown, the rate declined to zero at 3PSM.[23]

Figure 10.4: PM Platform Density & Passenger Alight Rate

Town Hall Station Simulation



Source: Arup (2007) "Town Hall Station Redevelopment Project – Desktop Economic Study"

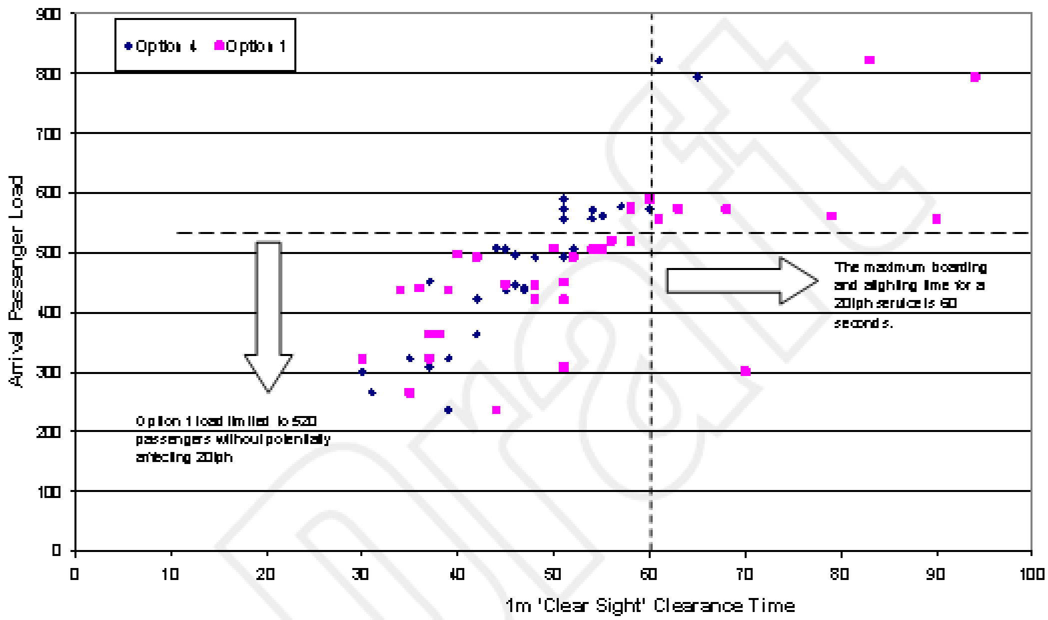
10.5 Town Hall Platform Clearance Time Simulation

Arup used the Legion package to assess platform congestion at Town Hall. The AM analysis looked at the impact of platform crowding on the time for the platform attendant to give the signal for the train to depart (1 metre wide clear sight along the platform). At Town Hall in the AM peak, most passengers are alighting trains. The width of the platforms, passengers waiting to board, limited stair/escalator capacity all combine to produce backlogs of passengers that restrict the platform guard's line of sight. Arup investigated the time taken for passengers to clear a distance of one metre away from the platform edge and used this time as an indicator of when the platform guard could provide an "all-clear' message for the train operator to depart.

[22] The three options were a current (2005) demand and timetable, a 2021 'Clearways' timetable and a 2021 'Clearways' timetable with an upgrade of Town Hall station including increased stair and escalator capacity.

[23] A non linear relationship allowing for the train alight rate to decrease but at a declining rate as platform density increases would allow for a slow alight rate above 3PSM.

Figure 10.5: Platform Clearance Time



10.6 Comparing Pedestrian Simulation Models

The following criteria are suggested to compare different software:

- Ability to represent station, passenger profiles and behaviour accurately
- Size limitations, computational time & memory consumption
- Quality of visual presentation such as 2D, 3D
- Presentation and output of results to enable further analysis
- User friendliness such as the ease of building and changing the layout and running simulations

10.6.1 Accuracy of Representation

The ability to represent the station, passenger profiles, circulation speeds and crowding behaviour accurately should be the most important criterion for assessing models.

Unfortunately, there are few published studies that have compared the accuracy of alternative simulation models. Nash trialed three simulation packages to model Zurich railway station SimWalk, PedGo, and SimPed (Nash, 2006). He concluded that *"The pedestrian simulation programs were helpful in evaluating the motion of pedestrians on facilities such as stairways and platforms, but were not useful in modeling the boarding/alighting process itself since the models are not yet able to account for the* *great variety of pedestrian behavior at the doorways (e.g. whether or not people wait until everyone exits the train before starting boarding)".* This was in 2006 however.

The 'rules' by which the board and alight process are governed also determine the appropriateness of the simulation. The model of Berne station by Rindsfuser (op cit) fixed the arrival and departure times of the train to the timetable. The 'agent' governing the train doors did not wait for all passengers to board before closing the doors and departing. Simulated passengers who did not board were deleted from the model. The number deleted was used as a performance criterion. Clearly, this model would not provide an assessment of train dwell times.

Pedestrian simulation of train dwell times at London Bridge Station undertaken as part of Thameslink project were problematic because of the 'rules' governing passengers' choice of carriage. The simulations did not produce very realistic results because the last few boarders apparently insisted on walking almost the length of the platform before entering the train. It is worth noting that the simulations were conducted in the early 2000s and since then, simulation techniques are likely to have improved. However, passenger flows during train alighting and boarding are significantly more complicated than those within the rest of a typical large station, with passengers having more decisions to make during boarding than on a simple movement from point A to point B. 24

Likewise Professor Luis Ferriera of the University of Queensland, who used VISSIM to model North Melbourne station considered that the passenger and speed profiles input' into the simulation largely determine the result. Often these parameters are not varied from the recommended 'default' values. Ideally, model parameters should be estimated locally and the simulation results validated on observed data. [25]

Paul Stanley of Arup provided the following comment: *"We can model station performance in Legion. But often the timetable used is provided by the operator and is fixed. Boarding and alighting is assumed to always occur within the limits set by the timetable, and perturbed scenarios are almost always major delays resulting in a missed headway. How often does the service actually delivered on a daily basis match the timetable (remember 'on time' is within 5 mins, and is generally recorded only at the terminus)?"*

10.6.2 Computational Requirements

In terms of size, most station pedestrian models have been applied to single rail stations. Legion has been used to model each of the three major Sydney CBD stations: Central, Town Hall and Wynyard. Each of the three main CBD stations (Central, Town Hall and Wynyard) handles barrier entries and exits

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[24] Email correspondence between Neil Douglas and John Rosser (now of the IEE) and Dr Peter Howarth (now of Interfleet) who were transport engineers on the London Thameslink project.

[25] Views provided by telephone by Professor Louis Ferriera to Neil Douglas.

of over 40,000 in the AM peak 3.5 hours plus transfer trips ranging from 1,500 at Wynyard, 9,000 at Town Hall and 16,000 at Central (Douglas Economics, 2003).[26]

Legion can currently simulate and store details on up to 100,000 agents thus would be capable of modelling and storing the passenger details for a single station for the full 3.5 hour peak.

When combined however the three stations would have barrier throughputs of over 120,000 which exceeds the modelling capacity of Legion. There would also be around 30,000 transfer passengers to model and 20,000 passengers travelling through the CBD (Douglas, 2003).

Limiting the simulation to the one hour peak would halve the task to simulating around 75,000 barrier and transfer passengers (excluding passengers who travel through the CBD) and 10,000 'through' passengers. These totals are within the 100,000 limit but do not much room for future patronage growth or for the inclusion of buffer periods to pre and post load the simulation model.

10.6.3 Quality of Visual Presentation

A key advantage of dynamic simulation modelling compared to static modelling is the ability to present train and station operations in 'real time' on a computer screen. Visual representation can vary from simple 'overhead' representations station areas using dots for passengers to 3D imaging of passengers and vehicles. In a micro-simulation of bus options using SParamics, Kaenzig considered that *"the most useful aspect of the micro-simulation exercise was simply to take time watching the progress of the various bus services down the corridor in 'real' time, seeing behaviour of the buses at the stops, the interaction of the various trunk and feeder services, and watching the build up of buses at the major junctions along the route. This simple analysis allowed greater insight into what problems might be thrown up in live operation, and aid the imagination in questioning 'What if . . .' scenarios"*

Some simulation packages particularly emphasise the visual realism aspect using techniques employed in the cinematic industry.

The AureALIS simulation package has its roots in the cinematic industry. The techniques were originally deployed on the Lord of the Rings Trilogy to emulate armies fighting each other.

[26] The proposed CBD relief line will affect future station use.

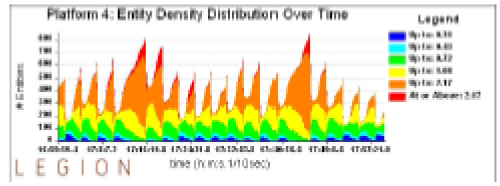
10.6.4 Presentation & Output of Results

Station simulation packages track thousands of individual passenger movements. Simulation packages can be compared in terms of how well they can store, retrieve and analyse data statistically and graphically within the package and how easy it is to output data to enable further analysis in spreadsheets etc.

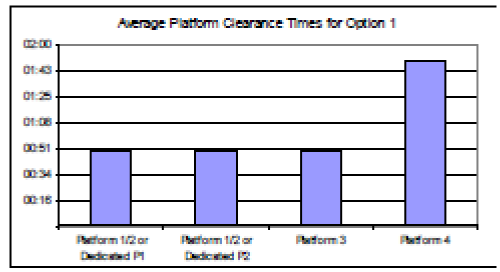
10.6.5 Ease of Use

The model should enable station layouts, train timetables, demand data and simulation parameters to be input and changed easily.

Platform 4 Entity Density



Vertical Transport



Shown above is an entity density graph produced by the Legion simulation package and subsequent Excel analysis of output by Arup. The graphs were taken from the Town Hall station evaluation by Arup which was undertaken in 2007.

11. Train & Station Simulation

11.1 Unlinked Simulations

The review was unable to find a study that has simulated train and multi-station performance simultaneously. Current 'best practice' seems to be to feed the results of station dwell time simulations into train simulation models or vice versa in a recursive fashion.

There are several established rail simulation packages that model train operations. Rolling stock design is modeled in terms of train operating performance. Passenger volume is not of direct consequence. Station dwell times are usually modeled in rudimentary way as an average time with an associated plus or minus range. Longer averages and wider ranges may be set for busier stations at busier times. Dwell times may be further differentiated by rolling stock and service type. None of the times are internally determined by the model however.

Station pedestrian crowding models largely determine train board and alight times by input assumption either by specifying the arrival and departure time or by determining the board and alight speeds. Clearly, the first approach is of no use in determining dwell times. The second approach rests on the board and alight speeds or by the passenger profiles, desired walk speeds and internal algorithm of the simulation. The parameters can be assumed, estimated or validated on observation studies.

Most station crowding models focus on the layout of the platform rather than the internal layout of the train. Train and is usually determined by assumption. The variability of arrival and departure passenger loads by train service will also be determined by the modeling inputs and assumption rather than solved endogenously by the model.

Rolling stock board and alight simulations have modeled individual carriages or train and usually do not address platform crowding. Usually they time the alighting and boarding process for an individual train service for a particular passenger load. The interaction with other train services or stations is not modelled.

11.2 System Simulation

Some simulations have been undertaken of Bus Rapid Transit lines that have involved simulation or bus operations and pedestrian activity at multiple bus stops using VISSIM. It is noted that Aurecon, who use a software package called Aurelis are simulating a rail station – bus interchange in Melbourne. Aurecon considers that modelling more than one station would be an extension of the Melbourne application. However the software remains unproven for what would be a considerably larger task.

Rapid development is continuing in vehicle/pedestrian simulation including 3D visualization that could enable a single model to be developed of the Redfern-Chatswood corridor. Currently, such modeling is in its infancy and no comparable study to that required has been undertaken. It is also considered that calibration and validation of linked pedestrian and train operations will be highly problematic.

11.3 Linked Simulation

The approach suggested by most consultants contacted was to feed the results of a station simulation (or from a static model) into a train operation simulation model or vice versa. This could be either done once or per modeled time slice. The trade-off being greater modeling 'accuracy' but at a cost of repeated data transfer especially so given the need to run the model many times for a through scenario test.

Discussions with Arup have suggested that it should be possible to develop a complete linked simulation package of the rail corridor covering Central, Town Hall and Wynyard. Arup suggested using Legion together with Railsys.

In this regard, Arup have undertaken separate crowding modelling studies using Legion of all three stations. Arup considered the plus points of such an approach would be a high level of detail with good quality of output metrics available and the ability to calibrate the models to real-life parameters.

However the negatives to be the difficulties to integrate the two models together; a high cost of set-up and maintenance of models both in time, training and licensing costs and a reliance on consultants to deliver modelling".

11.4 Dwell Time

In terms of modeling station dwell times, there seems to be no substitute for observation based statistical methods either as a way of deriving parameters for a static or dynamic model or as a way of validating predictive accuracy. In the case of Sydney, which is relatively rare in having double deck rolling stock, the need for locally appropriate parameters is even more paramount.

Statistical based dwell time models have been estimated for particular rolling stock. However, a model estimated on double deck data is unlikely to be accurate for single deck trains and vice versa. Ideally, statistical models should therefore be estimated for the range of rolling stock and platform conditions required for forecasting purposes. The review also established that simulated board/alight experiments using volunteers tend to be slower than actual station observations. Therefore wherever possible, models based on or calibrated to actual station observations should be used. These findings suggest that dwell time surveys of Melbourne and/or Brisbane single deck trains would complement Sydney surveys of double deck trains especially so if the same survey method was used.

In this regard, a multi station dwell time survey covering train and platform crowding would be useful in providing estimation and validation data. As an initial modelling step, the results could be integrated within a simplified dynamic train-station simulation model built in Excel, Arena or other simulation software building package.

11.5 Concluding Remarks

No example of a linked train and station simulation model could be found on the scale required to model Sydney CBD. However, the continued rapid pace of development in simulation modeling suggests that such applications will become available in the near future.

Before embarking on developing an integrated simulation of train and station performance for Sydney CBD, the adequacy of the patronage forecasts, representation of rolling stock and stations and the algorithms underlying passenger behaviour and train/station operation should be assessed in terms of their likely predictive accuracy.

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APPENDIX: TRNFLW Parameters in Wardrop Nomagram

$$T = \frac{3600}{(t + d)} \quad (1)$$

Relates train flow to signal clearance times and station dwell times

$$d = \frac{KP}{C} \quad (2)$$

Relates dwell times to a train's access and egress channels and appropriate loading and unloading times

$$K = \frac{TP}{F} \quad (3)$$

Determines platform turnover volumes from train flows and station ons and offs

$$U = TSL \quad (4)$$

Determines on-board passenger flows from train flows, seating capacity and load factor

$$D = \max\{0, S\frac{(L-100)}{100}\} \quad (5)$$

Relates seating and standee levels and load factors

Where: **T** is the hourly train flow (trains per hour)

t is the intrinsic clearance time (sec) of the signalling system

d is the station dwell time (sec) for a particular train

k is the loading/unloading time (sec) per access/egress channel

P is the theoretical train turnover (ie the number of passengers boarding and alighting a train at a station in passengers per train)

c is the integer number of 750 mm wide access/egress channels per train

f is the practical platform turnover correction factor

K is the theoretical hourly platform turnover (ie the total number of passengers boarding and alighting at a station platform in passengers per hour)

U is the hourly passenger flow (in passengers per hour)

S is the number of seats in a train

L is the train load factor, expressed as the percentage of seats occupied at the maximum load point along a line

D is the number of standees in a train