The City Logistics paradigm for urban freight transport

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ABSTRACT

Freight transport in urban areas is of increasing interest and concern. Significant changes in patterns and intensity of freight movements are occurring as a result of technological and societal change and the growth in e-business, the environmental consequences of road based transport systems, and urban land use and transport systems management policies. One significant problem is the Browne-Allen dilemma of conflicting objectives relating to urban freight operators and their customers on one side, and the community on the other. The City Logistics paradigm is one approach to resolving this problem. City logistics is the study of the dynamic management and operations of urban freight transport and distribution systems. The aim is to deliver a win-win for business and the community by ensuring optimum productivity, reliability and customer service whilst reducing environmental impacts, air pollution emissions, energy consumption and traffic congestion. Current research is being directed at building a city logistics systems simulation model that optimises logistics efficiency under congested urban traffic conditions, and that reflects the unique commercial, traffic and urban form characteristics of Australian cities. A case study for Sydney involving the evaluation of likely impacts of transport policies aimed at mitigating the environmental impacts of urban freight transport is presented.

INTRODUCTION

Urban freight transport and goods distribution is a significant issue in the economic, commercial, social and environmental operation of our cities. The Bureau of Transport and Regional Economics (BTRE) suggests that this area of transport activity is growing at a much faster rate than other areas of land transport activity such as private vehicle travel or long distance freight transport (BTE, 2001). This trend is set to continue if not accelerate in the face of new changes in society. More and more trucks will be on urban roads as society embraces just-in-time manufacturing, e-commerce (business to business, B2B), quick response systems for retailers, and e-commerce (business to customer, B2C). Although passenger traffic activity is expected to plateau in the near future at least in per capita terms (Gargett and Cosgrove, 2004), there is no sign yet of that happening for urban freight activity. As a result, the environmental impacts of urban freight traffic, especially in terms greenhouse gas (GHG) and other air pollution, are of increasing concern to the community. Further, whilst there may be viable alternatives to road vehicle transport for personal travel in urban areas and for long distance freight, there are no such alternatives for urban freight in general.

The extent of urban freight activity
The varied nature of urban freight must be recognised. Urban freight activities include tasks such as the transport of building materials, waste collection, retail deliveries and courier services. All of these tasks are common to urban areas, but have quite different characteristics are conducted using different types of vehicles, may occur at different times of day and involve quite different patterns in terms of frequency and spatial coverage. They therefore need to be considered separately. One initial requirement is thus to produce a systematic segmentation based on freight function and characteristics. The following market sectors can be seen as an appropriate basis for studying urban

freight movements, on the basis that these sectors capture a wide range of the differences in trip making and vehicle types:

- courier
- general carrier
- specialist commodities
- oversized or hazardous loads
- external haulage

The key characteristics of these market sectors may be summarised as in Table 1, which is adapted from D'Este (2000). This table highlights the main sectors covered by freight distribution activities in urban areas. The courier and general carrier sectors in Table 1 are those covering most urban freight distribution tasks. Of particular note in the categorisation of Table 1 is the explicit recognition of the light commercial vehicle (LCV) as an important component in its own right. This is especially although not exclusively true for urban freight distribution. Previous freight studies have tended to deliberately ignore LCVs, often because the models employed in these studies have been traffic network models and LCVs behave in kinematically similar fashion to cars in the traffic stream, and they are in any event largely indistinguishable from cars (e.g. Mendigorin, Peachman and White, (2003)) – except, perhaps, in their emissions performance (e.g. Taylor, Smith D'Este and Zito, (2004)). The LCV sector is growing and changing rapidly in response to changing logistics, life styles and consumption patterns. For instance, the increasing level of home deliveries produced by mail order, internet shopping, and e-commerce is a future (if not present) trend that could have significant effects on urban traffic and its impacts (e.g. air pollutant emissions). The problem is that this area is very difficult to understand and to model compared to other freight transport sectors – see Peachman and Mu (2000) for example. In terms of responses to policy initiatives, the freight industry can provide illustrative examples of unanticipated responses. For instance, one plausible but unintended response to new policy measures aimed at reducing emissions by freight vehicles would be for operators to switch from larger vehicles to LCVs, thus.

Table 1: Market sectors in urban freight and their general characteristics (adapted from D'Este (2000))

Market Sector	Truck Type	Commodity	Load Type	Route	Trip Type
Courier	LCV	Mixed	PTL	Variable	Very Complex Linked Trips
General Carrier	Medium (Rigid)	Mixed	PTL or FTL	Variable	Variable – Simple or Linked Trips
Specialist Commodities (e.g. container, bulk liquid)	Large (Articulated/ rigid)	Specific	FTL	Regular	Mostly Simple Trips
Over-Sized/ Hazardous	Large (Articulated)	Specific	FTL	Fixed	Simple Trips
External haulage	Large (Predominantly articulated)	Mixed or Specific	FTL	Regular	Simple Trips – External to/from a Single Point

[PTL = partial truck load, FTL = full truck load.]
[Shaded part indicates market sectors involving most urban distribution freight operations.]

further increasing the numbers and usage of these small vehicles (Kockelman, 2000), which may then result in more vehicle-kilometres of travel (VKT). Whilst this might generate less emissions per freight vehicle VKT, it might also lead to more emissions overall due to increases in total freight vehicle VKT.

On a wider scale general urban traffic congestion is an important factor influencing urban freight transport operations and resulting pollutant emissions, so that general congestion management and traffic control measures need to be considered. This would include any moves to introduce electronic road pricing for congestion management, and traffic management and control policies and programs in as much as traffic control may have significant impacts on the movement of heavy goods vehicles in particular (Taylor, 2001). The anticipated development of congestion in Australia's major urban areas over the 20 years from 1995 to 2015 was investigated by the BTRE (BTE, 2001). This study indicated a general doubling of the costs of congestion over that period. The results of the BTRE study are summarised in Table 2, which shows the changes in congestion costs city-by-city under a 'business as usual' scenario.

Table 2: Costs of congestion in mainland Australian capital cities 1995-2015 (BTE, 2001)

	Annual cost of congestion (1996 $B p.a.)	
	1995	2015
Adelaide	0.8	1.5
Brisbane	2.6	9.3
Canberra	0.05	0.2
Melbourne	2.7	8.0
Perth	0.6	1.9
Sydney	6.0	8.8
Total	13.75	29.7

The 'city logistics' paradigm described later in this paper consciously uses an assumed underlying level of traffic congestion on an urban network as the environment in which to attempt the optimisation of freight distribution activities.

Trends in urban freight activity
As discussed by Smith, Ferreira and Marquez (2001), current trends in business management practice (e.g. 'just-in-time' and other supply chain management practices), technology developments (including Intelligent Transport Systems (ITS) implementations and related activities such as e-commerce) and societal expectations, stand to have major impacts on the ways that urban freight distribution systems function. One outcome may be that these trends will accentuate the demand for flexible road-based delivery services in urban areas. Figure 1, developed in a recent CSIRO study of the likely impacts of e-business (Smith, Ferreira and Marquez, 2001) provides a conceptual representation of the apparent trends and their possible impacts on urban land use, personal travel, and freight transport.

Smith, Ferreira and Marquez (2001) suggested that, in terms of its impacts on urban freight transport, e-business is likely to lead to:
- higher levels of demand for goods and services as a consequence of wider choices and lowered business transaction and administration costs, including increases in travel by LCVs for home and local centre deliveries
- increases in freight transport demand due to wider choices of supplier or service provider, especially for road transport where flexibility, level of customer service and ability to value-add to services will be increasingly important

Figure 1: Main linkages between urban freight transport and e-business (Smith, Ferreira and Marquez (2001))
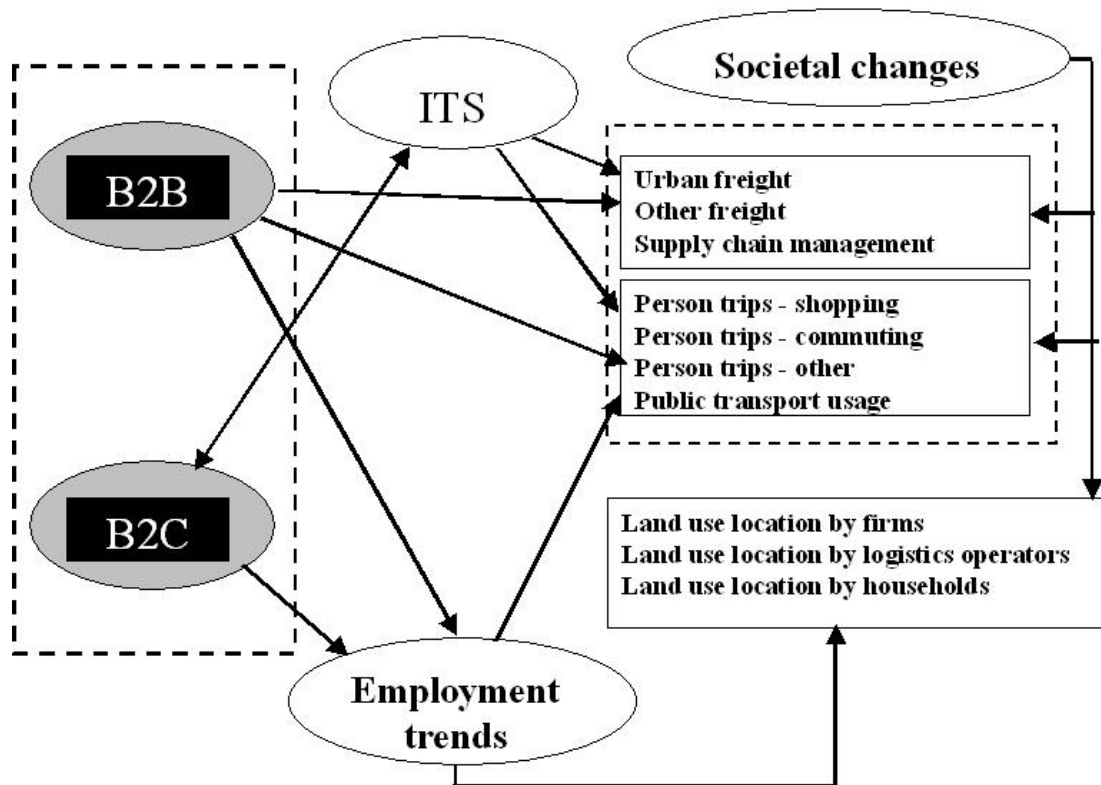
- increased freight productivity through better scheduling and routing software, so that costs will reduce – the impacts on travel will then depend on whether the price reductions for transport services lead to more shipments
- reductions in supply chain delays due to the availability of better quality and more timely data on supply chain performance.

TRANSPORT POLICY AND URBAN FREIGHT

Within the complex system that is urban freight distribution, the following important behavioural choices are available to operators and managers:
- the extent to which shared facilities and cooperative arrangements between operators can work
- choice of vehicle type and vehicle technology, including fuel type
- the utilisation of these vehicles in terms of factors such as VKT, types of commodities carried, and amounts of commodities carried, and
- trip chaining and scheduling of a vehicle during its daily operations.

A reasonable assumption is that mode choice is not applicable, i.e. the substantial majority of urban freight will continue to be moved by road – although the choice of vehicle type is available. Most segments of the urban freight task have no alternative modes available, with alternatives such as rail or water transport limited to (say) some external haulage transport, while other possibilities such as pipelines and underground freight transport systems are likely to be limited in Australian cities to special if not unique applications only. The possible policy instruments that could affect emissions from urban freight transport may be grouped into three broad classes:
1. *policies that operate on measures related to vehicle technology*. These involve requirements that can be set at the level of the individual vehicle, and could include measures such as targets or limits on emission rates per unit distance travelled or per unit time when stationary, specific technology, or fuel use requirements. Note that vehicle technology includes vehicle design, propulsion system, fuel or energy source, and vehicle-based aspects of ITS technology

2. *policies that operate on the transport system.* These could involve changes to the transport system and infrastructure, such as expansion of capacity, utilisation of capacity, intermodal enhancements, congestion management, road pricing and road user charges, access restrictions, traffic control and traffic management, ITS technology and similar factors, and

3. *policies that operate on land use distribution and intensity.* These include zoning-related measures, new industrial development and redevelopment, measures that influence the number, types and locations of households and businesses, and other measures that could affect the flow of commercial vehicles in a region.

Four key stakeholders may be identified for urban freight transport: (1) shippers; (2) freight carriers; (3) residents; (4) planners and regulators. Each group has its own specific objectives and tends to behave in a different manner and has its own needs to be considered. Not all of these objectives or needs relate to transport systems (especially for the shippers and consumers – and, indirectly, for the carriers), and here is the root cause of a certain dilemma for transport planners and policy makers. The interlaced relationships among those groups and different conflicts within the freight transport system are shown in Figure 2. Basically, the generation of freight demand is from the shippers to the consumers. Freight carriers and planners/regulators set the overall framework under which delivery tasks take place, and the carriers then operate within that framework to satisfy consumer demands. The balance ('equilibrium') in Figure 2 is delicate. A slight change in one part may strongly affect the balance. For instance, a freight carrier with poor efficiency can impact on the service quality of the overall system and hence increase the difficulties of management for planner and regulators. In addition, this would reduce the satisfaction level of consumers and also the reliability of firms and increase their operating costs. There is also the potential outcome that the response to a (transport) policy aimed at improving transport systems efficiency or reducing adverse environmental impact may lead to behavioural responses by one or more of the other stakeholders that can lead to other transport (or land use) problems (e.g. see Browne and Allen (1999) and Kockelman (2000)).

Figure 2: Key stakeholders in urban freight transport
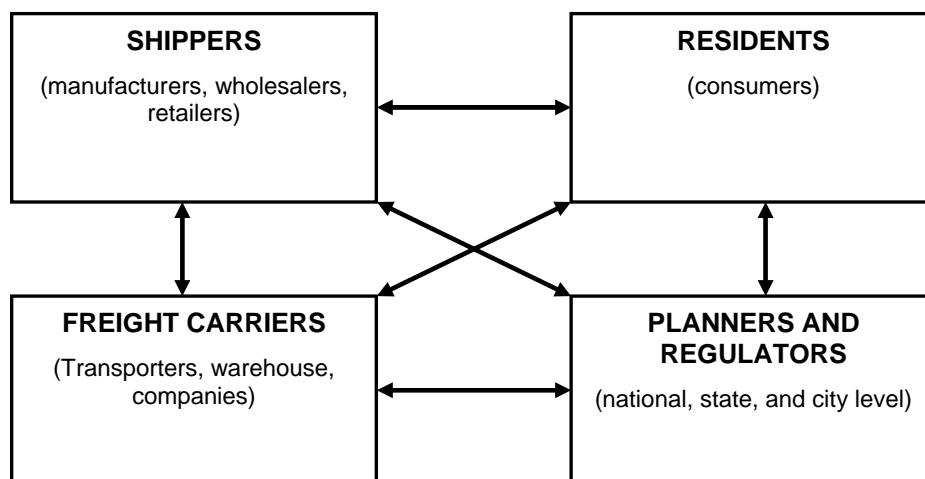
Browne and Allen (1999) reported a study of the environmental impacts of freight transport operations in London. They examined the environmental impacts caused by freight under existing conditions, and then modelled the effects of a range of strategies designed to make freight transport more environmentally sustainable. The starting point for the study was to define two broad types of strategies by which freight transport could contribute to sustainability goals:

- *changes implemented by governing bodies* – the introduction of policies and measures that compel companies to change their actions and thereby become more environmentally or socially efficient. These measures include traffic management schemes, land use zoning, infrastructure developments, licensing and regulation, terminals and transhipment centres, road pricing and taxation. They are unlikely to offer internal gain to the company from its changed behaviour and may in some cases lead to a reduction in economic efficiency, and
- *company-driven changes* – those changes implemented by a company or its customers that achieve internal economic advantages (improved economic efficiency or increased market share) whilst delivering environmental or social benefit. Such changes might include increased vehicle load factors through consolidation of urban freight, deliveries made outside normal hours, the use of routing and scheduling software, improved fuel efficiency of vehicles, and improved collection and delivery systems (the supply chain).

Browne and Allen considered five scenarios aimed at reducing trip numbers, VKT and fossil fuel energy use in road freight in London, on the basis that these were the three key factors implicated in the environmental impacts caused by road freight transport. The scenarios were:
1. the base case of road freight activity in London in 1996
2. improved vehicle load factors due to load consolidation
3. prohibition on the use of heavy goods vehicles in the London area
4. reductions in empty running
5. compulsory use of transhipment centres

As such they include separate scenarios for operational changes imposed by government (scenarios 3 and 5) and instigated by freight companies (scenarios 2 and 4). Scenario 2 assumed an increase average vehicle payload from 50 to 60 per cent. Scenario 3 prohibited the use of heavy goods vehicles (i.e. gross vehicle weights GVW > 17 tonnes) and assumed that the work of these vehicles would be undertaken by medium good vehicles (3.5 < GVW < 17 tonnes). For scenario 4, a reduction in the percentage of empty running trips from 30 per cent to 24 per cent (a 20 per cent decrease in the incidence of empty running) was assumed. For scenario 5 only LCVs and small to medium goods vehicles would be allowed to operate within central London after the introduction of transhipment centres.

The results of this study were interesting and, at the time, quite surprising. They suggested that the community-imposed scenarios (3) and (5) could actually yield increases in fuel usage and CO_2 emissions (of between nine and 20 per cent), whereas the company initiative scenarios (2 and 4) could lead to decreases (of between eight and 17 per cent) in these. The major issue arising from this result was just how public agencies (the planners and regulators) could then devise and implement policy instruments to encourage companies to adopt practices leading to lower fuel and emissions, when the required instruments appeared to deviate so much from the conventional approaches adopted by planners and regulators. This result lead Browne and Allen to conclude that the economic and environmental performance of urban freight transport is strongly influenced by the following dilemma:

> *policies aimed at improving community outcomes from freight transport operations may often run counter to the improved operations of freight companies and their customers.*

Given that some combination of company initiatives and government policies is almost certainly required for the optimal development of urban freight systems, some form of reconciliation of this dilemma is essential. One possible way forward is the 'City Logistics' approach.

THE CITY LOGISTICS PARADIGM

A substantial school of thought concerning urban freight transport has emerged in recent times, known as 'City Logistics'. Its broad goals are to measure the performance of urban freight systems using multi-criteria analysis and to devise methods for optimising the overall performance and

impact of urban freight. The school has its origins in Japan, The Netherlands and Australia, but it now has adherents from around the world. City Logistics involves a combination of traffic simulation and travel demand methods and models, traffic management and control systems, and the application of ITS technologies to freight transport systems to solve problems of economic efficiency, social concerns, and environmental impacts.

Taniguchi, Thompson, Yamada and Van Duin (2001) define City Logistics as:
> '*the process for totally optimising the logistics and transport activities by private companies in urban areas while considering the traffic environment, traffic congestion and energy consumption within the framework of a market economy*'.

The aim is to achieve global optimisation of logistics systems within an urban area, by considering the costs and benefits of schemes to the public and private sectors alike. Private shippers and freight operators aim to reduce their freight costs while the community attempts to alleviate traffic congestion and environmental problems. In the City Logistics schema the Browne- Allen dilemma between policy measures imposed by government or initiated by private companies is, if not removed, then at least blurred. The aim of City Logistics is to minimise the total costs of freight movement within urban areas, while at the same time reducing the environmental, social and broader economic costs.

In its current implementations City Logistic*s* includes a subset of the following initiatives, combined and varied for compatibility with transport planning policies for a particular city:
- load factor controls
- underground freight transport systems
- traffic management plans
- advanced travel information systems
- cooperative freight transport systems (including local 'freight brokers')
- public logistics terminals (transhipment centres), sometimes termed 'freight villages'

A typical City Logistics implementation will involve a combination of some or all of these initiatives, ensuring compatibility with the transport planning policies appropriate in the local area. The urban freight system is complex, involving interactions between physical, economic, traffic and environmental systems in an urban region, and a multiplicity of goals and objectives, as indicated in the definition of City Logistics given above.

Taniguchi *et al* (2001) developed a modelling framework for City Logistics applications. The framework defines three component models and their data and information needs, and is based on the generic traffic systems modelling framework described by Taylor, Bonsall and Young (2000). The three component models are:
1. a *supply model* that uses the network characteristics and an estimate of network usage to estimate the network level of service (e.g. link travel times)
2. a *demand model* that uses the population and industry characteristics of the region (e.g. land use distribution) and the estimate of network level of service to estimate the network usage, and
3. a set of *impact models* that use the outputs of the combined demand-supply modelling subsystem to estimate impacts in terms of financial costs, economic impacts, social impacts, environmental impacts and energy impacts.

The supply model and the demand model operate as a combined model subsystem, iterating until an equilibrium between network usage and level of service is obtained. Impacts are estimated once the equilibrium state is established.

The 'BOX' model proposed by Taniguchi and Van Der Heijden (2000) is an example of this modelling framework. It involves a freight vehicle routing and scheduling submodel that is sensitive to delivery/pickup time requirements (vehicle routing problem with time windows, VRP-TW) connected to a simulation model of travel times on the urban road network. In the BOX model, a

dynamic traffic simulation model estimates the travel times and congestion levels by time of day for the urban road network, taking account of all travel demands in the network as they vary over the hours of the day. The VRP-TW model uses this information to determine routes and schedules for freight vehicles operating in this traffic environment. It does this for a set of freight carriers. Each carrier has its own depot and fleet of vehicles, and a number of customers. The vehicles can collect goods from customers and deliver them to the depot, or deliver goods to customers from the depot. Each customer has a pre-defined time window for pick up or delivery of their goods. The VRP-TW submodel (e.g. Thompson and Tanaguchi (2001), Jung and Haghani (2000) and Chang and Wan (2005)) determines a schedule of pick ups and/or deliveries for each vehicle operated by each carrier, on the basis of customer demands and the prevailing traffic conditions and travel times. The time and routes of the freight vehicles are included in the dynamic traffic simulation model, which updates the travel time on each link every 30 minutes throughout the modelled time period. For computational speed and efficiency a macro-level simulation of link travel times is employed in the 'BOX' model. Iteration between the two submodels is required until a pre-defined convergence criterion is satisfied. The model outputs on vehicle routes and travel times may be used to estimate a range of impacts from the freight movements, including environmental impacts such as emissions.

In our current research we are developing a version of the Taniguchi-Van Heiden model suitable for use in Australian urban areas and able to use Australian traffic information systems. Figure 3 provides an overall conceptual systems view of this model system. A particular feature of this model system, taking advantage of our expertise in microsimulation modelling, is the use of a traffic microsimulation model to inform and extend the traffic information database (TIB) through off-line modelling and analysis of a wide range of traffic circumstances, events and incidents which can include circumstances that may not have been observed or included in the database. This allows the anticipation of the impacts of unusual events and the development of traffic management plans to address a wide range of traffic scenarios. For 'on-line' operations of the model in Figure 3, a macro-level simulation of network travel conditions (especially link travel times, intersection delays and bottleneck locations) is to be employed. Previous research by the author in the area of local area traffic analysis led to the development of the TrafikPlan software package which contains a suitable macro-level simulator (Taylor, 1999a).

This overall model is an extension of the Taniguchi-Van Der Heijden model, incorporating alternative methods for the supply of dynamic traffic information for use in vehicle routing and scheduling. This information will come from one of two sources, either from real world traffic control and information systems (e.g. the SCATS demand responsive traffic control system used in most Australia capital cities (Vogiatzis, 2005), 'e-tag' vehicle monitoring and data collection systems such as that associated with the Melbourne City Link project, or fleets of probe vehicles (Taylor, Woolley and Zito, 2000) – which would include the freight vehicles themselves) or from simulation models. Macro-level simulation models of the type suggested by Taniguchi and Van Der Heijden are most suitable for 'on-line' applications, given the need for fast data processing. Such models have to be developed and implemented for Australian cities, as part of the research. The most effective way to do this will be to build operational macro models based on data taken from traffic information systems or generated by off-line microsimulation models, implemented using modern traffic micro-simulation packages such as Paramics or Aimsun. Taylor's TrafikPlan local area traffic model includes a macro model of network travel conditions that can be adapted and extended to fit the purpose.

The model structure of Figure 3 indicates the analytical components of a City Logistics model and the linkages between those components. Figure 4 indicates how the model may be used for policy analysis and evaluation. It also indicates how different policy instruments may be expected to affect the operation of a City Logistics system.

Figure 3: Schematic structure of a City Logistics model for Australian cities
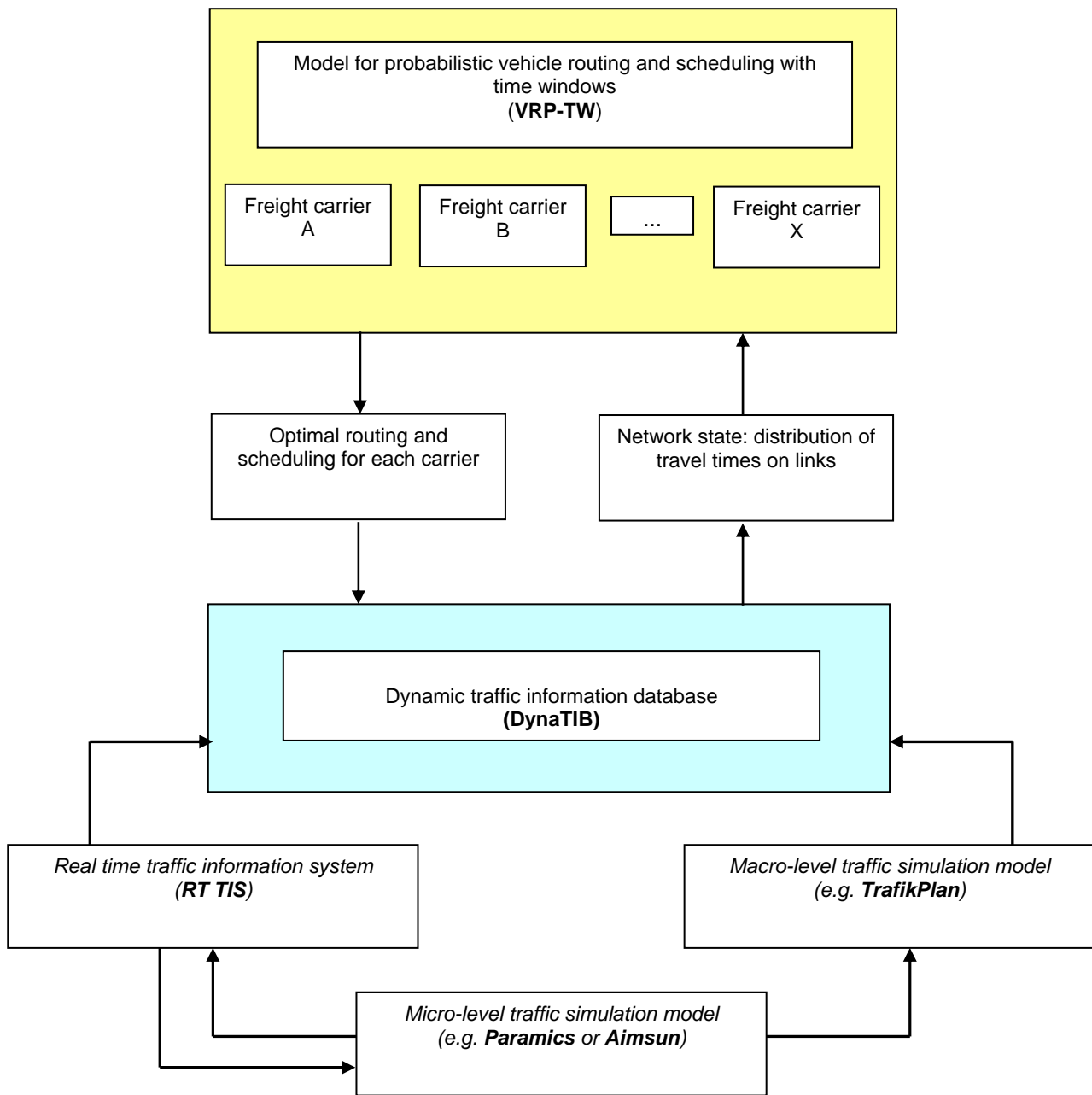
The microsimulation models can use information from the traffic information system and can be configured to provide additional information of similar type and format to that available from them. Microsimulation models can be used to explore a full range of different traffic conditions in a network, including incidents and their traffic and environmental impacts (Taylor, Woolley and Zito, 2001). In our research the microsimulation modelling is being used to extend and amplify the sets of traffic conditions available from the traffic information systems, from which the TrafikPlan model is updated. This new TrafikPlan will thus include a wider range of alternative scenarios (e.g. incidents and bottlenecks at different locations throughout the network) than is possible based on a limited set of observed conditions.

Figure 4: Use of the City Logistics model as a decision support tool in policy analysis
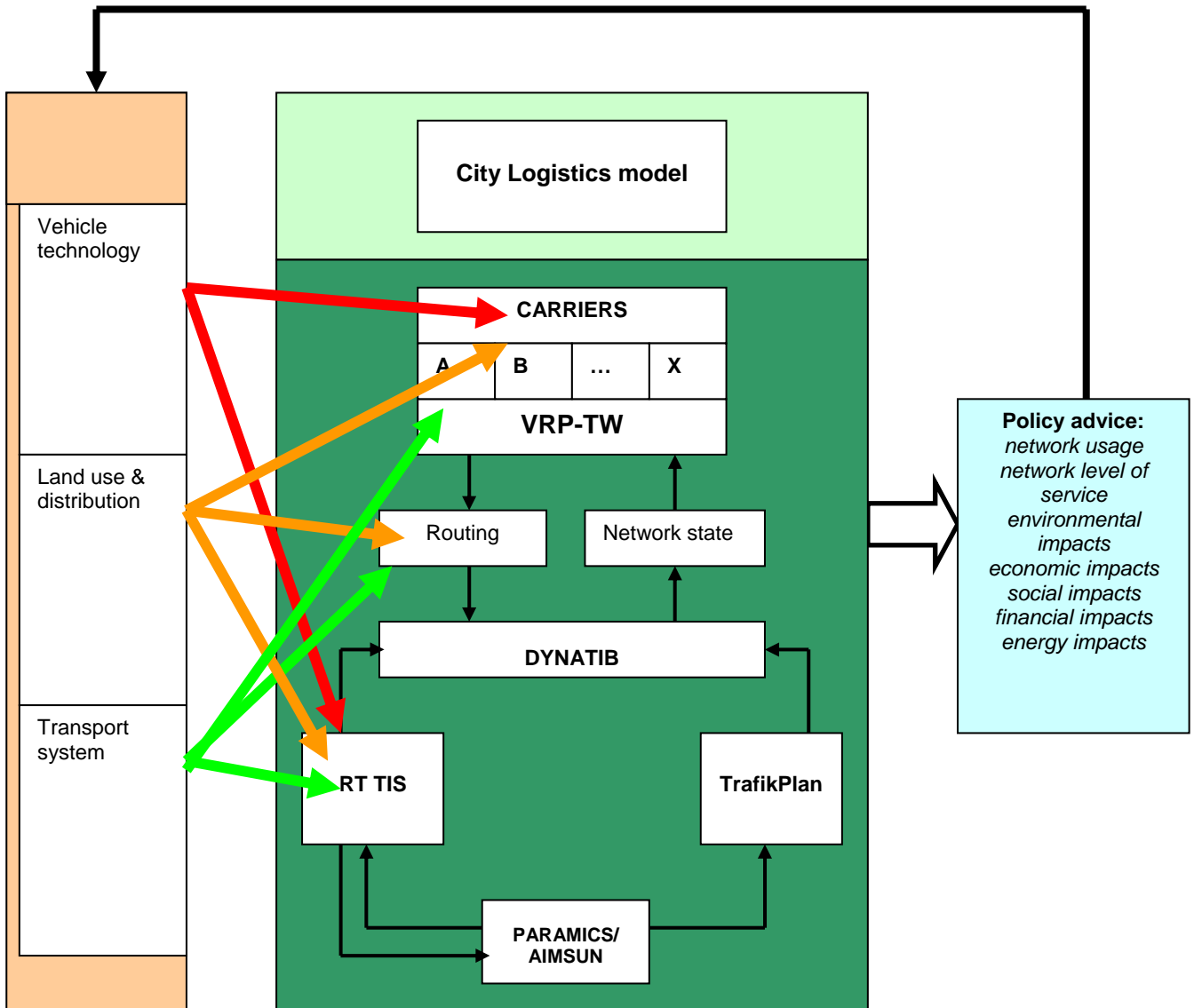
SYDNEY CASE STUDY

Whilst we do not yet have a fully operational City Logistics model for Australian cities, the recent study reported by Taylor, Smith, D'Este and Zito (2004) incorporates a number of the important considerations in City Logistics. This study examined the impacts of alternative policies aimed at reducing the greenhouse gas (GHG) emissions produced by freight transport in urban areas. A combined travel demand, traffic network and pollutant emissions modelling system was established, to test the impacts of the following generic policy initiatives: 'best practice' truck fleet fuel efficiency, general reductions in peak period traffic congestion, improved traffic management, provision of real-time traffic information, infrastructure improvements, changes to industrial land use distribution, and improved vehicle load factors. The Sydney region was use as a case study, because of its national importance and because it is still the only Australian urban area for which there is a reasonable freight transport database – the Sydney Commercial Transport Study (CTS).

GHG emissions due to urban freight depend upon the fuel usage of freight vehicles. This in turn depends upon vehicle technologies and fuel types, plus travel speed and flow and hence prevailing traffic. It also depends on the numbers of trips required, the loading of vehicles and the location of the industry and business dispatching or receiving freight together with the transport infrastructure,

predominantly roads, linking freight origins and destinations. Policy measures expected to produce positive GHG outcomes may thus be conveniently divided into the categories shown in Table 3.

Table 3: Urban freight policies, measures and influences on GHG (Taylor, Smith, D'Este and Zito, 2004)

Category	Influences
Vehicle measures	The type of fuel, efficiency of motors, and influences such as vehicle weight, aerodynamic properties and driving style all influence emissions.
Traffic measures	Emissions vary with speed and differ between free flow and congested conditions, thus are affected by prevailing traffic conditions.
Vehicle movement measures	Emissions depend on numbers of trips, total trip distances, loading of vehicles and size of the vehicle used for the task.
Infrastructure and land use measures	Land use governing the location of industries and business and their distances from suppliers and customers influence trip lengths, hence fuel use and emissions as does new infrastructure to provide better connectivity.

Table 4: The scenarios tested

|	Policy Outcome	Scenario Modelled
0	Base case	Travel in Sydney in 1996
1	Lower congestion	15 per cent reduction in car use in AM and PM peaks
2	Better traffic management	Five per cent extra capacity on arterial roads and speed increased 3 km/h at saturation
3	Logistical changes	Same quantity of goods moved between same places but with higher load factors and some transfer of goods to larger vehicles
4	Real-time traffic information	Major approaches to CBD and Parramatta and major orbital routes modified as per 'better traffic management'
5	Infrastructure improvement	Sydney Orbital route at freeway standard added to 1996 road network for Sydney
6	Infrastructure improvement with land use change and distributional feedbacks	Sydney orbital route added; plus westward shift of employment assumed, thus modified freight trip patterns
7	Improved fuel consumption	Base case traffic with all commercial vehicles operating with fuel and emission efficient engines

A set of seven model scenarios was developed, as shown in Table 4. These scenarios represent anticipated policy outcomes from a broad range of policies. Freight transport performance was then modelled for each scenario to estimate the likely impacts of each policy on fuel consumption, GHG emissions, and air quality emissions. A procedure using advanced traffic assignment techniques was developed to combine outputs of the two processes – trip matrices of light, rigid and articulated commercial vehicles from the CTS, and trip matrices of passenger vehicles from the Sydney Strategic Transport Model (STM), and assign them all to the road network using a multi-class equilibrium assignment model in which the effects on each type of vehicle can be distinguished. Model assumptions were applied to the basic 1996 travel patterns of cars and commercial vehicles and produced detailed link-by-link estimates of traffic volumes, speeds and composition. This required the development of a comprehensive set of fuel and emissions models at the network link level, which were responsive to

- VKT by vehicle type and by fuel type
- variations in the loads carried by freight vehicles
- average travel speeds for vehicles on each link in the network under different traffic conditions and congestion levels
- effects of changes in engine and fuel technology for freight vehicles.

See Taylor, Smith, D'Este and Zito (2004) for further details of these submodels.

Figure 5 compares the contents of the CTS and STM modules that are implemented in different transport modelling packages (CTS in TRIPS, STM in EMME/2). Figure 6 then describes the integration process where multi-class traffic assignment was carried out using the STM. As Figure 6 shows, the policy interventions applied in the scenarios enter the modelling framework either by changes to the CTS tables, changes to the passenger car O-D matrices or changes to the road network.

Figure 5: Comparison of CTS and STM processes
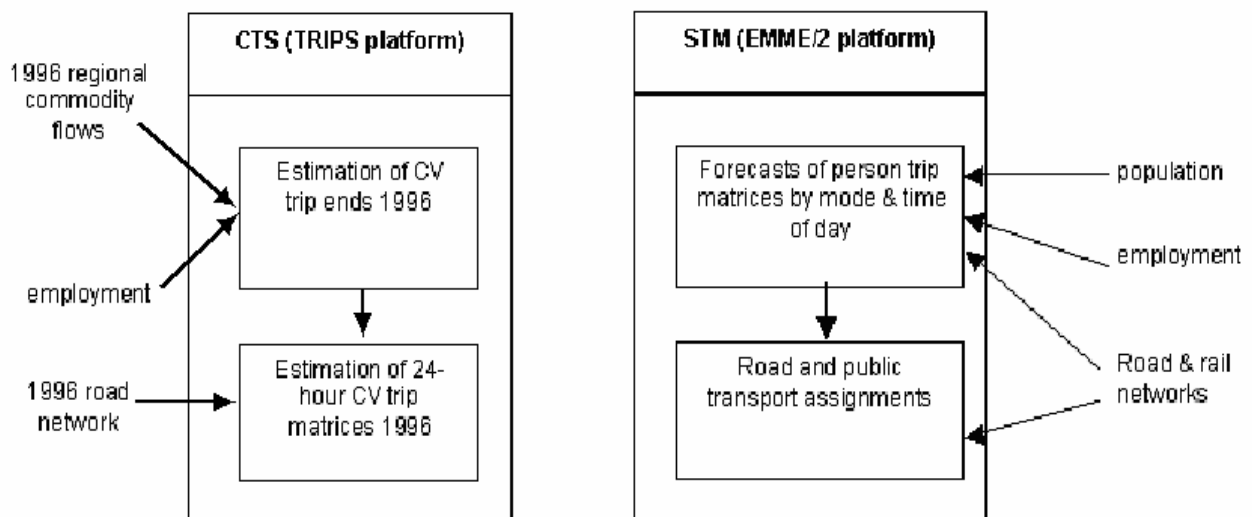
Figure 6: Use of CTS and STM processes in policy scenarios
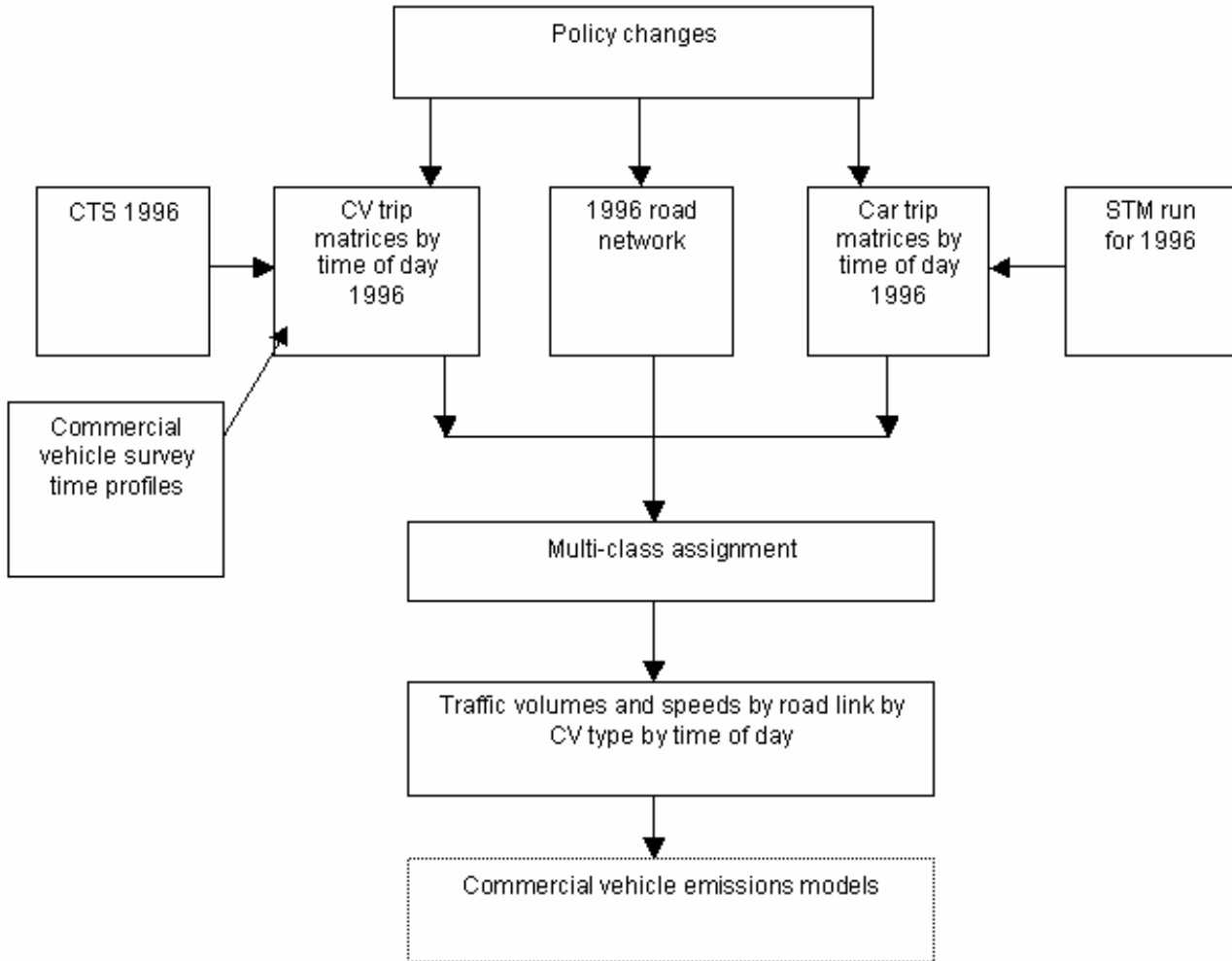
Transport and travel effects of the policy scenarios

The 1996 base case gave the benchmark against which policy variations were compared. As noted previously, the purpose of modelling was to obtain strategic level estimates of policy impacts and compare options rather than produce absolute values for forecasting purposes. The results of the scenario studies may be summarised in qualitative terms as shown in Table 5. The quantitative results are fully described in Taylor, Smith, D'Este and Zito (2004).

Environmental impacts of the policy scenarios

In terms of their suggested environmental impacts, the results of the scenario investigations provided policy implications of two types:

- *implications of scenario results*: The study results provide comparative impacts of policy outcomes and hence comparative impacts of a wide range of policy measures as each outcome represents multiple measures, and
- *viability and value of the process*: The study showed that it was possible to model the impacts of greenhouse abatement measures for urban freight in Australian cities at a fine grained network level by making best use of available data sources; and also showed analysis at that level is worthwhile since location of the measures impacted both locations of outcomes and their total impacts.

This section first reviews the study scenario results, discusses the implications and concludes with a consideration of broader implications of the value of the methodology for policy testing, using the scenarios identified in Table 4.

Table 5: Transport effects of the policy scenarios

Lower congestion
Lowering peak congestion reduced both peak VKT and VHT. The percentage reduction in VHT exceeded that of VKT and average travel speeds increased. This only occurred in peak periods and the 24-hour performance was therefore watered down – the majority of commercial vehicle movement takes place outside the peaks.

Better traffic management
Improvement of the performance of arterial roads improved traffic flow but the overall effect was small, because the better-performing roads tended to attract more traffic, which slowed them down again.

Logistics Measures
A move to higher load factors and load consolidation produced a large net decline in VKT by commercial vehicles and hence is likely to reduce emissions. There was very little change in operating speed, since VHT declined in roughly the same proportion as VKT.

Real-time traffic information
This increased the performance of the principal arterial and orbital routes. It had practically no effect on commercial vehicle VKT but VHT decreased slightly and hence higher operating speeds were achieved (for LCVs and rigid trucks).

Effects of infrastructure improvement
If trip patterns did not change, the addition of the Sydney Orbital to Sydney's road infrastructure in 1996 would have encouraged longer but faster trips by both cars and commercial vehicles, with the result that VKT would go up, VHT would go down and average travel speed would increase.

Effects of infrastructure improvement with land use change
Relocation of some freight-generating employment from inner areas to Western Sydney actually increased commercial vehicle activity because some of the displaced movement would still have the docks and central industrial areas as its destination pattern. Some increase may be a result of modelling assumptions but it is also likely that larger scale land use changes such as new freight terminals are needed when industry is moved.

Scenarios 1, 2, 5 and 6 affected all traffic demands and movements, i.e. private vehicles as well as freight vehicles. Scenario 4 – real-time traffic information systems – was set to affect all traffic in our model but could be directed explicitly at the freight vehicle fleet only. Scenarios 3 and 7 affected freight vehicles only.

In all scenarios except 3 and 6, the freight vehicle travel demand was the same as that in the base case, in terms of vehicle trip O-D patterns in space and over time. In scenario 3 (higher load factors), the number of freight vehicle trips was reduced, although the total freight movements (in terms of tonnages) were the same as in the base case. In scenario 6 (industry relocation with infrastructure improvements) spatial patterns of freight vehicle trips and private vehicle trips were modified as some industries moved west from their present eastern area locations in the metropolitan area, although the total numbers of vehicle trips remained unchanged. In scenario 1 (reduced peak period congestion), the numbers of peak period private vehicle trips were reduced but off peak private vehicle trips and all freight vehicle trips were unaltered. In scenarios 2 (better traffic management) and 4 (real time traffic information) all travel demand remained the same as in the base case.

Consideration of the model results for the different scenarios allows the exploration of the likely impacts of the alternative policies on greenhouse gas emissions, and on the emissions of air pollutants. A starting point for this exploration is to consider the modelled contributions of freight vehicles in the base case 1996 Sydney network, divided into the three vehicle classes of light commercial vehicles, rigid trucks and articulated trucks, to travel demand and to overall greenhouse gas emissions. To visualise the overall impacts of freight transport in the study area network, it is also necessary to compare the freight transport task and the emissions from that task with the task and emissions from private vehicles (PV). A summary of this visualisation is given in Table 6, which includes the estimation of 'passenger car equivalents' (PCU) for each vehicle class, in terms of the contributions of each vehicle class to total GHG emissions.

Table 6: Percentage contributions to total travel and total greenhouse gas emissions by different vehicle classes

Vehicle type	Trips	Veh-km of travel	Veh-hours of travel	Total GHG emissions (CO2e)	*PCU equivalent of GHG emissions*
Private vehicles	92.1%	90.5%	90.7%	82.9%	*1.00*
Light commercial vehicles	5.8%	6.1%	6.3%	6.6%	*1.18*
Rigid trucks	1.8%	2.7%	2.4%	7.3%	*2.95*
Articulated trucks	0.3%	0.7%	0.6%	3.2%	*4.99*
Totals	100.0%	100.0%	100.0%	100.0%	

Given that the PCU value for a private vehicle is 1.00, the PCU equivalent for LCVs may be taken as about 1.2, whilst that for rigid trucks 3.0 and for articulated trucks, about 5.0. Thus, for instance, six LCVs may be considered as producing GHG emissions equivalent to five passenger cars, on average, whilst one articulated truck produces GHG emissions equivalent to those of five passenger cars. These GHG-PCU values may be compared to the commonly assumed traffic-PCU values, predominantly based on vehicle lengths, of 1.0 for LCVs, 2.0 for rigid trucks, and 3.0 for articulated trucks, used in the assessment of traffic operating conditions and traffic capacity of roads.

Interpreting the study results

In terms of the policy scenarios, the study results may be summarised as follows:

- all of the policy measures, except for that of infrastructure improvements coupled with land use change through industry relocation, provided some positive impact on GHG emissions. In the case of the land use change scenario (scenario 6) there were specific reasons why a negative impact GHG emissions from freight transport occurred (see below), which could be overcome by complementary policies including other infrastructure improvements
- the policy initiative that has the largest positive effect on GHG emissions from freight transport was that of higher load factors for freight vehicles. This measure produced a reduction of about 17 per cent in total GHG emissions when compared to the base case
- the application of best fuel technology was the second best policy measure, and indeed this initiative produced the largest reductions in certain specific emissions (methane (CH_4) and nitrous oxide (N_2O)) from urban freight vehicles
- for all of the other policy measures producing reductions in GHG emissions from urban freight transport, the percentage reductions in total GHG emissions from freight transport were relatively small, of the order of three per cent or less. However in absolute terms of total quantities of GHG emissions the policy options were still important

- the policy option of infrastructure improvement coupled with industry relocation, for the case of the Sydney Orbital (scenario 6), led to an increase in overall GHG emissions from freight transport of about 6.5 per cent. This increase was almost entirely due to a singular effect, the doubling of the work tasks of articulated vehicles (as measured in terms of VKT performed), which led to an increase of about 30 per cent in GHG emissions from this vehicle class. The reason for this increase in vehicle work is the major role played by articulated vehicles in transporting commodities and goods between the port and the industrial complexes. The location of the port obviously remains fixed, whilst the industrial sites have shifted a considerable distance to the west. Modelling for this scenario reasonably assumed that the port-factory movements would continue to be made by road using the largest freight vehicles (i.e. articulated vehicles), as no alternative transport mode was available. Complementary measures, such as constructing new rail infrastructure which provided a direct connection to the port, could mitigate GHG emissions from this particular freight task.

Taylor, Smith, D'Este and Zito (2004) showed that all of the policy options had positive effects on GHG emissions when total emissions from all road transport sources are considered (i.e. private vehicles as well as freight vehicles). This included scenario 6 with industry relocation and infrastructure provision, which yielded a total GHG emissions reduction of about five per cent when private vehicle trips were included. The reductions in GHG emissions from private vehicle travel in the modelled scenario outweighed the increased emissions from the freight vehicles. The policy option with the greatest effect on total GHG emissions from transport was that of reduced peak period traffic congestion. The 20 per cent reduction in private vehicle trips assumed under this scenario led to an overall decrease of around eight per cent in total GHG emissions. The decrease in GHG emissions from freight vehicles in this case was around 2.3 per cent, indicating that the main benefit in this case came from reductions in the GHG emissions of private cars.

The policy question is how to achieve such reductions? One potential answer is the application of congestion charging ('road pricing') for peak period motor vehicle trips, as adopted in Singapore (with electronic road pricing) and in central London (through a cordon charge licensing scheme enforced by video surveillance). A number of previous studies – see for example May et al (1996), Bray and Tisato (1997) and Taylor (1999b) – have suggested the potential for congestion charging to reduce air pollutant emissions from urban road transport.

The infrastructure improvement option (without industry relocation) provided the second best result in terms of total GHG emissions (6.2 per cent). The benefit is derived from free flowing traffic. However it is important to remember that such an effect will only apply if the new infrastructure does not induce extra passenger vehicle trips. We believe evidence from the literature supports our assumption that the new infrastructure will not induce extra *freight* trips but that assumption would not hold for passenger trips, although as numbers of the links on the Sydney orbital are, or will be, subject to tolling, induced demand could be dampened. The other scenarios affecting general traffic activity (i.e. better traffic management and real time traffic information) led to reductions in total GHG emissions of about two per cent.

The freight transport-specific policy measures of higher load factors and best fuel technology found to offer the most promise in reducing GHG emissions from freight vehicles provided reductions in the total GHG emissions of 3.3 per cent and 1.1 per cent respectively, because these measures were solely targeted at urban freight transport. Private vehicle emissions were not directly affected by these policy measures except at the margin – higher load factors mean slightly fewer freight vehicles on the road.

The modelling results provide a detailed view of the emissions impacts on each vehicle class under each policy scenario. For the case of the total GHG emissions (measured in terms of CO_2 equivalents, CO_2e), Figure 7 shows the overall emissions impacts for each freight vehicle class.

Figure 7: Total modelled CO2e emissions (tonne/day) by freight vehicle type under the different policy scenarios
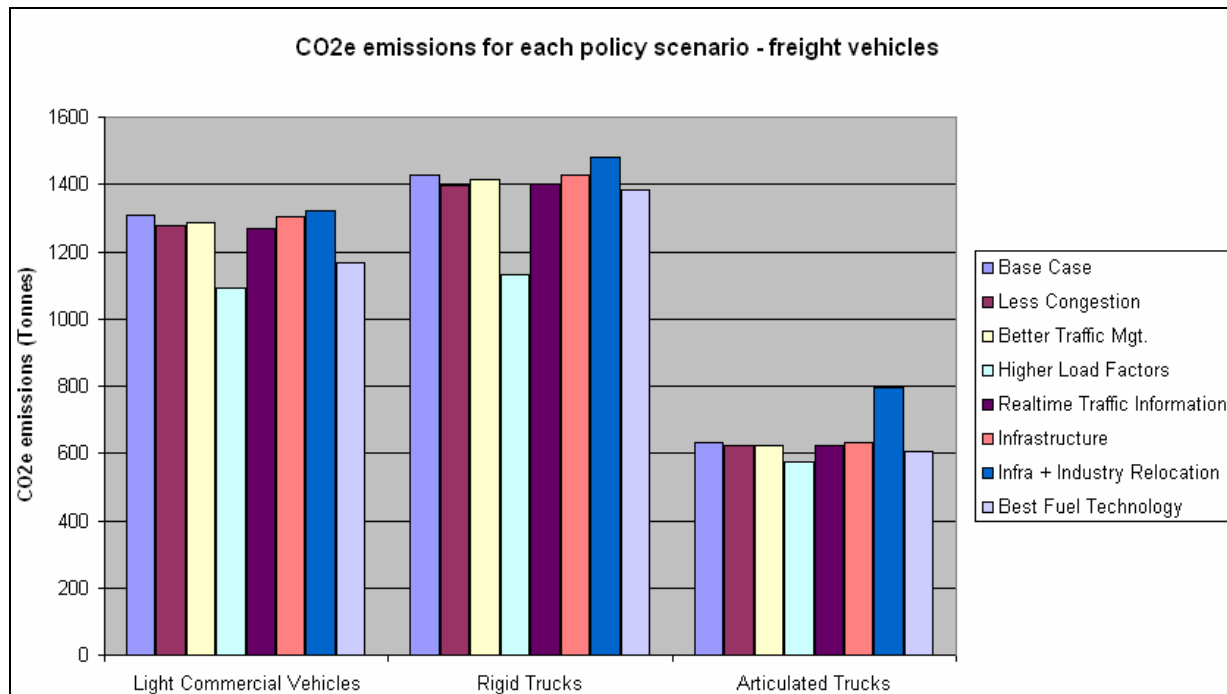

Figure 7 indicates that the different policy options can have different effects on the freight vehicle classes. Higher load factors had most effects (both absolutely and proportionately) on the GHG emissions performance of LCVs and rigid trucks. The impact of this policy scenario on articulated trucks was much less, probably reflecting the more specialised freight tasks undertaken by this vehicle type in urban areas. Similarly, best fuel technology had most effect on the emissions performance of LCVs, the freight vehicle class known to be growing in importance in urban freight. The impact on GHG emissions from articulated vehicles in the scenario with industry relocation following the construction of the Sydney Orbital was also apparent, whilst this scenario had only a small effect for the other freight vehicle classes. Note again that while the size of this impact may be overestimated, due to modelling simplification in moving only manufacturing west, the direction of the impact is likely to be correct. The other policy scenarios showed slight decreases in total GHG emissions for all freight vehicles.

CONCLUSIONS

This paper has discussed some of the reasons why freight transport in urban areas is of increasing interest and concern. Significant changes in patterns and intensity of freight movements are occurring as a result of technological and societal change and the growth in e-business, the environmental consequences of road based transport systems, and urban land use and transport systems management policies. One significant problem for transport and urban policy formulation is the Browne-Allen dilemma of conflicting objectives relating to urban freight operators and their customers on one side, and the community on the other. The City Logistics paradigm is one approach to resolving this problem. City Logistics is the study of the dynamic management and operations of urban freight transport and distribution systems, aimed at multi-objective optimisation of the overall performance of urban freight systems in terms of public and private economic outcomes, congestion management and environmental impacts. City Logistics seeks to deliver a

win-win for business and the community by ensuring optimum productivity, reliability and customer service whilst reducing environmental impacts, air pollution emissions, energy consumption and traffic congestion. Current research is being directed at building city logistics systems simulation models that optimise transport logistics efficiency under congested urban traffic conditions, and that reflect the unique commercial, traffic and urban form characteristics of Australian cities. A case study for Sydney involving the evaluation of likely impacts of transport policies aimed at mitigating the environmental impacts of urban freight transport was presented. Whilst this case study provided a simulation of freight transport performance under different policy scenarios and did not therefore seek the optimal outcomes that a full City logistics analysis would, it was able to point towards certain policy directions that may be appropriate to this end.

ACKNOWLEDGEMENTS

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