WORKING PAPER
ITS-WP-99-16

# Modelling Urban Freight: What Works, What Doesn't Work?

by

Samantha Y Taylor
Kenneth J Button

July 1999

**ISSN 1440-3501**

*Established and supported under the Australian Research Council's Key Centre Program.*

**INSTITUTE OF TRANSPORT STUDIES**
The Australian Key Centre in Transport Management

The University of Sydney and Monash University

**NUMBER:** Working Paper ITS-WP-99-16

**TITLE:** Modelling urban Freight: What Works, What Doesn't Work?

**ABSTRACT:** There are now numerous models that seek to explain urban freight patterns. Many of these models are for short-term policy but others are used for long-term planning. This paper looks at the alternative approaches that are being used for planning based modelling. Some places, such as Portland Oregon, use a relatively pragmatic approach, other cities have adopted more academic approaches. The former have particular advantages in terms of data requirements. Much depends upon the nature of the overall policies being reviewed and these differ considerably between cities. In Europe for example, there is a tendency to focus on 'public' distribution centres at the outskirts of cities.

**AUTHOR:** Samantha Y Taylor
Kenneth J Button

**CONTACT:** Institute of Transport Studies (Sydney & Monash)
The Australian Key Centre in Transport Management
Department of Civil Engineering
Monash University
Clayton Victoria 3168 Australia

Telephone: +61 3 9905 9627
Facsimile: +61 3 9905 4944
E-mail: itsinfo@eng.monash.edu.au
Internet: http://www-civil.eng.monash.edu.au/centres/its/

**DATE:** July 1999

## 1 INTRODUCTION

The nature of urban areas in industrialised countries has been undergoing a transformation and with it the pattern of freight movements have been changing. In terms of urban form, the inner cores of many major cities have declined in importance as sub-urbanisation and the emergence of 'edge cities' has taken place. This has impacted on the demand for freight transport services and influenced the ways in which transiting movements are conducted. These changes have been accompanied on the supply side by the introduction of new supply chain management techniques, innovative technologies, including information systems, and new institutional frameworks.

There have also been important changes in the way freight transport is viewed by policy makers. The established emphasis on optimising in some sense the flow of traffic of a network in terms of money costs and transport time has been supplemented by concerns to contain environmental damage and social intrusion (Browne, 1997; Browne and Allen, 1998) and to ensure high levels of safety (Button, 1998a). This requires more sensitivity in the models used and the ability to explore a larger range of output parameters. From the transport side, the development of integrated freight management and such techniques as just-in-time management have altered the way that transport services are provided and the characteristics of the transport network that influence freight movement patterns. Policy cannot be isolated from these developments either in terms of facilitating their rapid up-take or shaping their form.

From the modelling perspective, there have been important advances as new ways of thinking about freight transport have emerged, new techniques of analysis have been developed and alternative methods of information gathering have been deployed. Computer power continually offers the scope for refining techniques and testing alternative model specifications.

Occasionally it is useful to take stock of where one stands. In this case our concern is in examining the usefulness of the current portfolio of urban freight models that are available to transport planners and to explore the respective merits of different approaches to freight modelling. To undertake this it is helpful to initially consider some of the objectives of planners and the ways in which they have traditionally approached model design and forecasting issues. The analysis then looks at a number of different contemporary modelling approaches and techniques and reviews them in the context of a selection of case studies in the field. The aim is less to provide arguments for some radical, new approach than to look at the most promising of the portfolio of existing modelling that may fruitfully be developed further in the future.

## 2 TYPES OF MODELS

There is no such thing as the ideal generic model. Models serve a variety of functions and are used for a diversity of purposes. A model that meets many of the needs of an urban freight operator concerned with optimising a company's delivery strategy is likely to differ substantially from a model used by urban planners interested in optimising, in the widest sense, the use made of a city's transport infrastructure networks. Here we limit ourselves very much to the latter types of model, those that may be of use in urban transport planning.

This means that the focus is on the physical side of urban freight transport and less on the pecuniary aspects other than that the latter are important for modelling traffic flows, traffic patterns and congestion bottlenecks. Figure 1 offers a sketch of how the various types of planning models we are interested in relate to each other and forms the basis for much of our discussion.

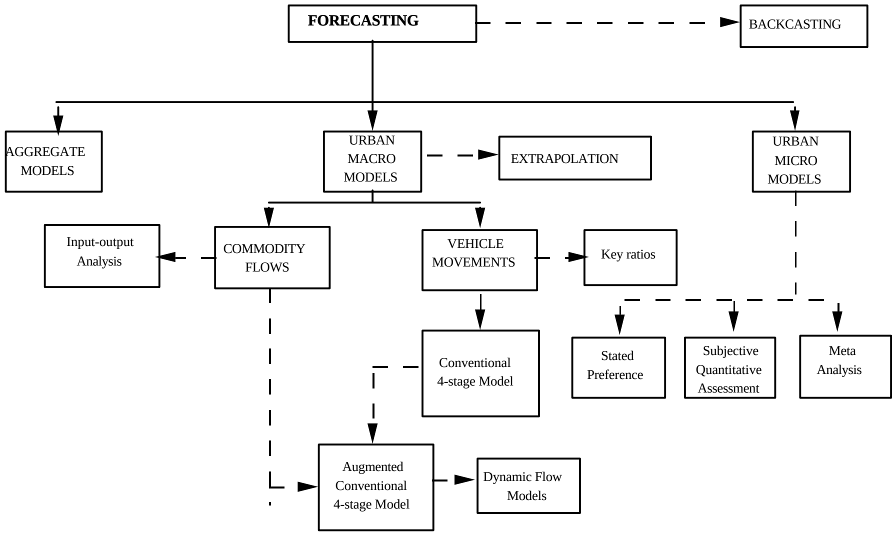


**FIGURE 1. Planning models of urban freight transport.**

In selecting a framework for modelling, there is the fundamental issue of what one wants from a model. In many cases the traditional concern has been on providing reasonably accurate forecasts .of traffic flows Indeed, one school of thought still maintains that the only true test of a model is its forecasting accuracy. There are two problems with this approach. From a pragmatic perspective, there are few retrospective studies of forecasts of urban freight transport. This makes *ex post* assessment difficult. Second, planners are often interested in obtaining a 'feel' for a situation and for the implications of alternative actions. Forecasting accuracy may be of importance in this context but there may be other factors that also come into play such as the amount of data required, the ease of testing alternative scenarios and the ability to assess qualitative impacts.

The issues that are now being addressed by urban planners often different to those that confronted their counterparts twenty or thirty years ago. The emphasis in the nineteen-sixties was primarily engineering driven and on the integration of freight movements within large-scale land-use/transportation plans. Urban freight was often seen as an inter-peak activity within this framework and, since this implied a minimal interaction with rush hour congested passenger traffic flows, was given relatively scant attention in traffic modelling. Models were in fact generally derivations of passenger transport models.

More recently planners have been confronted with a broader range of issues and the macro questions associated with land-use/transportation planning have been supplemented by more micro questions concerning such things as the implications of trucking routes, the location of loading bays, night curfews and vehicle weight limits. In some instances, such as the recent UK initiative to limit the development of out of town shopping centres, changes in local land-use policy also has significant implications for urban freight. These developments have necessitated the development of more micro-orientated models that reflect the need to analyse the impacts of specific policy shifts on discrete areas of cities. This has been combined with the need for these models to reflect a wider range of outputs that extend beyond traditional transport measures such as traffic flows and accident rates to include a variety of environmental parameters suitable to be fed into impact statements.

One way of considering the complexity implied by this latter development involves looking at the issue of optimal freight consolidation. Because the degree of transhipment is closely related to average payload – greater consolidation inevitably increasing the average payload – Figure 2 shows line-haul costs (A) falling with consolidation until the maximum physical or legal average payload is reached. If only haulage costs were to be considered this maximum would represent the optimal payload, but there are also the resources costs involved with consolidation itself – the provision of depots, handling staff, administrative costs, etc. These costs (B) are likely to rise with the level of transhipment. Consequently, the transport operator when considering transhipment views the optimal level of consolidation to entail an average payload of $L_t$. The final customer awaiting delivery will also have costs that vary with transhipment levels (C). The greater the amount of consolidation, and the higher the final average payload, the fewer the number of deliveries needed. Longer frequencies between deliveries push up the costs of stockholding for customers and the overall level of inventories held implying the time costs of increased consolidation rise with average payload. Thus the final recipients of goods would prefer a level of consolidation consistent with an average payload of $L_p$ (Nemoto, 1997). Simple transportation models seek to define these curves and to optimise the system accordingly. Increasingly, however, wider external costs of such things as environmental degradation need to be considered. Generally, increased consolidation and higher payloads will reduce these costs, because fewer trips are needed to transport the same volume of goods, and consolidation generally means less environmentally intrusive vehicles can be used in sensitive areas (D). From this point of view, the optimal level of consolidation is when all costs are minimised, that is, at point $L_s$. Full cost modelling and forecasting requires taking account of these additional costs.

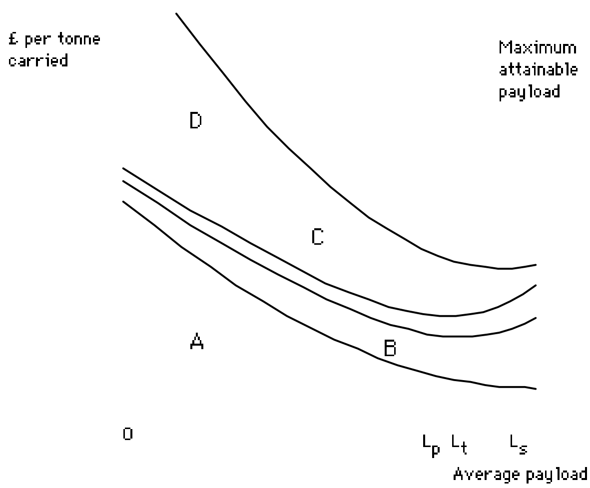


**FIGURE 2. Freight consolidation costs (represented cumulatively)**

Historically the development of even conventional freight forecasting has also been fragmented and cyclical. Its complexity makes it not only resource intensive but time consuming and more often than not requires considerable co-operation from government bodies and local authorities. Added to this, the underlying relationships have become more complicated. The demand for goods and services has become increasingly complex as wealth has been accumulated in the industrialised nations and as new technologies have been introduced into the freight distribution sector. The focus has turned from market advantage based on technological robustness of a product to value adding, niche markets and the growing service industries. The effect is that transport vehicle scheduling and operations have needed to change to satisfy higher goals within the production consumption chain. (e.g., just-in-time management, integrated logistics and supply-chain-management). The driving forces of freight travel patterns have moved even more notably outside the strictly transport industry adding greater complexity to the modelling task.

## 3 MACRO MODELS

Recent years have seen a number of important improvements and refinements in the ways that modellers treat urban freight at the macro level. The focus of this work has always been to encompass all the dimensions of urban freight traffic flows seen in Figure 2 although, since through traffic and inward and outward movements are largely along defined corridors, more concern has traditionally been put on intra-urban movements. Where through traffic and import/export traffic is more relevant is in national inter-urban freight flow modelling (see again Figure 1) which is not considered in any detail here.

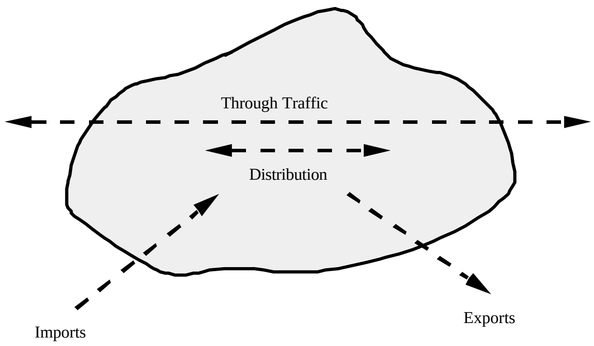


**FIGURE 3. Urban freight flows**

While in some cases relatively crude extrapolation techniques have been used for forecasting, much of the early macro modelling of urban freight transport relied upon derivations of the ‘four–step’ land–use–transportation models (Figure 4) that had primarily been designed to forecast person movements in 1960s (Hicks, 1977; Meyburg and Stopher, 1974; Button and Pearman, 1981). The approach was essentially mechanistic, initially looking at aggregate traffic flows in a city and then disaggregation down according to flow patterns, mode and routings (see Figure 3). From a technical perspective, the four-stage model suffers from a number of inherent limitations irrespective of whether it is applied for freight or passenger traffic (Button, 1976).

The underlying idea of concentric cities with radial transport networks and economic activities concentrated at the city core underscored many of these models. A further feature of the freight models is that they were largely truck based in their orientation, paying attention to vehicles flows rather than commodity flows. While this may superficial have an appeal because planners were mainly concerned with road investment policies, it is much less use in appraising wider changes in traffic patterns that can, for example, involve goods distribution in cities involving the use of private cars from superstores. Additionally, as supply change management has grown in importance, a narrow focus on vehicle movements implicitly ignores a range of strategies that may be considered when undertaking view commodity movements. Technically, the models were data intensive and allowed only limited feedback between the four stages (it was essentially a recursive formulation). Combined with this it was difficult to assess the overall quality of the model with testing reserved primarily for individual components. The components themselves were often mechanical and lacking in any firm theoretical underpinning.

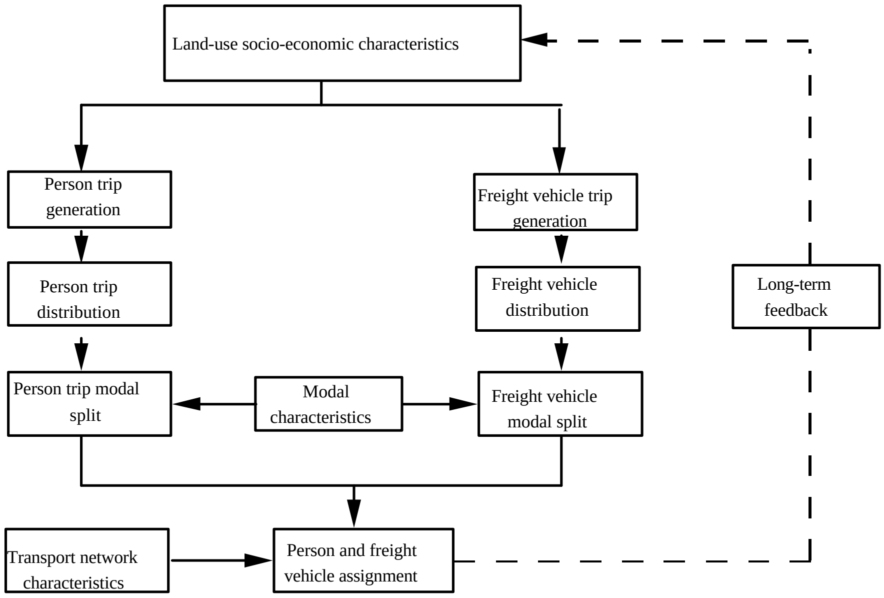


**FIGURE 4. The sequential model approach to forecasting urban transport**

Nevertheless, in the nineteen-sixties and early seventies there was success in freight analyses with London, Chicago and Melbourne all undertaking relatively successful urban freight studies along these general lines (Greater London Council 1975; Ogden 1977). The underlying individual models were commonly econometric in nature and of the regression and gravity-model kind and freight transportation land-use relationships were developed. At this time urban freight movement could be linked with some certainty to economic activity proxies such as blue-collar employment, population and floor area. Though contemporary micro-level research consistently indicated the need for an interactive model system relating commodities to land-use activity and to type of vehicle loading, this cruder analysis met the needs of planners at a time when urban transport planning did not significantly extend beyond road network design. Also the amount of urban freight movements were still generally relatively small in scale with much of it carried at off-peak times.

Further, intellectually, concepts such as input-output analysis and commodity flows, which were generally modelled independently of vehicles flows, satisfied the notion that freight forecasting needed to have an economic component since freight movement is closely related to economic activity. Indeed, the national GDP in most developed countries has been proportionally related to freight movement for the last two or three decades. The future of this relationship is uncertain, however, because planners, and transport policy-makers more generally, are moving away from policies designed to meet unrestrained demands for urban road space to managing transport networks and constraining growth traffic volumes (Australian Bureau of Transportation and Communication Economics, 1993; McKinnon, 1989; Netherlands Economic Institute,1998)). Indeed, a major objective of the European Union as part of its environmental strategy is to 'decouple' transport from economic growth.

The shifts in policy objectives together with improved modelling techniques and more powerful computer aids have resulted in significant changes to the basic four-stage model. Models developed for Sydney in the nineteen-nineties, for example, tie in more closely the link between commodity flows and vehicle movements albeit within a sequential modelling structure. There are now techniques that allow for feed-back from assignment to traffic generation and distribution models and computers now have the capacity to manipulate them. Their up-take, however, has been slow (Horowitz, 1996). The separate elements in the sequence have also been refined. The adoption of neural networks to the traffic assignment stage, for instance, adds sophistication. Despite this, however, the sequential approach still suffers from several basic weaknesses.

One of the biggest problems with the sequential approach is its greed for data. The common output of the sequential urban transport model with regard to freight movements is a trip matrix enabling traffic flows on a network to be produced. In the early days of traffic forecasting a matrix was created by expanding a sample of trip origin and destination flows, often delineated by broad classes of vehicle size. Data was usually collected using a travel diary survey methodology. Expanding a sample of trip data to the population poses problems, not least of which is obtaining an adequate sample. The zones of the trip table are required to be fine enough to provide a useful tool for planners (e.g., in Sydney the Greater Sydney Region is divided into over 1000 travel zones). Raimond (1997) identified the following problems in the development of trip tables from a sample of O–D data for Sydney:

- Limited sample sizes due to constrained funding has been a problem. This was particularly severe in the case of light commercial vehicles which constitute around 70% of commercial vehicles registered in the Greater Sydney Region (Taylor, 1997). In Australia, the national population of light vehicles has doubled since 1976 (Australian Bureau of Statistics, 1995)
- Biased sampling frames can also be problematic (e.g., by using the registration database by registered address as the sampling frame the sample does not include vehicles registered in other states or outside the region but operating within the region,
- Inadequate control totals for sample expansion.
- There are few methods suitable for determining trip table accuracy

In essence Raimond indicated the need, based on practical experience, to look beyond direct traffic measurement to embrace model freight traffic flows. This is not the only work along these lines and Zavaretto (1976) for the Chicago Area Transportation Study proposed a detailed framework suitable for practical implementation as did Bowyer (1991) for modelling urban freight using both commodity flows and vehicle trips.

A somewhat difference emphasis on the up-grading of the sequential model, and, in particular, to try to move it away from a purely strategic planning tool, can be seen in the Portland Commodity Flow Study (ICF Kailser, *et al*, 1999). Here the forecasting system was designed to provide decision-makers with information on commodity and vehicle movements into, through and out of the region. The model combines an input-output approach with the principles of the four-step approach and has two main components, the tactical model and the strategic model system database (Cambridge Systematics 1998). The database is a critical input to the tactical model and is designed to maximise the use of existing data with supplements obtained through targeted counts and surveys.

The approach works from two ends: commodity flows at one end and truck flows at the other. Commodity flows are derived from data obtained from the Port of Portland and truck flows are derived from the comprehensive network of truck classification counters in the region. The model categorises commodities by type, market segment and entry mode, allocates an arrival facility and from that a destination facility. Commodities are converted to vehicle equivalents, assigned to the network and compared to vehicle classification counts. The data steps are: (1) regional flows by commodity type; (2) regional commodity flows by market segment; (3) regional commodity flows by point of entry; (4) allocation of commodity origins and destinations; (5) distribution of commodity flows between origins and destinations; (6) linkage of trips to reload/terminal facilities; (7) conversion of flows to vehicle trips; (8) generation of empty trips; and (9) assignment of vehicle trips to the network.

Steps 1 to 3 are carried by manipulating the Strategic Model Database with information on seasonal adjustments for commodity production using data supplied by the Port of Portland. Steps 4 to 6 require a disaggregation of the commodity flows into geographic regions and Steps 7 to 9 involve application of a vehicle loading model, and trip assignment. The model is calibrated using traffic classification counts with outputs of the state-wide model (which is an integrated land-use model at the state level based on input output models and random utility theory) and vehicle miles of travel by vehicle type is also used for comparison purposes.

## 4 MICRO MODELS

Stimulated by the increased recognition of the role of logistics, contemporary academic work has identified an increasingly complex freight chain and decision-making process influencing truck movements (McKinnon and Woodburn, 1993). Researchers have effectively been forced to develop sophisticated and complex models to more closely imitate the changing world but in doing so there have been costs in terms of their practical usefulness. These models initially often required expensive data collection and necessitated large amounts of time to obtain useful results. They were not suitable for planning practitioners who largely continued to use proportions of total traffic as the basis of their freight movement modelling – the 'key ratios' in Figure 1 (Ismart 1996).

In short, the academic pursuits in the urban goods modelling area was until recently doing very little to assist practitioners in real world freight forecasting and policy design. This was particularly evident in the US when the introduction of Federal legislation in ISTEA, for example, established that state-wide and metropolitan planning in the US was to consider freight as well as person travel. The problem was that the authorities responsible for freight planning, the Metropolitan Planning Organisations were not adequately equipped to undertake freight modelling, compelling the federal agency, the Federal Highways Administration, to address the issue.

This situation is now changing somewhat with the development of more tractable micro models that are particularly important in tactical decision making, especially within small urban zones, and in the fine-tuning of more traditional macro models (see again Figure 1). There now exist several promising approaches and techniques that may ultimately economise on data needs and others that can add a more dynamic context to the modelling process or make it easier to explore a wider range of alternative policy options.

As we have seen, the majority of models have long relied on extrapolation based revealed preference functions for projecting urban freight movements. As social, political and technical changes break down these relationships so there is a need to predict changes in these behavioural functions as well as looking at simple shifts. One way of doing this is through stated preference analysis whereby, in simple terms, potential users of transport infrastructure and networks are confronted with a series of possible future scenarios and asked to comment on their likely reactions to them. Posing the appropriate questions is no simple task but it does offer the opportunity to gain some insights into possible behaviour in situations outside those of past experiences and to gain a better fell for how key parameters may change in the future.

While now routinely used in environmental evaluation exercises and passenger travel analysis, this approach is less common in freight modelling. The method was used, however, in the Portland study cited above. A survey of 15 major carriers was an attempt to understand some of the behavioural characteristics influencing freight movement. The pilot, however, proved resource intensive and complex. Identification of both the decision-makers and the potential impacts of policy decisions was difficult, leading to questions regarding the cost benefit of including a behavioural component of this nature in the overall modelling exercise. The decision making process is often a hybrid of the carrier's requirements and preferences and the shipper's operations. The process of obtaining data from carriers was found to vary considerable in accuracy and data richness; to be more forthcoming from FTL carriers than express freight carriers because of the highly competitive and responsive nature of the express freight business; and to require an experienced person to visit each site to collect the data to ensure data is in a useful format. Clearly there is a need to develop the methodology further but it is promising as a mechanism to circumvent the inherent rigidity of many of the assumptions of traditional approaches.

A second innovation in micro modelling has been the development and refinement of subjective quantitative assessment methods of which various forms of expert opinion analysis is the most common (Button, 1998b). An integral part of the commodity flow study in Portland was the serious nature with which consultation with experts has been pursued. The project management team comprised the Freight Work Team (those who will be using the model system in its final form), and both regional and international advisory

\committees. Each of the committees comprised representatives from consulting, academia, the freight industry, local, state and federal government and brought to the table wide range of experiences relevant to commodity movements and urban goods movement useful to the project. Again the procedure is not free of potential pitfalls. Selection of experts is not easy and posing the appropriate questions can raise difficulties but again it can inject more dynamism into the modelling of a rapidly changing situation.

The increased adoption of meta-analysis in many fields of transport modelling can also be extended to urban freight modelling (van den Berg *et al*, 1998). One of the uses of meta-analysis involves the statistical analysis of a set of prior studies in order to develop consistent common parameters. In the context of urban freight modelling there exists a significant number of studies that independently have generated parameter estimates of key ratios and elasticities. Additional studies will inevitably be called for to supplement this information base, but in systematically mining the findings of earlier work where consistent results have been found indicates that additional original analysis of these parameters would seem superfluous. Equally this mining will throw up areas where parameters are less robust and considerable uncertainties remain. Meta-analysis, by helping to isolate these latter situations, enables scarce data collection and modelling resources to be deployed more effectively. The technique is not a panacea and there remain issues of what prior studies to examine, the weight to be attached to each and the appropriate statistical techniques to employ.

Relevant, but in the past sometimes considered tangential, to the problem of forecasting is the increased interest by modellers in 'backcasting'. Traditional urban freight modelling was largely demand driven and designed to provide traffic engineers with information germane to road design and to the initiation of physical traffic management measures. Given the almost sea change in urban transport policy in many countries over the past decade, the focus is now more on developing sustainable urban transport systems. Sustainability at the urban level is a somewhat nebulous concept but, nevertheless, efforts at operationalisation generally involve the need to restrain traffic growth rather than simply accommodate it. The decision on future traffic levels is, therefore, essentially determined exogenously to conform to environmental and other criteria and the role of modelling is increasingly to explore policies that ensure these levels are not exceeded. The focus shifts to looking at how otherwise unrestrained traffic growth paths can be influenced to conform to the policy objective. This requires models to be more policy sensitive with greater emphasis on the reaction of urban freight undertakings to various policy intervention measures. Given that the demand for urban freight movement is, through the logistics chain, now seen as interdependent with other key parameters concerned with such considerations as warehousing, inventory control, information systems, and production and retail location a more holistic approach to modelling is required (Dumble, 1989). Inevitably this means closer ties between traditional traffic modellers and those expert in logistics systems within the backcasting framework. These are only at the embryonic stage compared to the development of more traditional frameworks and will need further sustenance to play a more productive role.

## 5 CONCLUSIONS

Urban freight movements can put considerable strains on the urban transport infrastructure and impose high social costs in terms of accidents and environmental intrusion. To develop appropriate policies that balance the benefits derived from high quality urban freight transport systems with their wider implications for society it is important to understand the factors that drive freight movements and to have the ability to produce reasonably accurate quantitative forecasts of longer term trends. A number of approaches have been developed with these objectives in mind. The nature of these models reflects the diversity of objectives that they are intended to meet, the institutions involved and the constraints that limit the modelling designs that are tractable.

More recently, the usefulness of conventional traffic forecasting models has been limited by the dynamic nature of the demands placed on urban goods freight service suppliers and rapidly changing technologies, especially regarding information systems, that makes any form of extrapolation problematic. Limited data, or at least the high costs of collecting data, adds to these difficulties and are often compounded by the lack of background, national surveys that indicate broader trends and relationships. These types of data limitations are particularly acute in cities in the developing world and in post-communist states but they are also major problems in most industrialised countries where the emergence of such features as edge cities often make existing data sets redundant.

Information about the current state of urban freight modelling is often constrained by the amount of it contained in the growing amount of grey literature on the subject. Much of the recent progress in freight forecasting has been achieved predominantly by consultants or in-house units of planning agencies. This has had the effect of reducing the availability of literature in the public domain as consultants compete for market contracts and retain confidentiality. In the longer term this will inevitably inhibit developments in the field and be a restriction of the use of such techniques as expert opinion analysis and meta analysis. Nevertheless, there are encouraging signs that be-spoke techniques are emerging that can help improve our understanding of particular developments in urban freight transport. They are not perfect, nor are they likely to allow all situations to be adequately modelled, but they do offer some opportunity for reflecting the dynamism that now characterises the movement of freight in cities.

## 6 REFERENCES


Australian Bureau of Statistics (1995) *Survey of Motor Vehicle Use, Australia (Preliminary)*, ABS, Canberra.

Australian Bureau of Transport and Communications Economics (1994) *Transport Greenhouse Emissions in Australian Transport*. Report to the Department of the Environment, Sport and Territories, BTCE, Canberra.

Bowyer (1991) *Urban Freight Model Development*, Australian Road Board, Melbourne.

Browne, M. (1997) Freight transport and the city, Round Table 108, European Conference of Ministers of Transport, Paris.

Browne, M. and Allen, J. (1998) Strategies to reduce the use of energy by freight transport in cities, *Transport Logistics*, **1(3)**, 195-211.

Button, K.J. (1976) The use of economics in urban travel demand modelling: a survey, *Socio-Economic Planning Sciences* **10(2)**, 57-66.

Button, K.J. (1998a) Freight traffic and safety – a European perspective. In H. von Holst, A. Nygren and A. Anderson (eds) *Transportation, Traffic Safety and Health*, Karolinska Instituet, Stockholm.

Button, K.J. (1998b) The three faces of synthesis: bringing together quantitative findings in the field of transport and environmental policy', *Environment and Planning C* **16(5)**, 516-528.

Button, K.J. and Pearman, A.D. (1981) *The Economics of Urban Freight Transport*, Macmillan, London.

Cambridge Systematics (1998) *Collection and Analysis of Commodity Flow Information for Metro and the Port of Portland*. Available from http://www.metro.dst.or.us/transpo/comflo/comscope.html.

Dumble P.L.(1989) *Urban Freight and Land-Use Interaction. Internal Report* AIR 316-1, Australian Road Research Board, South Vermont

Greater London Council (1975) Freight in London; full review paper. In *London Freight Conference*, Greater London Council, London.

Hicks, S. (1977) Urban freight. In D. Hensher (ed.) *Urban Transport Economics*, Cambridge university Press, Cambridge.

Horowitz, A.J. (1996) Freight forecasting: the context. In R.J. Czerniak and S. Gaiser (eds) *Urban Goods and Freight Forecasting Conference*, USDOT, Washington.

ICF Kailser, Columbus Group, Reebie Associates, the WEFA Group and Port of Portland (1999) *Commodity Flow Analysis for the Portland Metropolitan Area*, Metro, Portland.

Ismart, D. (1996) FHWA interests and activities in urban goods and freight modeling. In *Conference Proceedings of Urban Goods and Freight Forecasting Conference*, Albuquerque, New Mexico.

McKinnon A (1989) The growth of road freight in the UK, *International Journal of Physical Distribution and Materials Management*, **19(4)**, 3–13.

McKinnon A and Woodburn A (1993) A logistical perspective on the growth of lorry traffic. *Traffic Engineering and Control*, **34(October)**, 466–71.

Meyburg, A. and Stopher, P. (1974) A framework for the analysis of demand for urban goods movement, *Transportation Research Record*, **496**, 68–79.

Nemoto, T. (1997) Area-wide inter-carrier consolidation of freight in urban areas, *Transport Logistics*, **1 (2),** 87–103.

Netherlands Economic Institute (1998) *Relationship between Demand for Freight-transport and Industrial Effects*, Final Report REDEFINE, Contract RO-97-SC.1091, European Union, Brussels.

Ogden, K.W. (1977) *Urban Goods Movement*, Department of Civil Engineering. Monash University, Clayton.

Raimond, T. (1997) Urban freight data collection and forecasting. *Conference Proceedings of the Australasian Transport Research Forum* **21(1)**, 67-82

Taylor, S.Y. and Ogden, K.W. (1998) The utilization of commercial vehicles in urban areas, *Transport Logistics*, **1(4)**, 265278

Taylor, S.Y. (1997) A basis for understanding urban freight and commercial vehicle travel. Research Report ARR 300. ARRB Transport Research, South Vermont.

van den Bergh, J.C.J.M. and Button, K.J. (1997) Meta-analysis of environmental issues in regional, urban and transport economics, *Urban Studies*, **34(5/6)**, 927–944.

Zavarretto, D.A. (1976) Suggested approach to urban goods movement and transportation planning, *Transportation Research Record*, **591**, 41–43.