Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 2975 - 2990, 2005

FUNCTIONAL SPECIFICATION OF STRATEGIC URBAN FREIGHT MODELS: MODELING ATTRIBUTES FOR THE PORT AND LANDSIDE FREIGHT TASK IN SYDNEY

Paul BEAVIS
Doctoral Candidate
School of Civil and Environmental Engineering
The University of New South Wales
Sydney 2052
Australia
Fax 61 2 9385 6139
paulb@civeng.unsw.edu.au

John BLACK
Professor and
Director
Botany Bay Studies Unit (BBSU)
Faculty of Science
The University of New South Wales
Sydney 2052
Australia
Fax 61 2 9385 6139
j.black@unsw.edu.au

Raymond GOLZAR
Doctor
Former PhD Candidate
School of Civil and Environmental Engineering
The University of New South Wales
Sydney 2052
Australia

Abstract

Infrastructure suppliers and operators, either government utilities or private enterprise, need to be involved in strategic freight processes at the urban scale. This is to ensure that infrastructure investment remains effective in facilitating whole network access and minimizing impacts in often congested and competitive networks. Infrastructure suppliers and operators need to be equipped with a capacity to gauge demand matching and demand steering concerns. In Australia, strategic urban planning, especially the freight task, remains piecemeal. This potentially leads to infrastructure investments that neglect or exacerbate existing system deficiencies. We analyze existing system conditions for the Port-Landside network and arrangements in Sydney. From a review of current freight modeling capacity, we develop a freight modeling taxonomy. This taxonomy is translated into a functional specification for infrastructure suppliers and operators through an analysis of their modeling needs with respect to inter-modalism. We present this as a general freight transportation infrastructure planning procedure.

Keywords: Freight Models, Port- Landside Inter-modalism, Infrastructure Investment

"They were admirable equilibrists."

Louis de Carne observing in 1865 the skill of Cambodian boatmen in navigating the Mekong in *Travels on the Mekong* (1995, p.49)

1 INTRODUCTION

As countries increasingly encourage private-sector participation in transport infrastructure, suppliers and operators have a wide range of strategic information needs for a highly complex system. Both government authorities and private companies have a major role in capacity supply, and in ensuring an adequate future level of service for users. The aim of this paper is to provide a blueprint of how infrastructure suppliers/ operators might become more closely involved with strategic freight network planning. With such a framework linking information needs with available modeling methods, infrastructure providers can avoid the risk of system sub-optimization when designing and augmenting networks (Woxenius, 1998, p. 152). Hensher *et al*., (1999) have documented the likely responses of fleet service providers to changing infrastructure but the behavior of private infrastructure owners and operators is not well understood (Rietveld *et al*., 1998). Consequently, identifying their needs and sourcing pertinent modeling methods to address these needs is useful.

Current problems of freight network planning are identified in Section 2. In the following sections, this paper maps the information needs and modeling requirements of transport infrastructure suppliers and operators with respect to freight. By using a conceptual model of the freight task (Section 3), we discuss the spatial and dynamic implications of various driving forces in freight and logistics. Addressing system deficiencies is a core interest of both private and government infrastructure operators and we outline the generic characteristics of appropriate models and their information value. Based on an extensive international literature review of freight models (Section 4) we assess current modeling approaches and construct a novel taxonomy combining physical and logistic activity interests (Figure 2). This taxonomy can be drawn on to formulate an analytical strategy to address the transportation issue on hand. It allows a functional specification to be addressed from potentially several modeling approaches. To illustrate this, we develop a case study of inter-modal freight terminals with particular reference to Sydney, and the results are presented in Section 5. The conceptual model (Figure 1) is now reconfigured for the specific conditions of the case study area (Figure 3), and the linkages among the information needs made explicit (Figure 4). An illustrative template for associating infrastructure agent interests with specific modeling requirements is provided for demand matching needs and for demand steering needs for inter-modalism (Table 1).

2 PROBLEMS WITH FREIGHT PLANNING APPROACHES

Port-landside interactions of some Australian, European and USA ports, such as Baltimore (Donnelly, 2004), and the urban freight task generally, can be seen in terms of missing links and a lack of physical and logical connectivity (O'Sullivan, 2003). This fragmentation manifests itself in severe bottlenecks with resulting detours and delays. Integrity is undermined by the multitude of actors in the "freight industry" and missing and unreliable links in the transport/logistical system. Transshipment opportunities are limited by poor infrastructure connectivity, communications and oversaturated linkages due to the competition with passenger traffic for road and rail space.

There are private-sector interests in highway and rail financing and provision of infrastructure. Rimmer *et al*., (1982, pp.226-230) have described system conflict with reference to container port expansion in Sydney. Since that analysis the situation has become more complex in Sydney, as in many metropolitan regions of the world, because of demand growth and the increasing role of the private sector in transport infrastructure (Black, 1999). In Sydney, the first privately funded motorway scheme was the Sydney Harbor Tunnel (1986), and now there is a network of privately operated toll roads funded under variants of BOOT schemes. Consequently, a truck driver might use roads funded by three tiers of government (national, state, and local) plus the private sector.

The private sector's interest in transport modeling is project specific, oriented to delivery of a previously defined service or facility. From the abovementioned schemes, the private sector in Sydney is being granted increasing ownership rights over transportation networks (TAO, 1997). Consequently, they have become significant stakeholders in city transportation infrastructure strategies. Munoz *et al*., (1999) have argued that there needs to be more public – private partnership in strategic planning. Ideally, strategic planning controls lumpy (expensive, inefficient) infrastructure investment and maintains decision-making flexibility for future system augmentation.

In the Australian context, Fuller (2003, Chart 6.1, p.19) summarizes the relationship of transport knowledge, datasets, stakeholders (agents) and sectors dealing with freight modeling and forecasting. There remains a lack of connection amongst these actors in pursuing novel freight studies and model development. For instance, there are a preponderance of studies into container freight movements but no interconnected studies into break-bulk movements. Additionally, there is a dearth of analytical strategic frameworks for freight transport planning from which infrastructure providers may assess information needs from a suite of modeling methods. Exceptionally, some methods have been outlined briefly for a port authority in landside logistical analysis (Cartwright, *et al*., 2003). Techniques in forecasting passenger transportation needs are well established, but in government practice, freight planning uses the more traditional models in the transportation planning toolbox, such as a synthetic approach with forecasting based on extrapolations of cross-sectional data. Nijkamp *et al*., (1987, p.314) have observed that these techniques have two limitations: ignorance of behavioral drivers; and an orientation towards past experience and not towards future mobility. In summary, land-use activity is not considered as a driving force.

Kanafani *et al*., (1982, Fig.1, p.6) developed the blueprint for a national transportation plan. This showed the necessary interaction of components supporting Financial, Supply and Demand Analysis. The interacting components include the identification of operational and capital improvements, calculating zonal activity growth, future modal options and anticipating the evolution of transportation deficiencies. We develop aspects of this blueprint for the complexity of the urban scale and tie the information needs of a major stakeholder group - the infrastructure supplier and operator - with the analytical capacities provided by freight system modeling methods.

3 CONCEPTUAL MODEL

A conceptual model abstraction is essential to understand the nature of the freight task and the changing driving forces that should be incorporated into urban freight modeling studies. This is because of the multi-stakeholders involved in freight and logistics, the intertwining involvement of public and private sectors, and the parallel processes of physical movement of goods and the accompanying information flows in the logistical chain. A generalized freight conceptual model was proposed by Rimmer *et al*., (1981), but this now requires considerable supplementation given the great changes in supply chain management and physical distribution systems.

Figure 1 represents the supply of transport infrastructure and services as a network of links and nodes. A variety of freight flows underpin the conceptual model and invite an analysis of possible interactions amongst these flows: external flows to the urban system – through-transit flows with either a domestic or a global destination (through the ports without urban transshipment) or direct flows with urban destinations (with or without transshipment) or transit flows with urban transshipment – and internal or intra-urban flows with linked trip patterns or single destinations. The trip made on the network can be described in terms of a tour, which consists of two arcs (directional links). Additionally, freight traffic has distinct diurnal peaks, in parts of the network often controlled by a formal or informal curfew in order to provide service to passenger transport.

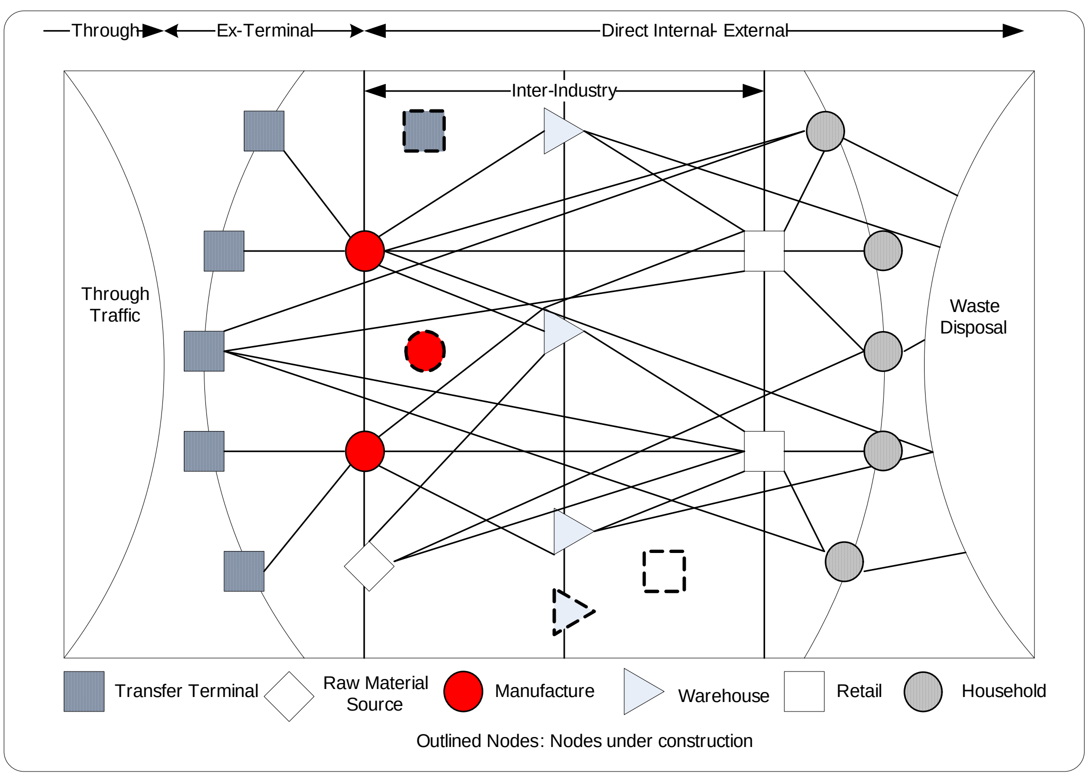

Figure 1: Freight Conceptual Model (Source: Rimmer *et al*., 1981, Figure 1, p.16)

Land-use nodes represent freight generators or attractors. However, freight infrastructure may also become a component with repercussions on freight demand because consignment translocation must navigate through the network infrastructure. Roson (2000) has noted that inter-modal terminals could invoke Just-in-Time logistics practices by reducing transport impedance. Additionally, transshipment (via terminals) may lead to increasing consolidation of flows (discretion), later to be distributed (diffusion). The freight trip is measured not only by the links taken but also by the nature of node visitations or how the consignment characteristics change at each node.

Logistics trends are only faintly outlined in this conceptual model. A shipper has a number of options and conditions for delivery. As a manufacturer involved in process and assembly, the shipper can also reconfigure his/her supply chain. Supply chain logistics trends can affect the attributes of the freight task. For instance, Just-In-Time or Time Compression Principles make inventory holdings more mobile and increase freight traffic (Zografos *et al.*, 2001). Logistics initiatives have reduced the loading factor of freight vehicles and increased the average distance traveled. Logistics dynamics contribute to freight growth more than the economic (linear) requirement for the physical movement of goods. The introduction of intelligent transportation systems (ITS) is possibly seen as a means to radically improve system performance - for example, inter-operability (Giannopoulos, 2002) - and obviate the need for new physical infrastructure. Technology that provides close to perfect information, may effect widespread trip chaining and reduce the large proportion of freight vehicular traffic carrying empty loads.

4 COMPREHENSIVE FREIGHT MODEL TAXONOMY

The freight model taxonomy presented here has the initial purpose of classifying freight models. Kanafani *et al*., (1982) also noted that, along with the first order tasks in a transportation planning framework, there is considerable feedback among the tasks. Thus, this taxonomy anticipates that information needs for strategic urban freight planning will cross several model types (given by the linkage lines). This interlinked taxonomy becomes the basis for constructing a systematic modeling approach. With this taxonomy we might select several model approaches to address our particular functional specification.

Research that informed this taxonomy was organized into four areas. *Conceptual transportation models and the theory of logistics* acted as a foundation for the research. Papers summarizing specific modeling fields formed the research area *Model Archetypes*, and were significant in composing the model taxonomy. *Strategic Freight Studies* were reviewed with an emphasis on the experience for Sydney and the functional specification needs for that city. *Freight Models and Modeling Methods* were reviewed with a focus on urban models (or how inter-regional models grant insights into urban activities). This approach is equally applicable to other cities. In all, more than 150 freight modeling, modeling method papers, and strategic studies contributed to this taxonomy. We have categorized Freight Models as Forecasting, Travel Demand Management, Integrated Urban, and Logistical (Figure 2).

Modeling approaches could also be broadly categorized as strategic freight network models (Friesz, 2001) with an interest in supply or urban goods movement models (D'Este, 2001), dealing with supply chain and distribution logistics (SCL). The starting point might be forecasting. Freight forecasting models can be generated by various methods. Approaches include general equilibrium (Friesz, 2001; Oppenheim, 1993), time series (Garrido *et al*., 1998), commodity based (Rockcliffe *et al*., 1998), zonal truck trip (Black, 1977) or extrapolations (Cambridge Systematics, 1996).

Supply models, central to this paper, can be considered at several scales. As a constraint on forecasting growth on network links, simple supply issues can be measured through level of service (LOS) generation as inputs to network assignment models (Black, 1981). Physical network design models consider new and augmented feasible networks (Crainic, 2000). System capacity, performance and infrastructure quality models use optimization techniques to assess likely system bottlenecks (Morlok *et al.*, 1999) or the requirements of system maintenance (Kalaitzidakis *et al*., 2002).

Disaggregate models consider the behavior of the shipper – carriers in affecting decisions in the four-step forecasting sequence of trip generation, trip distribution, modal choice and route assignment (Roberts *et al.*, 1978; Friesz *et al*., 1986). Agent based models, such as neural networks, can run autonomously of this structure (Nijkamp *et al*., 2004). Activity models consider the generation of freight demand from activity nodes and are better placed to consider integrated demand from different distribution system configurations (Boerkamps *et al*., 1999). Disaggregate approaches have also been developed for acquisition models (urban trip-chaining) for light goods vehicle movements (Russo *et al*., 2004). It is envisaged that infrastructure suppliers and operators need to consider the output of such models to understand changing vehicle flows and classifications.

Travel Demand Management models consider rationing demand across the network. These can be vehicle routing and scheduling models (Thompson *et al*., 1999) infrastructure pricing models (Madsen *et al*., 2004), or more sketch modeling types, which may also include strategic decision support simulation (Tavassey, 1998). Vehicle Routing and Scheduling models consider the deployment of a vehicle fleet. Infrastructure pricing can be used to control congestion over parts of the network. Pricing studies are particularly apposite in Australia with the increase in toll roads.

Integrated urban modeling involves the integration of transport and land use, forecasting and logistics, transport and the economy, and passenger travel and freight. Models may consider that transportation drives land use or land use drives transportation growth. Noticeable developments in transport and land-use have been in micro-simulation (Parsons Brinkerhoff, 2001). Traditional models generally consider the economy as exogenous – the economy drives the transportation task (traffic models, activity based models). In transport and the economy, transportation influences the economy (location models and general equilibrium models), or transportation of goods interacts with the economy (structural input-output models) (Van der Vooren 2004). Infrastructure providers and operators need to consider how the evolution of certain land-use activities and intensities, as well as sectoral economic performance, drives changes in freight growth.

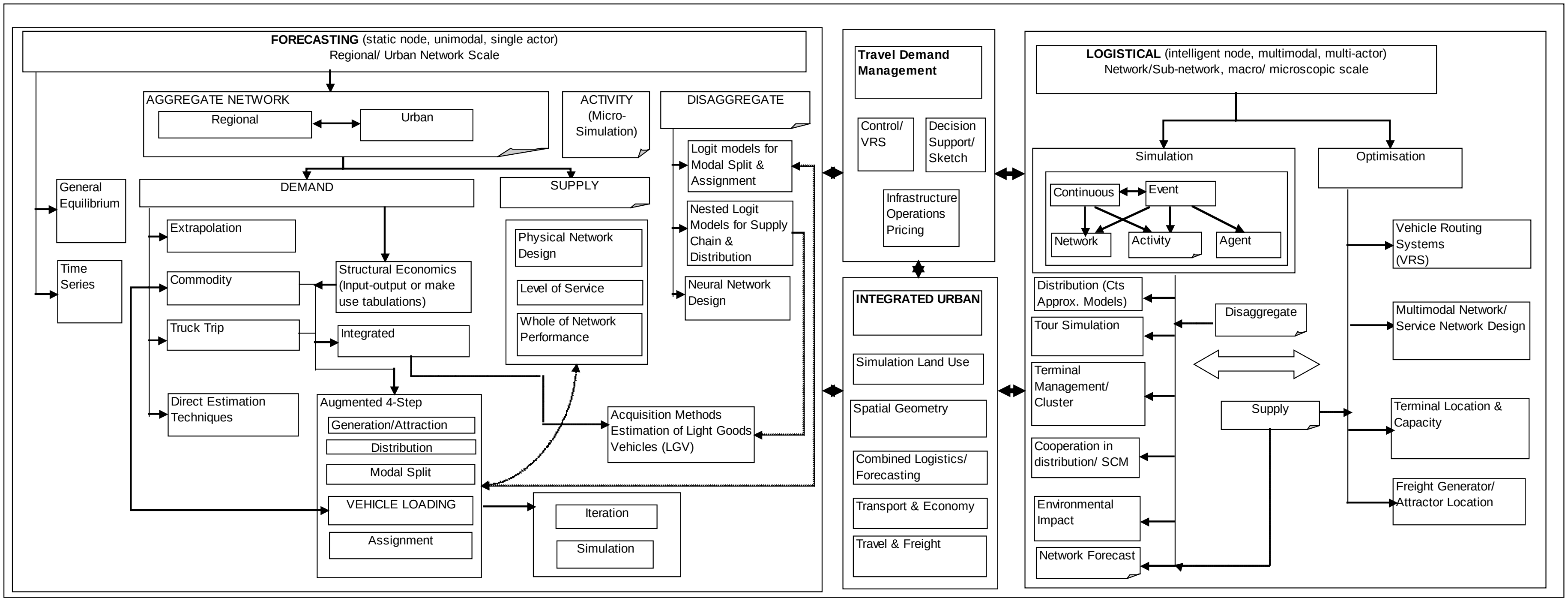

Figure 2: Freight Modeling Taxonomy

(The bibliographic classification and literature supporting this table are available at http://www.bbsu.unsw.edu.au)

Logistics models can be considered optimization and/or simulation approaches. Areas of modeling include Vehicle Routing and Scheduling, Service network design (terminal location and simulation (Crainic, 2000), Distribution models (Langevin *et al*., 1995) mobility demand and tour simulation (Russo *et al*., 2004). Models that attempt to abstract the reality of supply chain and distribution logistics are of great interest to infrastructure providers and operators as they depict assigned freight flows based on the demand generated by the transportation system, and not simply the demand for the commodity.

From this review of urban freight modeling, a number of gaps can be identified. Primarily, there are fewer modeling approaches for urban environments: they are often directed toward regional plans. System conflicts with passenger and freight, multi-modal (transshipment), multi-commodity models and land use activity generation models currently appear only theoretically and are not fully operationalized into models. Consequently, the taxonomy will not satisfy all information needs of planners.

The taxonomy presented in Figure 2 was created by considering both documented freight model types and urban (drayage) information needs derived from published strategic freight studies. The taxonomy is organized into root categories. We draw explicit linkages based on existing model frameworks. However, different linkages may be made for different functional specifications. Planners can see the spectrum of model types available in the context of their purpose. It requires further definition of planning needs, and, inevitably, knowledge of data availability, to select the model and modeling methods of value. Each set of information needs will assist in guiding the planner in tracing what modeling-by-purpose category is of value, and, within the category, the likely methods. Planners can also make connections between categories. It is envisaged that planners may combine a number of modeling approaches (crossing more than one category) toward an overall tailored functional specification. For instance, from general commodity forecasts in the region (forecasting), planners may wish to investigate the additional freight movements due to different distribution network infrastructure (logistics) and land-use activities (integrated urban) as well as behavioural response in the supply chain (Travel Demand Management). In the following illustration on the urban freight transportation issue of inter-modalism, we demonstrate how this taxonomy provides practical value.

5 INTER-MODALISM

5.1 Definitions

Inter-modalism is the transport process of transshipment between two or more modes or between different vehicle classifications in break-bulk sequences. The concept is usually associated with container transportation (Slack, 2001), but can also pertain to non-unitized domestic freight movements (Shih, 1999). Inter-modalism implies some form of flow synchronization of links adjacent to the terminal. However there is additional translocation delay and the network concept of impedance is transformed from links to transshipment nodes. The system of inter-modalism combines both demand matching and demand steering interests in that it can represent novel approaches to managing increased throughput of traffic without increasing physical capacity (Nijkamp *et al*., 1993).

Consequently, inter-modalism requires a strategic planning approach to succeed that involves cluster infrastructure and land-use planning.

For this case study we examine container rail-road inter-modalism. The practice of inter-modalism may be seen as redefining port nodes and landside networks and thus affecting the equilibrium of transportation. The port as a gateway node siphons transit and urban originating and destination freight. Seaport capacity then must also be measured in terms of its hinterland relationships and interacting infrastructure. The relationship between port related and local flows remains poorly understood in planning and design practice, yet port productivity is now recognized to encompass landside constraints (Kia *et al*. 2002; Marlow *et al*., 2004).

Global trade exerts pressures on the national freight landside condition. Servicing infrastructure and links in China are not sufficient to handle the variety of container throughput (Wang, 2002). Larger container types are inducing more transshipment operations in Southern California and further asymmetrical flow of empty containers (Le, 2004). This will necessitate greater interaction between freight infrastructure nodes. For Asian nations to maintain and develop their global trading links, inter-modal operations are integral to reducing landside impedance and improving hinterland reach (Armbruster, 2005). Australian seaport-landside linkages also need further integration and this must be negotiated through existing heavily built up urban areas.

5.2 Problem Definition for Sydney

The inter-modal problem in Sydney underlines the network and land-use concerns which infrastructure suppliers and operators should have. Port originating or destination freight has secondary and unconsolidated flows in the urban and regional hinterland that need to be estimated. Inter-modal terminals mediate these secondary and primary flows. Inter-modal terminals require sufficient capacity in both links and terminal nodes. They may need ancillary terminals where bundling can occur for sufficient flow densification. Complementary land-use activities need to be located which can build these flow densities. New infrastructure needs to leverage off existing networks. Inter-modalism represents a major structural change to the network and the increases in accessibility it brings may cause further (induced) growth in mobility.

An opportunity to define the desirable role of infrastructure suppliers/ operators can be seen with the constraints on inter-modalism in Sydney. A diagram of the Sydney freight network is portrayed in Figure 3. The majority of container freight is shipped through Botany Bay. Whilst there is a network of inter-modal terminals in greater Sydney (triangles), the use of most of them is constrained by congested rail space shared with passenger traffic. Only the planned terminals of Chullora and Enfield have a dedicated freight line with Botany terminal. An obstacle for through (transit) freight traffic is the incomplete ring road circling Sydney (the M7 orbital is under construction). There is currently no dedicated road freight corridor in Sydney. Eighty-five per cent of container traffic has an origin or destination within the greater metropolitan area (within a 40km radius) to or from Botany terminal (Mack, 2000). Sixty percent of this traffic is south of Sydney Harbour and the Parramatta River. Shaded areas represent origin and destination concentrations of containers. While not more than ten percent of total road freight movements (Brooker, pers. com.), they are of high value, they have significant localized diurnal loads and also create secondary and unconsolidated flows that connect with intra-urban movements.

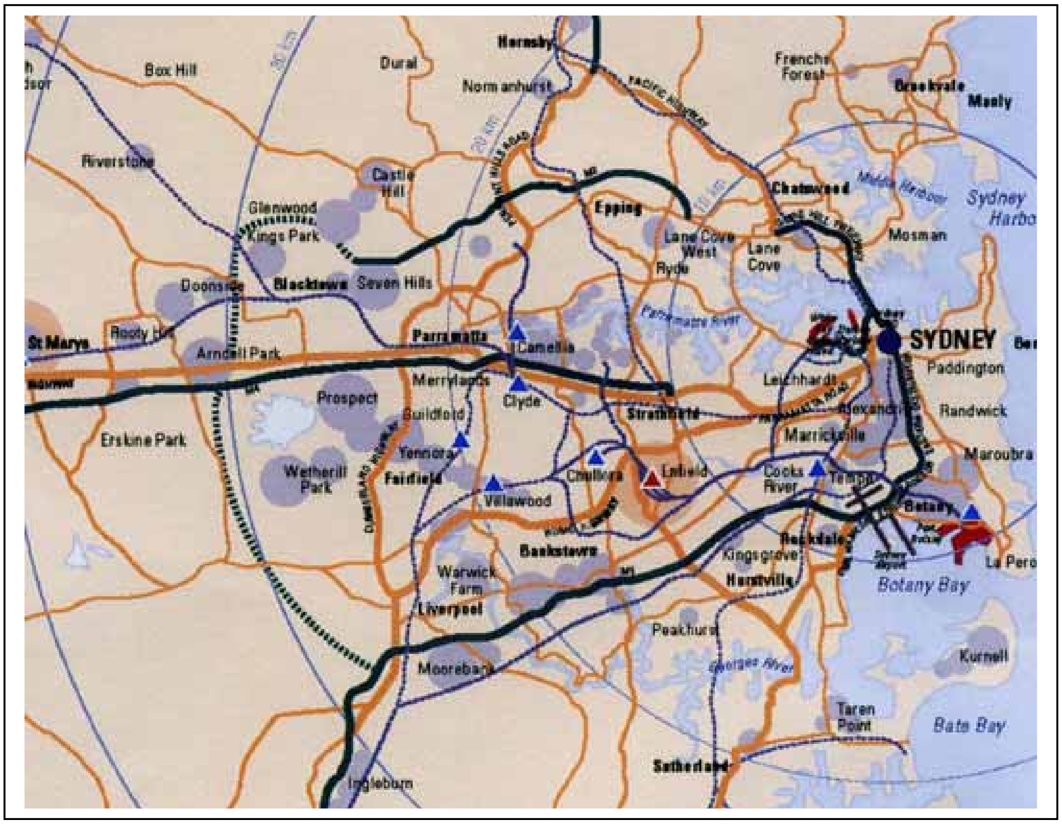

Figure 3: Freight Configuration for Sydney (Sydney Ports Corporation)

Rail share has since declined with container freight consolidation at Port Botany. Recently, as part of the planned expansion of Port Botany, The Port Authority has committed itself to an increased modal shift from short-haul road to rail from under 25% to 40% of tonnages. This modal shift is necessary to control the growth of freight road traffic to approximately 1.4 million TEU/yr (Port Botany will have a planned throughput of 3 million TEU/yr by 2016). New inter-modal terminals and expansion of existing terminals are key concerns in the metropolitan strategy being developed in 2005 (see, www.metrostrategy.dipnr.nsw.gov.au). Increasing the rail share to 40% of container tonnages should reduce growing road traffic by 20 million VKT/yr by 2021 (Brooker, pers. com.).

Inter-modalism is seen as relieving the landside constraints to port throughput growth. These landside constraints to transit flows have already led to shippers and receivers in the hinterland eschewing the Sydney port for the Ports of Brisbane in the north and Melbourne to the south (Sea Freight Council of NSW, 2004). Introducing inter-modalism on an existing congested network may be a means to relieve road transportation pressures. However, the land-use requirements and local impacts can be prohibitive. The NSW State Minister for Planning recently reduced the size and scale of a planned inter-modal terminal in Ingleburn, south Sydney, to one which will not be able to include container flows, despite claimed significant reduction in truck trips (Goodsir, 2004). The scale of the proposed Enfield terminal is being reconsidered since the Morris Inquiry rejected the proposal for a capacity of 500,000 TEU/yr due to perceived concentration in secondary container and other flows (Smith, pers. com.).

Additionally, there remains a poor understanding of the land-use drivers to freight growth when infrastructure development is considered. A report by the Rail Infrastructure Corporation nominated a number of terminals for development over the next 20 years (RIC, 2003). The report however stressed that land-use drivers were significant deciders on the future utilization of terminals, rather than selecting terminals on land availability and existing infrastructure only. Consolidation of flows in a network, as is discussed below, however, requires a detailed analysis of the transportation and land-use system, where intermediate *bundlepoints* may be identified, and the facilitating infrastructure determined.

5.3 Unpacking Information Needs in Developing Inter-modal Terminals

The information needs to develop inter-modalism may be summarized into three sections. These are: the physical and logical connections required; the means to engender desirable behavior; and the assessment of distributional impacts on existing networks and land-use activity. The NSW SFC (2004, p.6) further defines the financial sustainability criteria of these connections on the basis of considering terminals as places, entities, and elements in chains. In essence, terminals must have proximity to substantial and suitable volumes, and have access to road and rail infrastructure. Terminals must be fit for purpose of allowing frequent service by rail and vehicle inter-operability (physical access to different vehicle classifications). To be competitive, terminals must exist within efficient supply chains. Whereas measuring these mechanical connections is demanding enough, embedding inter-modal terminals within existing supply chain networks, so that such terminals may divert flows, is even more challenging.

A tailored strategic-tactical framework for deciphering inter-modal terminal problems for container transshipment in Sydney is presented in Figure 4. This may be seen as combining physical and service design elements (Crainic, 2000). We constructed this broad needs analysis from our review of inter-modal planning in Sydney and discussion with public and private stakeholders. Infrastructure suppliers need to link their information needs as suggested in Figure 4 in order to map modeling methods. It is evident from Figure 4 that no one tool can address the many pertinent strategic issues at play. Additionally, the strategic physical network is intertwined with the tactical service network, and functional approaches must address both design aspects concurrently. Tactical issues are guided by existing physical infrastructure. Aspects such as synchronisation and consistency (the complementary nature of vehicle movements) depend on physical accessibility. Possible indicators that can be derived from this framework might be demand matching as well as demand steering indicators.

Demand matching indicators pertain to provision of adequate system supply. Predicting land and sea freight growth, and assessing and planning for physical system capacity, are key tasks. Demand steering indicators enumerate travel demand management issues.

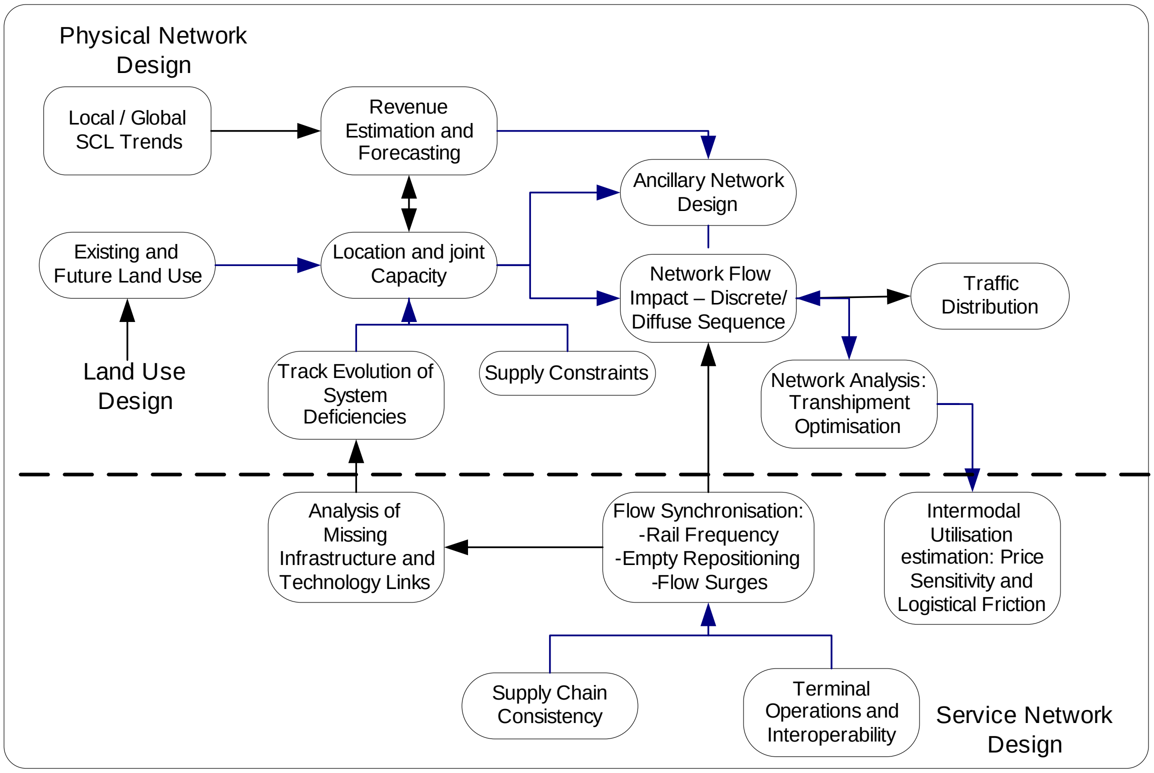

Figure 4: Interlinking Aspects of Transportation Infrastructure Planning for Analysis: Urban Inter-modal Terminal Illustration

These consider more service delivery concerns to improve distribution of freight impact and promote land-use activity to control freight growth. With this information requirement defined, we can proceed to develop a functional specification and use a multi-model template to address this coordinated requirement (section 5.4).

5.4 Mapping inter-modal information needs to mathematical models

Table 1 relates interests with relationships for analysis and modeling methods that acts as a template to coordinate a preliminary functional specification - a freight modeling typology tailored to infrastructure suppliers and operators. The modeling needs are identified from the conceptual model. These relationships are further developed, and suggested modeling methods are applied. The stakeholder links information (Figure 4), and modeling methods are sourced from the freight modeling taxonomy in Figure 2. Such a typology can be collated (Table 1). The typology demonstrates particular modeling attributes which cut across conventional model categories (Figure 2). This provides a sequential and comprehensive approach by mapping the information needs with modeling methods. This leads to an understanding of how infrastructure providers may appreciate, and become involved in, urban strategic freight planning with respect to inter-modalism, for instance.

Where available, references in Table 1 are given to actual modeling examples. This list is a comprehensive approach to coordinate studies and models to address systemic issues involved with inter-modalism. The interests are designated according to the information

Table 1: Inter-modal Planning Issues and Modeling Approaches

Interests	Modeling Relationships	Modeling Methods	Examples
Physical Network: Flow Forecasting (General/Regional)	General Consumer Demand/ GDP growth	Extrapolation (Quick Trip Estimation Tool); Spatial- Price Equilibrium	Cambridge Systematics (1996); Nagurney(2000)
Forecasting for Urban Area	Zonal specific growth; Growth from Supply Chain Logistics drivers	Regression model; Activity approach of distribution logistics linkages.	Black (1977); Boerkamps *et al*., (1999)
Forecasting infrastructure uptake	Likely use of infrastructure Domestic diversion potential (demand sustainability)	Conceptual diffusion model; Choice survey according to LOS parameters relate to origin-destination movements	Bontekoning (1999); Cutler(2000)
Network Impact and Flow Distribution	Secondary movements from primary movements	Continuous Approximation methods	Langevin *et al*., (1995)
System Integrity (Minimize fragmentation)	Anticipate supply chain logistics trends and resulting infrastructure needs of shippers/ carriers	GIS mapping of shipper reported mode sequences	Southworth(2000)
Ancillary Network: Technology Requirements for Inter-modalism	What architecture is required amongst multi-chain actors; Effects of combined ITS in system reconfiguration.	Simple Inter-modal Tracking and Tracing Solutions (SITS); Sketch scenario planning	Duerr *et al*., (2004); Argiolu (2004)
System Capacity Performance	Facility capacity, fleet capacity, costs in linked terminals	Optimization model	Morlok, *et al*.,(1999); Morlok *et al*., (2004)
Land Use Design	(Demand) Flow bundling capacity	Spatial clustering of urban logistics activities and businesses	Button (2001)
	(Demand) Storage location and capacity, trip tours, fleet size leads to optimum shipping strategies	Multi-criteria Optimization; Continuous Approximation Models	Schmeddling (2004); Langevin, *et al*., (1995)
Service Network: Trip/ Transshipment requirements	The optimum level of consolidation	Continuous Approximation methods	Langevin, *et al*., (1995)
Optimal Terminal Location in a Network	Accessibility assessment	Covering and centre models. Method to assess contribution to improved network access	Crainic *et a/*., (1997); Anderson *et al*., (1998)
	Circulation time assessment; Shipment/ Transshipment costs	Terminet Model; Nodus Model	Priemus *et al*., (2001)
	Impact on existing local linkages	Macroscopic performance modeling (Intanal/Scates)	Mack (2000) Yamada (2001)
Terminal operations	Stack configuration	Queuing models	Vis *et al.,(2003)*
System Consolidation Design (Frequency Service Network Design)	(Supply) Select routes for service to be offered and determine characteristics of service ie. frequency	Network service models	Crainic *et al*.,(1997)
Rolling Stock supply	Impact on repositioning empty flows	Dynamic Service Network; gravity model	Crainic *et al*., (1997)
System Supply Impacts and Constraints	Link- time windows (customer); system node-link congestion	Continuous Approximation Models; Augmented 4-step; Landside event modeling	Danganzo (1987); Pope (1995)
Traffic Distribution	Specify routing of each origin-destination pair; Identify services required and terminals of transit	Optimisation models; Tactical Vehicle Routing and Scheduling; Continuous Approximation Models	Crainic *et al*., (1997); Langevin, *et al*., (1995)
Performance: Financial Sustainability	(Demand) Propensity to use infrastructure	Value of Travel Time Savings and demand elasticities	De Jong (2000)
	(Supply) What are the cost components in the extended pricing network to service flows	Calculate opportunity costs of link-node conveyancing	Yan, Berstein *et al*., (1994)
Distribution effect of new infrastructure on network and economy	Changes in network time/ delay relationships;	Network models; Econometric structural models (Input-Output); Multipliers	Black (1991); Madsen, *et al*., (1996; 2004)

needs defined in Figure 4. The table has been informed by the taxonomy of inter-modal studies presented by Bontekoning *et al*.,(2004). The studies and models listed come from a wide range of cities and regions (mainly European and North American). Consequently, they may not be all applicable to other urban contexts. Stakeholders can develop modeling capacity directly, or learn from the insights of examples referred to here.

5.5 Enfield Illustration

There are a number of knowledge gaps in addressing the development of the Enfield terminal in inner western Sydney (Figure 3). There are issues of: appropriateness of location given existing network and hinterland land use; use of the inter-modal facility given impedance and service characteristics; necessary capacity and technology inter-operability; supporting link/node infrastructures; and fostering of necessary flow characteristics – that is, load unit densification road-side and frequency of rail service. The above discussion for Sydney has anticipated the need to investigate the possible trade-off in the conflicting objectives of concentrating flows to sustain inter-modalism, terminal optimum capacity, and minimizing flow concentrations that might otherwise lead to localized spatial disutility. Infrastructure planners need to develop an assessment of what are the discrete-diffuse freight transport sequences created by the specific inter-modal network envisaged, and their likely impacts.

Forecasting might consider current and potential industrial and commercial land use as well as current activity patterns according to supply chain logistics. Whilst it has been generally identified that the northwest and southwest of the city have the greatest land availability for industrial development (RIC, 2003), the desired mix of industrial development for consolidating freight flows has not been considered. Land-use forecasting can extend to intra-zonal intensity analysis. Bundlepoint optimization studies may consider the potential for flow densification of the product of cluster industries to particular warehouse and consolidation and distribution sites (Schmeddling *et al*., 2004). Clusters of inter-modal terminals can be considered in different patterns to reveal the traffic dispersion or concentration impact implications of infrastructure location and capacity. This then has clear implications on the carriageway infrastructure required to support traffic flows. Local impacts based on terminal location, using distribution modeling (Langevin *et al*., 1995) or regressors of container freight generation for specific industries, can indicate the zonal density of container traffic and assess the subsidiary traffic load from primary container flows.

The current logistical friction (cost) of local inter-modal freight drayage must be controlled and realistically assessed to determine operator profitability. In assessing the potential uptake of the Enfield inter-modal facility, an accurate assessment of impedance values and value of travel-time savings needs to be made. Total costs need to be assessed (link impedance, transshipment, handling) against competition costs. Conceptual diffusion models are valuable in identifying the logical and physical constraints to inter-modal uptake by service providers/ carriers (Bontekoning, 1999). Diversion studies (Cutler, 2000), may indicate the degree of modal shift achievable with new infrastructure.

Introducing inter-modal terminals in an urban environment may be considered a means of network retrofit. Ancillary systems, carriageways and communications must be assessed for deficiencies. There may be opportunities to leverage off existing infrastructure. With projected transshipment impedances and estimated inter-modal node visitations, iterative assignment modeling can be undertaken to assess effects over the network. The introduction of new infrastructure will be most successful if the operations improve freight flow synchronization as well as preserving reliability and reach of service.

6 CONCLUSION

We have provided a framework for infrastructure providers and suppliers to map their information needs to available modeling methods. The infrastructure supplier and operator are guided in how to consider assembling a modeling approach to their various concerns in a sequential manner. Listing the perceived problems, needs of, and solution for, infrastructure providers can be derived from a generic freight conceptual model and linked, as Figure 4 for the inter-modal investigation illustrates. These linked issues act as criteria to select models, depicted in Figure 2, for particular uses.

Modeling approaches were presented in the case study of inter-modalism (Table 1). The concerns bridging port and landside activity include: the effect of locating an inter-modal terminal on existing freight flows; the estimation of secondary flows from primary flows; the attractiveness of inter-modal flows and the potential to bundle existing flows given existing land-use activity; and the capacity supply limits of existing networks. Further research is needed to apply these models to the particular problem context.

Designing a functional specification for urban freight issues should not be seen as building one mega-model. Planning and modeling issues for urban inter-modal terminals are complex and need to rely on a range of modeling approaches to yield insights. This paper has illustrated such a coordinated planning and modeling technique.

Inter-modal solutions, undoubtedly desirable in relieving landside network load, may seem unsuitable for urban environments, particularly Asian mega cities with diffuse product origins in the hinterland and uncoordinated service networks (Cal, 2004). However, a strategic-tactical, demand steering approach to infrastructure provision will encompass an interest in land use and transportation planning which can alter flow characteristics and thus ration freight traffic flows. The capacity to link information needs using a suite of modeling methods is a move to equip infrastructure providers for strategic freight urban planning, and for them to become “admirable equilibrists” for the planning demands of the mega-urban environment. In Sydney, the role of inter-modalism as facilitating landside relief to the rapid growth of global container traffic is incompletely understood and only modeled in a highly segmented fashion. Facilitating this infrastructure system represents a major research and policy interest as it often necessitates the retrofit of certain existing elements of the urban network. It is hoped that this paper contributes to reconciling the investment return priorities of infrastructure suppliers and operators with a strategic approach to urban freight infrastructure.

ACKNOWLEDGEMENTS

We thank these colleagues for advice on the Sydney freight network and modeling: Dr. Tim Brooker, Kellogg Brown and Root; Mr. Kym Norley, Booz Allen and Hamilton; Mr. Denis Dillion and Mr. Morgan Noon, Sydney Ports Corporation; Mr. Oman Wijayaratna, Botany Bay Council; Ms Lita Mendigorin, NSW Department of Infrastructure, Planning and Natural Resources; and Dr. Russell Thompson, University of Melbourne.

REFERENCES

Black, J. (1999) Transport services in P.Troy (ed.) **Servicing the City**. Allen & Unwin, Sydney.

Cartwright, K., L. Cottrill, H. Hamick, M.Leue, L.Nye (2003) Ports of Long Beach and Los Angeles Transportation Study. **Transportation Research Record, No. 1820**, 26-35

Donnelly, R. (2004) Integrated Freight Models. **Presentation at International Workshop on Planning Urban and Multi-Modal Freight and Logistics Systems**. University of Melbourne 26th August 2004

Fuller, T. (2003) Panel Issues: Urban Freight Data Processes **Urban Transport Demand Modelling and Urban Freight Forecasting and Analysis Workshop**. Austroads, September 2003

Giannopoulos, G.A. (2002) Integrating freight transportation with intelligent transportation systems: Some European issues and priorities. **Transportation Research Record No. 1617**, 50-55

Hensher, D. and Golob, T. 1999. Searching for policy priorities in the formulation of a freight transport strategy: A canonical correlation analysis of freight industry attitudes. **Transportation Research Part E**, **No. 35**, 241-267.

Kanafani, A., Sperling, D. (1982) **National Transportation Planning** Developments in Transport Studies 3. Martinus Nijhoff. The Hague.

Munoz- Loustaunau, A., Sussman, J.M. (1999) Scenarios and regional strategic transportation planning. **Transportation Research Record No. 1685**, 90-98

Nijkamp,P. and Reichman (1987) **Transportation Planning in a Changing World**. European Science Foundation.

O'Sullivan, P.J., Patel, T. (2003) Fragmentation in transport operations and the case for system integrity. **Transport Policy Vol. 11**, 215-225

Rimmer, P.J., Black, J.A. (1981) Urban goods and commercial vehicle movements in Sydney: A research framework. **Australian Road Research No.11**, 15-29

Rimmer, P.J. , Black, J.A. (1982) Land use transport changes and global restructuring in Sydney since the 1970's: The container issue. **Why Cities Change**. R. Cardew, J.Langdale, and D. Rich (eds.) Geographical Society of New South Wales. Allen and Unwin, Sydney.

Roson, R., Soriani, S. (2000) **Intermodality and the Changing Role of Nodes in Transport Networks**. Fondazione Eni Enrico Mattei.

Shaw, J., Walton,W., Farington,J (2003) Assessing the potential for a rail renaissance in Great Britain. **Geoforum Vol. 34**, 141-156

TAO (1997) Review of The Eastern Distributor. The Audit Office of New South Wales. Sydney, Australia

Woxenius, J. (1998) Development of Small-Scale Intermodal Freight Transportation in a Systems Context PhD Thesis Department of Transportation and Logistics, Chalmers University of Technology, Goeteborg, Sweden.

Zografos, K., Giannouli, I. (2001) Emerging trends in logistics and their impact on freight transportation systems **Transportation Research Record No. 1790**, 26-44

References for freight modeling and inter-modalism are available at http://www.bbsu.unsw.edu.au