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NATIONAL AND INTERNATIONAL FREIGHT TRANSPORT MODELS: OVERVIEW AND IDEAS FOR FUTURE DEVELOPMENT

Gerard de Jong
Hugh Gunn
Warren Walker
RAND Europe
Newtonweg 1
2333 CP Leiden
The Netherlands[1]

Abstract

This paper contains a review of the literature on freight transport models, focussing on the types of models that have been developed since the nineties for forecasting, policy simulation and project evaluation at the national and international level. Models for production, attraction, distribution, modal split and assignment are discussed in the paper. Furthermore, the paper also includes a number of ideas for future development, especially for the regional and urban components within national freight transport models.

1. INTRODUCTION

In a number of European countries, national model systems have been developed that can be used for forecasting future freight transport volumes and/or vehicle flows. This paper contains an overview and comparison of a number of such systems, including:

- The Swedish national freight model system (SAMGODS);
- The Norwegian national freight model system (NEMO). Both SAMGODS and NEMO use the STAN software for multi-modal assignment;
- The Walloon region freight model system in Belgium (WFTM), which uses the NODUS multi-modal assignment software;
- The Italian national model system, which for freight uses input-output models and disaggregate mode choice models;
- The Dutch models TEM (Transport Economics Model) and SMILE (Strategic Model for Integrated Logistic Evaluation). The former uses input-output methods, the latter has make-use tables and a logistic module for the location of distribution centres;
- Models used in the UK for national freight transport forecasts (e.g. based on the STEMM, Strategic European Multi-modal Modelling, project).

Furthermore, a number of international model systems are reviewed:

- The SCENES (Scenarios for European transport) and NEAC models for Europe;

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- Models for specific international corridors (e.g. fixed link projects in Scandinavia, Alpine crossings).

The material for these comparisons has been collected in the course of model review projects for the European Commission, in Sweden and the UK (EXPEDITE, 2000; RAND Europe and Transek, 2001; RAND Europe et al., 2002). The main differences between this review and existing reviews (e.g. in Hensher and Button, 2000 and Hensher, 2001) are that this review contains many models that have not been published in the academic literature (but are used in practice) and that the focus is on Europe, not on North America.

The second part of the paper focuses on ideas for future development of freight transport models that should increase the accuracy of the forecasts and the range of policy applications of the models. We recommend that two different types of models be developed:
- A fast policy analysis model, for initial screening and comparison of policy alternatives;
- A detailed network-based forecasting model, for predictions at the network level and to provide inputs for project evaluation.

2. REVIEW OF MODELS

Recent reviews of various types of freight transport models can be found in Cambridge Systematics (1997), Chapters 32-34 (by Friesz, D'Este and De Jong respectively) in the handbook edited by Hensher and Button (2000), EXPEDITE (2000), Pendyala et al. (2000), the chapters by Regan and Garrido and by Shankar and Pendyala in the book on travel behaviour reserach edited by Hensher (2001), and in Willumsen (2001). As part of the SPOTLIGHTS project for DGTREN of the European Commission, a European Model Directory (MDir) has been established, which contains information on 222 transport models in Europe (some double counting has occurred). Sixty-five of those models are freight transport models and 29 are joint passenger and freight transport models (Burgess, 2001; SPOTLIGHTS, 2002). Older reviews, some of which are still quoted regularly, are Gray (1982), Winston (1983), Harker (1985), Zlatoper and Austrian (1989), RTC/HCG/SDG (1991), Oum, Waters and Yong (1992) and Ortuzar and Willumsen (1994, especially Chapter 13). The current review takes into account these existing reviews, but also some additional literature.

2.1 Four steps

Many modelling concepts applied in freight transport forecasting have originally been developed for passenger transport. Most authors (e.g. Shankar and Pendyala, D'Este) seem to agree that the four-step transport modelling structure from passenger transport can fruitfully be applied to freight transport as well. However within each of the four steps the freight models can be very different from those in passenger transport. Important differences between the freight and passenger transport markets are the diversity of decision-makers in freight (shippers, carriers, intermediaries, drivers, operators), the diversity of the items being transported (from parcel deliveries with many stops to single bulk shipments of hundred thousands of tonnes) and the limited availability of data (especially disaggregate data, partly due to confidentiality reasons).

The four steps in the context of a freight transport model system are:

- Production and attraction. In this step, the quantities of goods to be transported from the various origin zones and the quantities to be transported to the various destination zones is determined (the marginals of the origin-destination, OD, matrix). The output dimension is tonnes of goods. In intermediate stages of the production and attraction models, the dimension could be monetary units (trade flows).

- Distribution. In this step, the flows in goods transport between origins and destinations (cells of the OD matrix) are determined. The dimension is tonnes.

- Modal split. In this step, the allocation of the commodity flows to modes (e.g. road, train, combined transport, inland waterways) is determined.

- Assignment. After converting the flows in tonnes to vehicle-units, they can be assigned to networks (in some models this is about assigning truck flows together with passenger cars to road networks).

Besides these four steps, a number of transformation modules are usually required within a comprehensive freight transport model system. Such transformations could involve converting trade flows in money units into physical flows in tonnes to determine production and attraction. This can be done by using value/weight ratios for different commodity groups. The ratios used here may have a large impact on the final predictions and therefore it is important to assemble good data on the conversions and if possible to make it an endogenous, policy sensitive choice within the model system. Another transformation module is that for going from flows in tonnes to vehicle units, such as heavy goods vehicles (HGV's), as might happen between mode choice and assignment. Actually, this is influenced by a great number of decisions on shipment frequency, shipment size, return loads and vehicle utilisation rates. These decisions could be modelled explicitly in additional logistic modules (e.g. in the SMILE model, see Tavasszy et al., 1998), but often fixed conversion rates are used here as well. Another type of transformation module is a regionalisation module to go from a coarse to a fine zoning system.

In the remainder of this section on the review of international experience, we shall discuss the types of models developed for each of the four steps and give examples of each of the types. For reasons of space, we shall not describe specific model systems one by one, but limit ourselves to a discussion by type of model. Models integrating several steps (e.g. production, attraction and distribution, or modal split and assignment) will be discussed as well. Models including additional choices (e.g. shipment size, location of distribution centres) will also be included. The focus will be on models at the national level, but models for international and urban flows will be included as well. Models for short-term operational decisions for operators are not covered.

2.2 Models for production and attraction

Within this first step we can distinguish four types of models that have been applied in practice:

- Trend and time series models;
- System dynamics models;
- Zonal trip rate models;
- Input-output and related models.

All these models are based on aggregate data. We have not found examples of production and attraction models in freight transport that are estimated on disaggregate data.

In trend models historical trends are extrapolated into the future. Time series data have been used to develop models of various degrees of sophistication, ranging from simple growth factor models to complex auto-regressive moving average models (e.g. Garrido, 2000). The latter model uses information only on truck flows and is meant for short-term forecasting. Time series models with explanatory variables, such as gross domestic product, GDP, have been developed as well.

In the ASTRA (Assessment of Transport Strategies) system dynamics model (developed in a project for the European Commission), the changes in the transported quantities over time and feedbacks to/from the economy, land use and the environment are modelled explicitly (ASTRA, 2000). In the macro-economic module of ASTRA, growth of GDP is predicted. The results are fed into the regional economics module, which yields freight demand in terms of flows in tonnes by OD pair. In the transport submodel this is assigned to modes and virtual links. Changes in transport demand in turn may affect GDP, through the transport cost. The parameters of a system dynamics model system are usually not obtained from statistical estimation, but from existing literature and by trying initial values and checking the resulting dynamic behaviour of the system (trial and error). A system dynamics model might include the distribution and modal split steps as well. System dynamics models, however, usually do not contain sufficient spatial and network detail to yield zone-to-zone flows and link loadings.

Zonal trip rates for production and attraction are usually derived from classifying cross-sectional data on transport volumes to/from each zone in the area under investigation (or another similar area) into a number of homogeneous zone types. Examples of such rates can be found in the Quick Response Freight Forecasting Manual (Cambridge Systematics et al., 1997) and in the Guidebook on Statewide Travel Forecasting (FHWA, 1999). The Quick Response Freight Forecasting Manual for instance contains trip rates for various types of road vehicles and classified by industry, for zonal production and attraction, to be used in urban regions throughout the United States. The approach in this manual is uni-modal (road transport only).

Input–output models are basically macro-economic models that start from input-output tables. These are tables that describe, in money units, what each sector of the economy (e.g. textile manufacturing) delivers to the other sectors, also including the final demand by consumers, import and export. National input-output tables have been developed for many countries, usually by a central statistical office. A special form of input-output table, which for many countries does not exist, is a multi-regional or spatial input-output table. This not only includes deliveries between sectors, but also between regions (trade flows). Most multi-regional input-output tables distinguish only a few, large regions within a country. The input-output model assumes that for forecasting, the multi-regional input-output table can be scaled up on the basis of predicted sectoral growth. The new input-output table can then give the future trade flows between regions, using either:

- Fixed technical and trade coefficients: the present production and trade patterns are extrapolated into the future.

- Elastic technical and trade coefficients: functions are estimated (e.g. multinomial logit) in which the fraction that is consumed in region i of the production of sector s in region j depends on the total production of region j in sector s and the (generalised) transport cost, in relation to other regions. This makes generation and distribution sensitive to changes in transport cost and time (a form of induced demand).

Examples of multi-regional input-output models in freight transport are:

- The Italian national model system for passengers and freight (Cascetta, 1997), which uses 17 sectors and 20 regions and also has elastic coefficients.

- The REGARD model for Norway, with 28 sectors, which produces demand used in the Norwegian freight model NEMO (see EXPEDITE, 2000).

- The model for Belgium developed by ADE with 17 sectors, which produces demand used in the Walloon Region freight model WFTM (Geerts and Jourquin, 2000).

- The SCENES European model system for passengers and freight and its predecessor STREAMS, Strategic Transport Research for European Member States (Leitham et al, 1999), with 33 sectors and more than 200 zones in Europe and elastic coefficients (SCENES Consortium, 2001).

The Dutch model TEM-II (see Tavasszy, 1994) and the present Swedish model system SAMGODS use a multi-sectoral input-output table for the country as a whole (not multi-regional), which is transformed from money units into tonnes and is regionalised (e.g. on the basis of regional shares in employment and population). The Dutch SMILE model (Tavasszy et al., 1998) does not use input-output tables but uses related 'make and use' tables with production and consumption by sector (using 222 sectors). The 'make' table has commodities in the rows and production sectors (and imports) in the columns. The cells give the production (in money units) of each sector. The 'use' table also has commodities in the rows, and in the columns are the sectors using the commodities (intermediate use), together with final consumption, investment and export. The cells here give the consumption of the commodities, again measured in money units. As in TEM-II, the analysis takes place at the national level, and is regionalised later.

The multi-regional input-output models and the related multi-sectoral economic models used in this first step, can be regarded as computable general equilibrium (CGE) models, establishing equilibrium in several related markets. CGE models in economics (not focussing on transport) often include economic issues that are not handled in transport models, such as type of competition and economies of scale. Spatial CGE models (e.g. Bröcker, 1998) have been developed recently, that might become operational models for (inter)national and regional forecasting and evaluation, but there is still a long way to go (Tavasszy et al., 2002). Just as system dynamics models, input-output and spatial CGE models can be used to give transport – land use interactions. However, unlike the spatial CGE models, the existing input-output models listed above (Italy, Norway, Belgium, SCENES), do not include such interactions. These models have a one-way dependency: the spatial distribution influences transport. A feedback to land use (e.g. in the form of a logsum variable, which gives the expected utility from the choices in the transport model) is possible in theory, but it would add considerably to model complexity and run times.

A model type that has not been applied in practice is that based on the 'new trade theory' (Markusen and Venables, 1998), in which a multi-national plant is studied that chooses the number and location of plants. National and international commodity flows then result from such location decisions. Table 1 summarises the advantages and disadvantages of the four types of models that can be used in step 1.

Table 1. Summary of freight transport production and attraction models

Type of model	Advantages	Disadvantages
Time series	Limited data requirements (but for many years)	Little insight into causality and, limited scope for policy effects
System dynamics	Limited data requirements Can give land use interactions External and policy effects variables can be included	No statistical tests on parameter values
Trip rates	Limited data requirements (zonal data)	Little insight into causality and limited scope for policy effects
Input-output	Link to the economy Can give land use interactions Policy effects if elastic coefficients	Need input-output table, Preferably multi-regional Restrictive assumptions if fixed coefficients Need conversion from values to tonnes Need to identify import and export trade flows

2.3 Models for distribution

As in the previous step, all freight distribution models found in the literature are based on aggregate data. In the distribution module of a freight transport system, the trade flows (in tonnes) between origin zones and destination zones are determined based on measures of production and attraction (usually the outcomes of the step described above) and a measure of transport resistance. The latter is expressed as transport cost or generalised transport cost. The most commonly used method is the gravity model. In such models the flow between zone i and zone j is a function of the product of production and attraction measures of zone i and zone j respectively divided by a some measure of the (generalised) transport cost. Gravity models for distribution in freight are included in:

- The Dutch TEM-II model (see Tavasszy, 1994);
- The Dutch SMILE model (Tavasszy et al., 1998);
- The Great Belt traffic model (Fosgerau, 1996);
- The Finnish study on different distribution model types (Iikkanen et al., 1993).

In the Italian national model, the freight OD flows follow from a multi-regional input-output analysis with elastic coefficients (after transformation from money units into tonnes and after regionalisation). In other words, a multi-regional input-output model can supply both production/attraction and distribution. A similar method was used in STREAMS and SCENES. The European freight transport model NEAC (see Chen and Tardieu, 2000) also models distribution simultaneously with production and attraction on the basis of value added per sector and transport cost in a gravity-type model. The Fehmarn Belt freight transport model uses a gravity model for the joint determination of attraction and distribution as well (Fehmarn Belt Traffic Consortium, 1998). Table 2 summarises the advantages and disadvantages of the gravity and input-output models for step 2.

Table 2. Summary of freight transport distribution models

Type of model	Advantages	Disadvantages
Gravity	Limited data requirements Some policy effects through transport cost function	Limited scope for including explanatory factors and policy effects Limited number of calibration parameters
Input-output	Link to the economy Can give land use Interactions Policy effects if elastic coefficients	Need input-output table, preferably multi-regional Restrictive assumptions if fixed coefficients Need conversion from values to tonnes

2.4 Models for modal split

For modal split for freight, both aggregate and disaggregate (including stated preference, SP) models can be found in the literature. The following models for modal split are distinguished:

- Elasticity-based models;
- Aggregate modal split models;
- Neoclassical economic models;
- Econometric direct demand models;
- Disaggregate modal split models (including inventory-based models and models on SP data);
- Micro-simulation approach;
- Multi-modal network models.

Elasticity-based models reflect the effects of changing a single variable (e.g. the cost of some mode). The elasticities are derived from other models or expert knowledge. Such models are mostly used for strategic evaluations and/or for a quick first approximation (followed by more detailed analysis using other model forms) or in situations where data are very scarce. Examples in freight transport are the PACE-FORWARD model (Carrillo, 1996) for The Netherlands and the EXPEDITE (EXpert-system based PrEdictions of Demand for Internal Transport in Europe) meta-model for freight transport (EXPEDITE, 2002).

Aggregate modal split models are mostly binomial or multinomial logit models estimated on data on the shares of different modes for a number of zones. They are meant to give the market share of a mode, not the absolute amount of transport (tonnes) or traffic (vehicles) as the direct demand models do. Consequently the elasticities from such models are conditional elasticities (conditional on the quantity demanded; see Beuthe et al., 2001). The aggregate modal split model can be based on the theory of individual utility maximisation, but only under very restrictive assumptions. A disadvantage of using the multinomial form is that the cross elasticities are equal. Examples are Blauwens and van de Voorde (1988) for inland waterways versus road transport and the modal split model within NEAC.

Neoclassical models start from the economic theory of the firm. For a cost function, with transport services as one of the inputs, a demand function for transport can be derived using Shephard's Lemma. Examples of estimations of such transport demand functions can be found in Friedlaender and Spady (1980) and Oum (1989). The explanatory variable here is the budget share of some mode in the total cost. This makes it hard to combine these models in a larger (four-step) transport model system, because here the share in the transport volume is the relevant variable.

In a direct demand model, the number of trips (or kilometres) by some mode is predicted directly (unlike the market share forms discussed above, which are conditional on an external prediction of total demand over all modes). A classic example is the abstract mode model by Quandt and Baumol (1966). This model is also hard to incorporate in the four-step framework.

Disaggregate modal split models use data from surveys of shippers, commodity surveys and/or stated preference surveys. Most of these models are multinomial logit (MNL) or nested logit (NL), which for disaggregate observations can be based on random utility maximisation theory under quite general assumptions. The decision-maker here is the firm (e.g. the shipping firm). The indirect utility functions, that are used in modelling passenger transport, can be reformulated in this context as profit functions (the difference between revenues and the cost function). The underlying theory then becomes one of 'random profit maximisation' consistent with the micro-economic theory of the firm. The property of identical cross elasticities found in aggregate modal split models applies in disaggregate MNL models as well, but not in NL. The current proliferation of logit-based functional forms in passenger transport modelling and elsewhere (e.g. error components or mixed logit, see McFadden and Train, 2000) has not had much effect in freight transport modelling yet. Most disaggregate freight models deal with mode choice only. Examples are:

- Winston (1981): A probit model for the choice between road and rail transport by commodity group in the US;
- Jiang et al. (1999): a nested logit model on the French 1988 shippers survey;
- Nuzzolo and Russo (1995): the mode choice model for the Italian national model;
- Fosgerau (1996): a mode choice model on revealed and stated preference data;
- Reynaud and Jiang (2000): EUFRANET (European Freight Railway Network): a European freight model focussing on operating systems for rail developed for the European Commission with a mode choice model on revealed and stated preference data;

- FTC (1998): a mode choice model on revealed and stated preference data;
- De Jong et al. (2001): a mode choice model on revealed and stated preference data for the north of France, developed for the French Ministry of Transport.

Furthermore there are several models on stated preference data only, but these are not developed for transport forecasting, but for providing value of time measures (reviewed in Chapter 34 of Hensher and Button, 2000). Such models can also include reliability and other qualitative variables.

Some other disaggregate freight transport models simultaneously deal with mode choice and logistic choices (inventory-based models). Disaggregate models in which the mode choice decision is embedded in a larger inventory-theoretic and logistic framework include:

- Chiang et al. (1981) for location of supplier, shipment size and mode choice;
- McFadden et al. (1985) for shipment size and mode choice;
- Abdelwahab and Sargious (1992) and Adelwahab (1998) for mode choice and shipment size (this is a joint discrete-continuous model estimated on the U.S. Commodity Transportation Survey);
- Blauwens et al (2001) for mode choice based on total logistic cost (also including handling and inventory cost).

In the US, a prototype freight transport model has been developed for the Portland region, with an upper level model that produces zone-to-zone flows in money terms (an input–output model) and a lower level model that estimates urban vehicle trip patterns starting from the outputs of the upper level model (Neffendorf, et al., 2001). The lower level model is called a micro-simulation model. This is a tour and trip level model for freight transport by lorry. It includes conversion to shipments, allocation to individual organisations, assignments of transhipment points, allocation to carrier type and vehicle type, generation of tours to get sufficient vehicle loads and conversion of tours to trips for assignment. Many of these steps are carried out by Monte Carlo simulation, but observed data on distributions are used, if available. A similar two-level system has been proposed (Neffendorf et al., 2001) for London, with the upper level model being based on the existing input-output models LASER (London and South East Region) and EUNET (for the Trans-Pennine corridor in the UK).

Multi-modal network models simultaneously predict mode and route choice (assignment). Many route-mode combinations through a network can be chosen for a specific OD combination and a cost minimisation algorithm is used to find the optimal combination (in most cases all traffic for an OD pair is assigned to this optimal alternative: all or nothing assignment). Multi-modal network modelling provides a way to handle transport chains in which several modes are used to ship a consigment from door to door (e.g. lorry first to the port, then short sea shipping, then rail transport and finally lorry delivery to the destination). Assignment to such combinations of modes in a transport chain can take place if the network not only includes links for each mode, but also ports and terminals for transshipment (between modes). The cost function can contain several attributes, including transport time components and terminal cost. It should be noted that all of these are aggregate models, in the sense that the unit of observation is not the individual firm, but an OD combination.

One of the commercial software packages for multi-modal network assignment is the STAN package (Crainic et al., 1990), which has been used in freight transport models in Norway (NEMO), Sweden (the current SAMGODS), Canada and Finland. The WFTM freight model for the Walloon Region uses a similar multimodal network assignment, but this is implemented in the NODUS software (Geerts and Jourguin, 2000; Beuthe et al., 2001). The selection of the optimal mode-route combination is done separately for different commodity groups, because different goods will have different handling requirements and values of time, and therefore the coefficients in the cost functions (e.g. for transshipment costs and time costs) will differ between these goods.

In the models STREAMS, SCENES and SMILE a multi-modal network assignment takes place as well (mode and route choice simultaneously). This is also the case for the European STEMM freight model. The Great Britain Freight Model (GBFM) uses the same methodology as STEMM (Newton, 2001). Sustantial network modelling has also been carried out in the CODE-TEN project (CODE-TEN consortium, 1999), for the assessment of corridors in the context of the Trans-European Networks (TEN). In SMILE and in the Appended Module of SCENES, mode-route combinations can be formed using distribution centres whose locations are specified endogenously. The non-road modes compete mostly on the long-haul market between the distribution centres and not so much on trips for goods transport to centres and goods distribution from centres. The SMILE model handles this by inclusion of two submodels that are usually not included in freight transport models: a model that predicts whether there will be inventories (stored at a distribution centre) for some commodity and a model that predicts the location of the distribution centres. The former choice depends on the possibilities to cluster goods flows from an origin to multiple destinations, and the location of distribution centres depends on attributes of the OD relation and the regions (e.g. land rents, wages, accessible destinations).

Table 3. Summary of freight transport modal split models

Type of model	Advantages	Disadvantages
Elasticity-based	Very limited data requirements Fast in application	Elasticities may not be transferable Only impact of single measures, no synergies
Aggregate mode split	Limited data requirements	Weak theoretical basis Little insight into causality Limited scope for policy effects
Neoclassical	Limited data requirements Theoretical basis	Hard to integrate in four-steps model
Direct demand	Limited data requirements	Hard to integrate in four-steps Model
Disaggregate mode split	Theoretical basis Potential to include many causal variables and policy measures	Need disaggregate data (shipper or commodity survey and/or SP)
Micro-simulation approach	Many behavioural choices Included links to theory	Either large data requirements or many assumptions on distributions
Multi-modal network	Limited data requirements Theoretical basis Can include elastic demand and policies affecting generalised transport cost.	Little insight into causality Mostly done with fixed demand

Another commercial multi-modal freight network model is FNEM (Freight Network Equilibrium Model), developed by the George Mason University for the US Department of Energy and the CIA (Friesz, 1985). FNEM is a non-linear mathematical programming model and does not need statistical estimation of parameters, but the predictions can be validated against observations. It encompasses STAN in that it includes a game-theoretic model (see Friesz et al., 1985) with interactions between shippers and carriers (STAN focusses on carriers). Furthermore, it has the possibility of elastic demand, making it a simultaneous equilibrium model for all four steps of the transport model. Details about the most advanced versions of FNEM are classified. Table 3 summarises the advantages and disadvantages of the six types of models that are used for step 3.

2.5 Models for assignment

In the assignment step, truck, rail or inland waterway transport trips are allocated to routes consisting of links of the respective modal networks. A number of freight models do not include the assignment step; most other models include only assignment for trucks. Assignment to the road network is in some cases done jointly with passenger traffic, since freight traffic usually is only a small fraction of total traffic (except near major freight terminals). For instance, OD matrices for trucks from the freight model TEM-II are joined with road passenger traffic in the Dutch National Model System (LMS) and passenger and freight trips are assigned jointly. In order to do this, the freight vehicle trips have to be converted into passenger car equivalents (PCEs), since a truck uses more road capacity than a passenger car. Another example of a separate assignment step (instead of a joint mode and route choice in a multi-modal network, as described in step 3 above) is the Italian National model, where mode choice takes place at a disaggregate level and assignment at the OD level. Table 4 summarises the advantages and disadvantages of having a separate assignment stage compared to combining the last two steps.

Table 4. Summary of assignment models in freight transport model systems

Type of model	Advantages	Disadvantages
Separate assignment stage	Mode choice model can be disaggregate Allows interaction with passenger trips if freight and passenger trips are assigned together	Absence of interaction between demand and assignment can be unrealistic; this can only be done iteratively Transport chains are difficult, but not impossible, to incorporate
Multi-modal network	Substitution takes place between mode-route combinations Chains with different modes on a route can be handled	Little scope for controlling the optimisation process (for some OD the cost minimisation can lead to unrealistic mode-route solutions, because of omitted factors)

2.6 Forecasting models in a broader context

The review so far has concentrated on freight transport forecasting models. In many countries and regions, these forecasting models, are part of a larger system for simulating policy measures and estimating the impact of policy options through the freight transport system on a variety of performance measures (including emissions, safety, congestion, economic impacts, and noise). Indeed, in most cases this has been the objective for the development of the freight transport forecasting model. An example of this is the PACE-FORWARD model (see Carrillo, 1996) for Dutch freight transport, which enabled the assessment of policy options for several economic scenarios extending to the year 2015. Nearly 200 tactics that might be combined into various strategies for improving freight transport were identified and evaluated. Recommendations were drawn from a ranking of tactics based on their cost-effectiveness.

2.7 Use of the models in practice

In Table 5 is an overview of applications that have been carried out in practice with the European models discussed above. The national models mentioned earlier have been used for similar simulations: for baseline forecasts, policy simulations and project evaluation.

Table 5. Overview of applications with European freight models

Project reference	Freight transport model used	Years simulated	Scenarios/policies studied for future years
Strategic Environmental Assessement (MEP et al., 2000)	STREAMS	1994 2010 2020	Reference scenario Common Transport Policy scenario Transeuropean networks (TEN-T) scenario Rail only TEN-T scenario
Forecast 2020 (NEA, 2000)	NEAC	1995 2000 2010 2020	Reference scenario Rapid integration scenario Sustainable policy scenario
ASTRA (ASTRA, 2000)	ASTRA system dynamics model	2000-2026	Improving safety and emissions package Increased fuel tax and reduction of labour cost package Balanced fuel tax and reduction of labour cost package Fuel taxation and investments in networks package Integrated policy programme
SCENES (SCENES, 2001)	SCENES model	1995 2020	External scenario plus four transport cost scenarios (constant cost, basic, observed trend and radical)
EXPEDITE (EXPEDITE, 2002)	EXPEDITE meta model	1995 2005 2010 2015 2020	Reference scenario and variants of this for 15 policy measures in freight transport

The EXPEDITE meta-model in Table 5 above is based on SCENES and NEAC forecasts and elasticities from SCENES and five national models (EXPEDITE, 2002). All models in Table 5 have been applied, in project for the European Commission, for the year 2020, and for most a base year validation (1994/1995) has been carried out. Other validation evidence is rather scarce. The STREAMS model has been used for backcasting 1975, with reasonable success. Predictions from the STREAMS model and the NEAC model for the base-year and 2020 have been compared as part of the SCENES project. For domestic transport (aggregated over modes) there was a close correspondence, but there were large differences in international trade and in the modal split. At the moment, within the THINK-UP project, results from the SCENES model are compared with outcomes from NEAC.

3. IDEAS FOR FUTURE DEVELOPMENT

3.1 Basic ideas behind the suggested approach

For future development of national and international freight transport models we recommend building an integrated family of mutually consistent models at two different levels of resolution: (1) a detailed (high-resolution) set of models, and (2) a fast (low-resolution) policy analysis model.

There are several reasons for building such a family of models. These include:

- Information needs: There will be many types of users for the models, who will be trying to answer different types of questions and to obtain different types of information.
- Cognitive needs: Humans reason at different levels of detail and therefore require information at different levels of detail.
- Economy: It is sometimes necessary to use a low-resolution model, because high-resolution comes with a cost.
- Accuracy: When decisions have costly consequences, decisionmakers are likely to value predictions free of bias and forecasts with low mean square error. Moreover, the decisionmakers will often want detailed information in such situations.

The family of several models should satisfy the principle of Occam's razor: each model is the simplest model for the desired purpose, but not simpler.

3.2 The proposed model structure

Figure 1 below gives an overview of the proposed model structure. The number over a box refers to the subsection below in which the specific model is discussed.

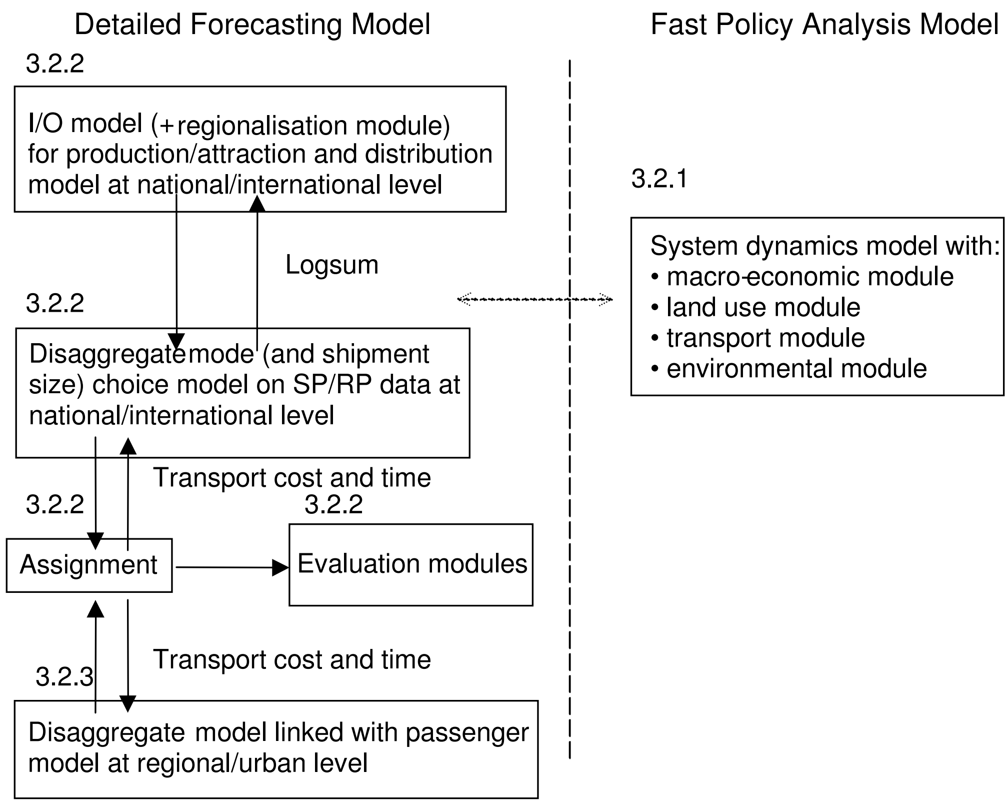

Figure 1 – Overview of model structure

The various components of the model are described below.

3.2.1 A Fast (Policy Analysis) Model

One of the many uses of the family of models will be for policy analysis. Policy analysis is a process that generates information on the consequences that would follow the adoption of various policies. Its purpose is to assist policymakers in choosing a course of action from among complex alternatives under uncertain conditions.

In a policy situation as complex as that dealing with national or international freight transport, it is easy to become overwhelmed by the "curse of dimensionality." That is, there are so many possible alternatives, so many uncertainties, and so many consequences of interest, that it would be difficult to evaluate the complete range of consequences for each alternative in a wide range of scenarios. One way to deal both efficiently and effectively with this situation is to use a fast model to gain insights into the performance of the alternatives. A more detailed model in the family might then be used to obtain more information about the performance of the most promising alternatives. Assessments based on the fast model, therefore, would be considered as first order approximations in discussions on transport or related policies (Carter et al., 1992).

Design Considerations

A policy analysis model must be designed around the information needs of its users. Thus, the first step in designing the fast model will be to assess these needs. There is no requirement that the fast model need be an aggregate version of the detailed model(s) in the family. In fact, because it is fast, it can contain features that would be impossible to include in the high-resolution models (Davis and Bigelow, 1998). High-resolution models must be limited in scope, lest they become so unwieldy as to be useless. For, example, we expect that the fast model will have impact assessment modules for estimating not only the effects of changes in policies and/or changes in scenarios on transport demand (which will be the focus of the high-resolution models), but their effects on the national economy, regional economies, land use, and the environment.

Figure 2 shows how the planned uses of a model are major considerations in determining the model's scope (number of factors included in the model) and its depth of detail (amount of detail for the factors that are included). Policy analysis models include a wide range of factors (e.g., a variety of impacts, geographical regions, commodities), but little detail about each of the factors. Implementation planning, engineering and scientific models are needed for examining fewer alternatives according to a smaller number of factors, treated in more detail.

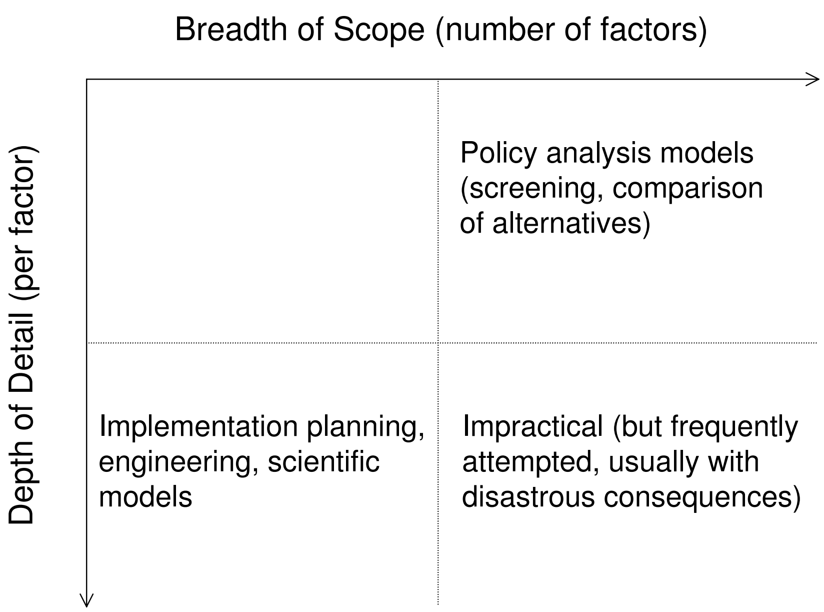

Figure 2 – Different types of models have different scopes and levels of detail

For the fast model, large-scale assignment, I/O output analysis or sample enumeration with discrete choice models is not a feasible option, due to the run times and data requirements involved. Dynamic models, such as system dynamics models, are faster and less data-hungry and have the additional advantage of not only incorporating interactions and feedbacks among transport, land use and the economy within a single forecast year (or for a few intermediate steps), but providing a time path. The ASTRA System Dynamics model platform (ASP), which was developed to perform integrated long-term assessment of European transport policies, is a good illustration of this approach (ASTRA, 2000; also see section 2.2 of this paper).

In most cases, the fast model system will include mechanisms for transforming the system changes produced by the various policy measures into model variables, e.g., through the use of elasticity relationships. This is an approach that RAND Europe used successfully in the TRACE (Costs of private road travel and their effects on demand including short and long term elasticities; see De Jong and Gunn, 2001) project, which it carried out for the European Commission. For example, the price elasticity of demand, within a carefully defined segment of the market, can be used to translate an increase in fuel price into a change in transport demand. The EXPEDITE consortium has been using similar methods to apply results from national passenger and freight transport models within a fast European-wide model for the European Commission, called the EXPEDITE meta-model (EXPEDITE, 2002).

The elasticities for the low-resolution model can be based on accepted published results and/or from fitting functions to the output from experiments with high-resolution models. (In the latter case, the elasticity is called a “repro model”, since its behaviour “reproduces” the behaviour of the more detailed model.)

3.2.2 A detailed model for international/national freight transport

An input-output model for production/attraction and a distribution model

If a model system is needed that includes feedbacks from transport to land use (e.g. regional economic development), there are basically two ways of doing this: integrated land use–transport models and system dynamics models. No system dynamics model has been developed that predicts outputs in the form of flows between a large number of origins and destinations and network loads and the sensitivity of these to policy changes, and we do not foresee the development of such models. That is why we recommend to develop a fast model using system dynamics concepts on the one hand and another detailed model that will be capable of providing outputs in the form of OD matrices and network flows on the other hand.

In state-of-the-art transport models, such as the Italian national model and the SMILE model, input-output or related models are used. Also the prototype freight transport model for Portland and the proposed model structure for London contain input-output models (Neffendorf et al., 2001). A major disadvantage of using I/O models (apart from the limited availability of up-to-date I/O statistics) is that the I/O data and models are in money units (trade flows). A freight transport model should produce flows in terms of tonnes, tonne-kilometres and vehicle-kilometres. In transport model systems with I/O models, a conversion takes place from money units to tonnes using fixed weight to value ratios. These ratios are usually based on mean values from the trade statistics and mean weights from the transport statistics for commodity classifications that are assumed to be uniform. This is one of the weakest points of model systems using the I/O approach, or indeed any other economic model. To include economic development, world market prices, production, consumption and trade in a freight transport model, the only possible way seems to be to use an economic model (I/O, CGE) that uses money units. We recommend strengthening this weak link by carrying out specific surveys among shippers asking about the value and the weight for the same shipment and about its frequency.

To make traffic generation (production and attraction) and distribution dependent on transport times and cost, the technical and trade coefficients in the I/O model need to be elastic (with time and cost, e.g. in a logsum variable from mode choice as explanatory variable), as in the Italian national model and the SCENES model. The transport disutilities can be used as feedbacks (with a time lag) to land use (location of population and employment).

A disaggregate mode and shipment size model

Disaggregate behavioural models are very uncommon in freight transport – unlike passenger transport – for two basic reasons:

- absence of data on disaggregate units of observation;
- difficulties encountered in the estimation when disaggregate data are available; mode choice model estimation on shippers' surveys in some

cases has not been successful due mostly to correlation between time and cost components.

We think it would be possible to develop a mode choice (and choice of shipment size, possibly also choice of receiver/sender) model based on shipper or shipment survey combined with SP data from shippers/carriers. The SP survey needs to be carried out to obtain time and cost information that unlike the RP is not (highly) correlated. Such a disaggregate submodel can then be used in application through sample enumeration, as has been done for several passenger transport models. The proper design (who to interview, which contexts used for presenting hypothetical alternatives, which kind of alternatives offered at the same time) is crucial for getting a good understanding of decision-making in freight transport.

Transport activities increasingly take place within a larger context of logistic choices (including inventory policy, warehouse location, consolidation of flows to distribution centres). Such considerations can be added to the freight transport model in a disaggregate fashion, as Ben-Akiva and co-authors did in the 1980s on RP data and in the 1990s on joint RP/SP data. This can also be handled in an aggregate way as has been done in the SMILE model (which includes the choice of location and use of distribution centres between the origin and destination of the shipment) and in the SCENES appended module. We recommend to treat the wider logisitic choice processes in the context of disaggregate modelling on joint SP/RP data, possibly linked with micro-simulation as in the Portland model.

The increased awareness of the logistic context should also have repercussions on the commodity classification. Ideally this should be based on the handling characteristics of the goods being transported and also on the fact that different commodity groups have different values of time. The categories that are created when using attributes with regards to logistic processes are sometimes called ‘logistic families’. In some cases it has proved possible to translate a detailed classic commodity classification (NSTR) into logistic families.

Assignment

If a separate disaggregate mode choice model could be developed for freight transport, the task remaining in the assignment step would be route choice only, not mode and route choice as in multi-modal assignment models. An advantage is that this paves the way for integrating the assignments of freight and passenger flows to the road network. Multi-modal transport chains can be handled in a two-step mode choice and assignment model by defining the options available in the choice set of the mode choice model not just as single modes, but also as feasible combinations of modes.

3.2.3 A detailed model for regional/urban freight transport

Introduction

All the above ideas on the detailed model relate to models for international freight transport and between 'not too small' regions inside a country.

The focus of this section is on the very last part of the chain, leading to final consumption. Here, we are thinking of the physical movements, made by actors or agents in the supply of goods, that immediately precede the consumption or use of the goods. Although we know there is a shopping trip needed to 'bring the bacon home' (for example), we are assuming this is already reasonably modelled as a personal trip in a passenger transport model.

These movements just before final consumption include:

- Delivery of goods to shops;
- Delivery of materials to offices;
- Delivery of goods and services to homes.

Some of these (e.g. light services) are not usually included in freight transport, but should be accounted for somewhere in a national model system, because all types of road vehicles matter when it comes to assignment to the road network. This approach would offer a chance to improve the network supply/demand processes that should jointly affect both freight and passenger transport.

Input and output features of passenger demand models that should affect predictions of light goods vehicles (LGV's) activity

We are assuming that a disaggregate demand model for personal travel has already been constructed and that the necessary background data (behavioural diaries, contextual networks and zonal data, validation data) are available. A modern disaggregate model contains income information at the zonal level and a prototypical sample of household units. Network speeds in the base year will also be available, together with a base-matrix of passenger flows, preferably along with counts by vehicle type.

The data and models will allow base-year and scenario-specific changes in journey-to-work and business trips of all sorts, in which not only the number of **trips** accessing a destination is known, but also details concerning the **travellers** accessing that destination. Ideally, we could imagine having details not only of the types of employment offered in a destination zone (assumed to be small), but details of the ages, incomes, and general occupations of the incoming travellers. Duration of visit, type of activity in detail and many more pieces of information that could be estimated on the basis of the behavioural models are potentially available. This information is raw material on which, with suitable data, estimates of the volumes and types of incoming goods and services to **offices** necessary to support the activities of the workers and visiting businessmen can be based, conditional on the number and type of traveller (and type of activity undertaken).

Similarly, for shopping and personal-business travellers (visiting shops, banks, doctors and so on), the person-based models can be used to trace back not only characteristics of a traveller, but of the household from which the traveller has come. This information is raw material on which, with suitable data, estimates of the volumes and types of incoming goods and services to **shops** necessary to support the activities of the shops, can be based, conditional on the number and type of traveller (and type of activity undertaken).

Lastly, for homes in the zone, the artificial sample (possibly enhanced to take account of housing type, which will affect house-maintenance services consumed) can be used to induce the home-delivery activities that will be needed for the functioning of the home. This information is raw material on which, with suitable data, estimates of volume and type incoming goods and services to **homes** necessary to support the activities of the home can be based.

Possible Uses

The ‘backwards-following’ logic of the analysis outlined above suggests that, from the demand models, we can know something about the **locations** at which future-scenario workers and businessmen, shoppers and personal-business travellers, and of course homes, will **require** goods and services. These locations will differ between frequent, quite frequent, middling-rare and rare needs, each of which will have a typical profile of service implications.

By collecting the needs for typical items at the ‘last-point-of-‘non-final-user’-handling’, for any given scenario the *volumes* and *destinations* of goods and services supplied by non-final-users can be assigned to zones at which final-users receive them.

It would then remain to **accumulate the goods, and the providers of the services**, at origin locations from which they would access these destinations, thereby defining potential trips on the network (yet to be assigned to modes and accumulated to loads). The origin locations might be warehouses or depots, or zones of (intermediate) production for goods. These would be output, in the current background of longer-distance models that are available, from the gravity-type and/or spatial input-output models. It may also be that this sort of modelling (like many others) is most safely done to generate **change factors** for the scenario relative to a current base, in which direct observation of flows was used as the real basis.

Next steps

It is hoped that the next steps will be a discussion and a linking of these ideas with current ideas of freight distribution at the local level. It is clear that additional data would be needed to implement this sort of approach. Some of this would take the form of household expenditure surveys, possibly extended to allow self-allocation to the frequency of purchase and indicate parcels of goods purchases simultaneously or as part of the same out-of-home tour. Additional counts by vehicle types and interviews with owners and operators of urban freight distribution vehicles would be needed.

4. SUMMARY AND CONCLUSIONS

In this paper we have reviewed freight transport models, focussing on Europe (some information on US and Australian models can be found in RAND Europe et al., 2002). We found that at the international and national levels, freight transport models are much better developed than at the urban and regional levels, where the link to economic processes is typically overlooked and the focus is on building up matrices from various sources. For each of the four steps of the classical (passenger) transport model, different types of models were distinguished in this paper and existing (inter)national freight transport models were classified according to this categorisation and briefly described. For production and attraction, several European and national models now use input-output and related methods. Distribution in those models is also based on the input-output analysis, or on gravity formulations. For modal split, many different model forms can be found in practice, but most of the larger model systems use multi-modal network assigment, in which mode choice and assigment are handled simultaneously.

The most promising combination of models for freight transport forecasting and evaluation are in our view the following:

1. A fast and relatively straightforward policy analysis model, developed as a system dynamics model and/or a model integrating outputs from other more detailed models.

2. A more detailed network-based freight transport model consisting of a number of interlinked modules:

   At the national/international level:
   - An input-output model for production/attraction and a distribution model;
   - A disaggregate model for mode and shipment size choice, based on combined stated and revelealed preference data; possibly combined with micro-simulation;

   At the regional/urban level:
   - A disaggregate model linked with the inputs and outputs of a disaggregate passenger model;

   At all geographical levels:
   - An assignment module.

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