

## **Recent developments in national and international freight transport models within Europe**

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### **Abstract**

The past decade has seen many new freight transport models for use in transport planning by public authorities. Some of these models have developed new concepts, such as logistics modules, inclusion of transshipments, storage and sourcing and the determination of shipment size. This paper provides a review of the European literature on freight transport models that operate at the national or international level and have been developed since 2004. The introduction of elements of logistics thinking is identified as a common theme in recently developed models, and further worked out. Furthermore, ideas on what might be the next key developments in freight transport modelling are presented.

Key words: freight transport models, logistics, national and international freight transport

## 1. Introduction

Policy analysis for freight transport is more and more on the agenda. Public agencies at the urban, regional, national and international level see a need for more and better quantitative impact assessments of policy measures. There has been an increasing interest in freight transport's impact on the global climate and on local air and noise emissions. Transport policies are moving to the forefront of the discussions at the European and global level. Examples are the "Roadmap to a Single European Transport Area" (European Commission, 2011) and the "Harmonised European approaches for transport costing and project assessment" (HEATCO, 2006). There is a pressure on transport modelling from European and national legislation and a growing understanding of the limitations of models to study the impacts of transport policies (Tavasszy, 2011).

New freight transport models and model systems are being developed. These models include both responses to changes in the transport system in a given environment and forecasts of future transport and traffic flows, transport costs etc. For the short run, models depict how policies influence transport and traffic demand. In long term models the impacts of factors that are largely exogenous to the transport sector (economic development, foreign trade, land use etc.) on transport demand are modelled. Freight transport models are used to assess the impacts of different types of policy measures, such as changes in national regulations and taxes or infrastructure investments in specific links, nodes and corridors. A wide range of models and model systems are applied by public agencies. There is also a lot of freight transport modelling in academic research including both aggregate models and disaggregate models based on approaches at the firm level. These two streams are in some cases combined in one model system.

This paper starts from the overview of national and international freight transport models carried out in 2004 (de Jong et al., 2004). This previous review found that:

- 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 items being transported and the limited availability of data, especially disaggregate data (partly due to confidentiality reasons). Most freight transport models apply simplifying assumptions on the first two issues and only use aggregate data.
- At the national and international level, freight transport models usually start from models of economic processes (production, consumption, trade), for instance in the form of input-output models. Urban and regional models, in as far as they are available, often overlook the link to the economy and focus on building up and assigning truck matrices.
- The four-step modelling structure from passenger transport (generation, distribution, modal split and network assignment) has been adopted in freight transport modelling with some success, but additional steps are often needed to transform trade flows in money units to physical flows of goods in tonnes and further into vehicle flows with specific vehicle utilisation factors. These processes can be modelled as fixed rates, but also by explicit representation of logistics choices. Also other logistics aspects that are related to the trade-off between transport and inventory costs are usually not included in freight transport models, even though the logistics solutions of firms influence the mode split.

This new review gives an overview of how freight transport models have been developed and applied since 2004. We restrict ourselves to models used by and for public authorities for transport planning purposes (such as the provision of infrastructure). This rules out models developed for the private sector (e.g. for logistics planning and operations) or models representing individual supply chains or private logistics networks. Nevertheless, public sector planning models can learn a great deal from private sector logistics and supply chain modelling, as will be shown by some of the national models discussed in this paper, that have embarked on including logistics decisions such as determination of shipment size and the choice of transport chains in distribution, using methods developed in logistics planning in the private sector.

The paper is partly based on the contributions given at a seminar organised by the Centre for Transport Studies in Stockholm 1 March 2011 (CTS, 2011). Other recent reviews of freight transport modelling are Chow et al. (2010) and Tavasszy et al. (2012). Chow et al. (2010) focuses on models developed in the US and also provides some European examples. The current paper on the other hand lays the emphasis on models recently developed in Europe, though it also describes some developments elsewhere in the world, notably in the US. As in Tavasszy et al. (2012), the current paper discusses in particular efforts to include elements of logistics decision making in national and international freight transport models, since we consider that this has been the most important recent trend in freight transport modelling at that spatial level. In addition, this paper also matches the state of the art in freight modelling against the state of practice, i.e. the main national model systems.

We address full freight model systems - from economic activities to assignment of vehicles in networks -, often comprising all of the following steps: economic activity, zone of production to zone of consumption flows, logistic choices, vehicle flows and network assignment.

In section 2 we give a general overview of the new freight transport models. Section 3 zooms in on developments that are related to including logistics thinking into freight transport models. Some potential key developments for practical freight transport modeling are described in section 4. Finally a summary and conclusions are given in section 5.

## 2. Overview of new models

Table 1 provides a summary of the main features of operational models developed for national/state authorities in Europe or for the European Commission since 2004.

The national freight models for Germany, Italy and France all build on older work, but have been included as they are truly national models that have been used in practice. The NODUS model, that has been used mainly for the Walloon region in Belgium, also builds on earlier work, but has been included because it has also been used for applications in other countries (notably France) and the European level.

Table 1. Summary of recent freight transport models developed for national or state authorities and for the European Commission

Model	Italian National Model System	SMILE+	MODEV	BVWP model	Transtools	Worldnet
Client	National Research Council	Dutch MoT	French MoT	German MoT	EU	EU
Sources	Marzano and Papola (2004)	Tavasszy et al.(1998), Bovenkerk (2005)	MVA and Kessel+Partner (2006)	ITP and BVU (2007)	Chen (2011); TNO (2008); Hansen (2011a); Tetraplan (2009)	Chen (2011); Newton (2008)
Year (development)	2004 (building on earlier work)	1998-2005	2005-2006 (building on earlier work)	2006-2007 (building on earlier work)	2005-2009	2007-2008
Study area	Italy	Netherlands	France	Germany	Europe	Europe (focus on trade with non-Europe)
Number of zones: internal +external	267 internal zones	Freight: 40 +60 (NUTS2)	342 internal and 230 external zones and 25 ports)	439 internal zones (NUTS3) and 112 external (NUTS0-2)	Freight: 277+19 (NUTS2)	Almost 1500 in total (NUTS3)
Number of commodities	5: perishable or not; value density	50 logistical families	10 NSTR1	10 NSTR1	10 NSTR1	10 NSTR1
Choices included	Generation, distribution, modal split and assignment	Generation, distribution, modal split, logistics and assignment	Generation, distribution, modal split and assignment	Generation, distribution, modal split and assignment	Generation, distribution, modal split , (logistics) and assignment	Generation, distribution, modal split and assignment
Modes	Road, rail, combined (road-rail)	Road, rail, IWW, sea, air, pipeline	Road, rail, combined (road-rail), IWW	Road, rail (4 train types), IWW (separate models for sea and air freight)	Road, rail, IWW, sea	Road, rail, IWW, sea, air

IWW: inland waterways transport.

Table 1 (continued). Summary of recent freight transport models developed for national or state authorities and for the European Commission - continued

Model	Norway	Sweden (Samgods)	ADA model for Flanders	NODUS model	LOGIS	Netherlands (Basgoed)
Client	National transport authorities	National transport authorities (since 1 April 2010: authority)	Flemish MoT	Several, including Walloon region	EU	Dutch MoT
Sources	Kleven (2011); de Jong and Ben-Akiva (2007)	Vierth (2011); de Jong and Ben-Akiva (2007)	De Jong et al. (2010)	Pekin (2007); Jourquin and Beuthe (1996)	NESTEAR (2010)	Tavasszy (2011); Significance et al. (2010)
Year (development)	2004-2009	2004-2009	2009-2010	2006 (building on earlier work)	2009-2010 (building on earlier work)	2010-2011
Study area	Norway	Sweden	Flanders and Brussels	Belgium or Europe	Europe (focus on France)	Netherlands
Number of zones: internal +external	475+61	290+174	309+22	Almost 600 in Belgium (NUTS5); more than 250 in Europe (NUTS2)		40+30
Number of commodities	32 (based on NSTR2)	35 (based on NSTR2)	9	10 NSTR1	10 NSTR1	10 NSTR1
Choices included	Generation, distribution, logistics and assignment	Generation, distribution, logistics and assignment	Generation, distribution, logistics and assignment	Modal split and assignment	Generation, distribution, modal split and assignment	Generation, distribution, modal split and assignment
Modes	Road, rail, sea, air	Road, rail, sea, air	Road, rail, IWW, sea, air	Road, rail, IWW	Road, rail, combined (road-rail), IWW	Road, rail, IWW

IWW: inland waterways transport

Marzano and Papola (2004) report new work on the Italian national freight transport model. These new developments mainly have to do with the multiregional input-output (MRIO) model with elastic trade coefficients, which is used for the generation and distribution steps within this model system. The Italian model does not include endogenous logistics, but some logistic characteristics (frequency of the shipments, value density and shipment weight) are explanatory variables in the modal split model (which is based on disaggregate data). This model has been used to produce reference forecasts for the short and long run and for sensitivity analyses for changes in the exogenous variables, like time and costs by mode (road, rail and combined road-rail transport). An advantage of input-output modeling is that it provides a clear link between economics and transport (and freight transport is a derived demand). Disadvantages (also see de Jong et al., 2004) are the assumption of fixed production technologies, the need to convert from money units to weight units and the heavy data requirements: for many countries, up-to-date input output tables, certainly multiregional ones, are not available.

The Netherlands may have been the first country where a national transport model with endogenous logistics was developed (the SMILE model, Tavasszy et al., 1998). This was later extended towards the SMILE+ model, Bovenkerk, 2005). The way SMILE and SMILE+ handle logistics decisions is described in section 3 of this paper. SMILE+ further includes a multiregional input-output model for production and attraction (yielding the row and column totals on the transport flow matrix), a gravity model for the distribution step and multimodal stochastic network assignment for modal split and route choice.

The model system has been used in conjunction with several scenarios for freight transport in 2030, for a pricing policy study, a cost-benefit analysis of multimodal network alternatives and strategic mode choice. However, it has now been replaced in part by the BASGOED model (see later in this section). The SMILE model has been used in several policy support studies since 1998 for the Dutch Ministry of Transport (Tavasszy, 2011).

MODEV (MVA and Kessel+Partner, 2006) is the national French freight transport model. Production and attraction are modelled on the basis of regression models estimated on cross-sectional data. A gravity model is used for the distribution step and an aggregate logit model for the modal split over road, rail, combined road-rail and inland waterway transport. Assignment in this model is unimodal. MODEV does not include explicit logistics components. It has been used for long run reference forecasts as well as for evaluating the impacts of infrastructure projects.

For German federal infrastructure planning (BVWP), a national passenger and a freight transport model are used. Generation and distribution use the same type of models as in MODEV. The modal split model (road, rail and inland waterway transport) however is based on disaggregate data, partly from stated preference studies. Apart from this, there are separate sub-models for sea freight and air freight. Assignment is carried out for road, rail and inland waterways (unimodally). The practical applications include a reference forecast for the year 2025 and inputs for the cost-benefit analysis for evaluating infrastructure projects. This model also has no explicit treatment of logistics.

Transtools version 1 (TT1) was a suite of models, that includes a passenger transport model, a freight transport model (along the lines of the older NEAC model, Chen and Tardieu, 2000), a logistics model and a spatial computable general equilibrium (SCGE) model (CGEurope). A separate data project (ETIS, now ETIS+) started to supply data for several purposes, including use in the TRANSTOOLS-

project (Chen, 2011). The freight transport model follows the conventional four-step approach. The logistics model in TT1 is similar to the Dutch SMILE+ model (Bovenkerk, 2005) and the logistics model within SCENES (SLAM; SCENES consortium, 2000) and explains the location and use of distribution centres, leading to the formation of transport chains. The user of TT1 can decide whether to use this logistics model as a sort of post-processor on the freight transport model or not (in most applications this was not used). CGEurope provides inputs to the freight model (GDP changes) and can also receive zone-zone generalised transport cost information from the freight model.

Transtools version 2 (TT2) was developed by a different team in the course of the TEN-Connect project for the European Commission, Tetraplan (2009).. The freight transport model was modified in various ways (e.g. to go from an unconstrained gravity model for international trade, which could lead to illogical results, to a doubly constrained gravity formulation). The modal split model is aggregated logit and assignment of trucks take place jointly with that of cars at the NUTS3 level (1441 zones). The European Commission has used the Transtools--models in policy analyses (Ibanez, 2011); Transtools has been used for evaluations of the Transeuropean network, cost-benefit analysis of infrastructure policies, pricing policies (including the Eurovignette), vehicle dimensions regulation, The EU White Paper on Transport and accessibility analysis. At the moment there is a project to develop a new version (Transtools 3).

Worldnet (Newton, 2008) was also a project for the European Commission. It developed a long distance freight transport model that covers Europe and its neighbours, but also intercontinental sea and air cargo routes. There has been a focus on including intercontinental flows and on taking a transport chain perspective in the modelling instead of forecasting the choice of main mode only. The OD flow matrices are derived by using gravity models. For mode choice, Worldnet has a multimodal transport chain builder that can produce direct unimodal routes as well as routes with several modes (road, rail, sea air and inland waterway transport) in a transport chain. The choice between these alternatives is made in a multinomial logit model. Worldnet has been used in practice for investigating the EU's Motorways of the Sea initiative and in a study on ports and their hinterlands.

Logistics models as part of the national forecasting model systems for freight transport were developed in a common project for the Norwegian and Swedish transport authorities, to replace the existing multimodal network models for freight transport. The logistics models for both countries are different (zoning system, modes and vehicle types used, commodity classification, costs functions, consolidation rules), but the overarching logic and aggregate-disaggregate-aggregate (ADA) structure is the same. This approach is described in section 3. In Sweden, these logistics models are combined with procedures for estimating PC matrices, which are based on the National Commodity Flow Survey and mainly use gravity type models (base matrices). In Norway there also is a SCGE model (PINGO, see the description later in this section) that can be used to produce forecasts of PC matrices (Hansen, 2010). For both countries, the logistics model produces OD matrices (e.g. in terms of vehicles) that are assigned to the road, rail, sea and air networks (unimodal assignment; Ben-Akiva and de Jong, 2008). The Norwegian model has been used in many applications (including a national transport plan, corridor analysis, various cost-benefit analyses, the Norwegian Climate project), whereas the Swedish model has so far been used in a limited number of practical studies (changing the requirements for maritime fuels, impact of rail user charges).

The model for the Mobility Masterplan of Flanders follows the same aggregate-disaggregate-aggregate (ADA) structure as the models for Norway and Sweden. The PC matrices in the ADA approach come from an existing trade model, called Planet. Then comes a newly developed logistics model for the choice of shipment size and transport chain. Assignment for road transport is done jointly with the assignment of cars. Besides this ADA model, there also is a more conventional multimodal freight transport model for Flanders (K+P Transport Consultants and Tritel (2006)). For the Walloon region in Belgium, a multimodal network model for freight transport has been developed, using the NODUS software (the model itself is also usually called NODUS). The model covers Europe at the NUTS2 level, and can also be used as a European multimodal assignment model for freight transport (Jourquin and Beuthe, 1996, Beuthe et al., 2001, Pekin et al., 2007).

A model system similar to that in Norway and Sweden is now being built for Denmark (Hansen, 2011b). A key change with regards to the Norwegian and Swedish models is that the Danish model will use a pivot-point procedure on the truck matrix. This means that the logistics model will only deliver **changes** in the OD matrices between a base and a future year. These changes will then be applied to a base year truck OD matrix, which will be based to the maximum possible degree on observed data (e.g. traffic counts, surveys), making the overall model less synthetic and better empirically founded. The new Transtools 3 model (for the European Commission; Nielsen, 2011), also plans to use an approach for freight transport and logistics based on the experiences in Norway and Sweden (and Flanders), in combination with base year OD matrices by mode, derived independently. Of course, base year matrix estimation is also a branch of modelling since observed data are never sufficient to fill all the cells in the matrix (see for instance List and Turnquist, 1994, Tavasszy, 1996, Holguin-Veras and Patil, 2008).

LOGIS is a freight transport model for Europe, developed for the European Commission (NESTEAR, 2010), with some focus on flows to and from France. LOGIS has been developed and applied in the work with the Trans-European Networks (EU-projects SCENARIOS, SCENES, THINK-UP, TEN-STAC, MEDA-TEN-T), the development of dedicated Rail Freight Networks (EUFRANET, NEW-OPERA, TIGER, MARATHON) and transport corridor-evaluations (TRANS-ALPINE, TRANS-PYRENEAN corridors). It uses regression models for generation, gravity models for distribution, aggregate logit models for model split and unimodal assignment. There is no specific logistics module. LOGIS has been used to produce a long run reference forecast and the transport impacts of various infrastructure projects in Europe. LOGIS is mainly used in intermodal, co-modal and multilevel “door to door” modelling and evaluation of infrastructure projects and policies, including the assessment of local and global environmental impacts (Reynaud, 2011).

The SMILE model (later SMILE+ , see Tavasszy, 1998 and Bovenkerk, 2005) has been the Dutch national freight model system for over a decade. SMILE was the first national freight transport model that took into account the effect of logistics choices on freight flows. In 2009, the Dutch MoT chose to invest in a more simple and straightforward freight transport model that would also be easier to maintain. A basic freight transport model was developed, called BASGOED (where BAS comes from basic and GOED from good). This model was developed in about a year, and should be able to answer the most pressing policy questions of the MoT (Significance et al., 2010). BASGOED is a conventional four-step transport model, with only a limited number of zones and commodity types. Its distribution and modal choice model coefficients were estimated successfully on aggregate data, leading to reasonable elasticity values. It uses inputs (row and column totals: generation and attraction) from

the economy model of SMILE+. Also for assignment, existing unimodal transport models are used. In addition to this basic model, a roadmap was built for the inclusion of logistics choices (Tavasszy, 2011; Tavasszy et al., 2012) on the basis of, amongst others, the SMILE+ logistic model.

The UK (Bates, 2011) has a Great Britain Freight Model (GBFM, MDS-Transmodal, 2003), as well as a road-rail mode choice model at the national scale (LEFT, Fowkes et al., 2010). GBFM uses 2650 domestic and 350 foreign zones and 10 commodity groups (NSTR1) and includes a modal split between road and rail, but no explicit logistics modelling. LEFT is a strategic model for the choice between road and rail for seven commodities and nine distance bands. It does not have a logistics component itself, but was combined with one in the PhD study of Maurer (2008; see below). Recently, a new national freight model of Great Britain was developed within the Base Year Freight Matrices project for the UK Department for Transport (WSP, 2011), but detailed documentation on the methodology used or any practical applications of this model is not available yet. A metropolitan variant of this national model was developed for London: the Freight in London Model (FiLM; Williams, 2011). These systems build on the EUNET model (see below) and, just like that model, include some logistics elements. They use spatial input-output models to provide a matrix of transport flows from production to consumption zones. These PC flows are then distributed over transport chains (in terms of the number of legs, not yet the modes) using a fixed proportional split by commodity type. Furthermore there are mode choice models for splitting the OD flows into main modes including their associated feeder legs to and from intermodal terminals and unimodal assignment.

Apart from these models that are being used in projects for national authorities and the European Commission, there have also been other new freight transport models at the national and international level since 2004:

- Freight transport models including logistics choices in North America:
  - Zhong et al. (2007) developed a spatial input-output model for the Canadian province of Alberta, with transport networks for road, rail and pipeline (also there was earlier work on a statewide model for Oregon in the US (Hunt et al., 2001).
  - In a (not yet finished) study in the US, Samimi, Mohammadian and Kawamura (2010) are developing a freight transport micro-simulation model (Freight Activity Microsimulation Estimator, FAME) for the US (not statewide, but nationwide). It generates firms and their incoming and outgoing goods flows, determines the relations between the firms (supply chain generation) and then in different steps chooses shipment size, mode (road or rail) and impacts on the transport networks.
- Regional freight transport models:
  - A regional, but international, freight model system for the border region of Denmark and Sweden is GORM (Hansen, 2011b). The model has 811 zones and covers freight flows within Denmark and Skåne (South Sweden), between Denmark/Skåne and the rest of Scandinavia and between Scandinavia and the European Continent. GORM is a nested logit model with modes at the upper level and crossings at the lower level.

The model has been used in infrastructure projects in the Danish/Swedish border region

- EUNET (UK) (Yin and Williams, 2005). The EUNET model uses spatial input-output modelling to obtain trade (PC) matrices and a logistics model to generate OD matrices from these. EUNET uses an aggregate logistics model (see section 3). It was originally applied to the Trans-Pennine region in North-England and was extended to two other regions in the UK later as pilot (Bates, 2011). EUNET now has 408 zones (NUTS4) and 19 commodity types.
- Developments in economic/trade models:
  - The PINGO model is a static Spatial Computable General Equilibrium (SCGE) model of the Norwegian economy (Vold and Jean-Hansen, 2007). It is based on a 2002 baseyear Social Accounting Matrix. The model includes an explicit production function for the transport sector. The cost data that act as input come from the Norwegian transport logistics model.
  - The Dutch SCGE model RAEM (Ivanova et al, 2007), is a recursive dynamic model of production, consumption and trade for the Netherlands, including international trade, federal government as a macroeconomic agent, labour markets and migration. The model uses cost data as input from the Dutch and European freight and passenger transport network models.
- PhDs on introducing logistics choices in freight transport models:
  - Liedtke (2006) at the University of Karlsruhe developed a micro-simulation model (INTERLOG) for logistics choices. These include generating firms and allocating these to geographical space, the receiver's choice of supplier, shipment size, the choice of carrier firm and the generation of truck tours. There also was an application to long-distance freight transport markets in Germany.
  - Maurer (2008) at ITS Leeds used a commercial software package (CAST) for logistics decision making (e.g. for the location and use of distribution centres) together with the LEFT model (for modal split in the UK between road and rail, by commodity group and distance class) in an application to freight transport at the national level.
  - Arunotayanun (2009) at Imperial College London specified and estimated discrete choice models for mode choice that accommodate supply chain structures using the French ECHO database.
  - Friedrich (2010a) at the University of Karlsruhe designed a freight model (SYNTRADE) for the German food retail sector. He shows that optimization procedures originally developed for the logistics planning of individual companies can be used to predict distribution structures at the sectoral level.
  - Combes (2010a) at the ENPC in Paris focuses on the choice of shipment size, which is often neglected in transport modeling. This includes applications on the national

French Shippers survey ECHO (also see Combes, 2010b). It also includes a model with shipment size and mode choice.

- Various mode and shipment size models have been estimated on the disaggregate data of the Swedish Commodity Flow Survey (CFS). The estimated models have also been applied to calculate mode/shipment size elasticities, but they have not been built into operational models.
  - De Jong and Johnson (2009): The CFS 2001 was used to estimate discrete choice models (both mode and shipment size treated as discrete variables) as well as discrete-continuous (continuous shipment size) models.
  - Habibi (2010) estimated models for discrete shipment sizes and transport chains for the commodity 'domestic steel products' on the CFS 2004/2005.
  - Windisch et al. (2010) used the CFS 2004/2005 to estimate models of (discrete) shipment size and transport chain choice.
- Other behavioural: A number of authors have studied behavioural interactions between different agents in freight transport:
  - Hensher (2002) proposed stated choice experiments that include interactions between agents and described how discrete choice models can be extended to include interactions. Hensher's interactive agency choice experiments (IACE) and the econometric models for estimation on these choice data start from the type of experiments and models that are well-known in transport analysis, and then introduce new elements. These include sequential choices, where agents are informed about the previous choices of other agents, and correlation over alternatives and choice sets within and between agents. This is done for pairs of agents (e.g. shipper-carrier) and the process of feeding back information continues for all pairs where agreements have not been reached. Interactive choice experiments have been carried out on the interaction between shippers and carriers (Hensher and Puckett, 2005). A disadvantage of IACE is that the survey costs of interviewing shippers on the responses of the carriers etc. can be quite high (compared to more standard stated preference surveys) and that the resulting samples are small. This led to the development of minimum Information group inference, MIGI (Puckett and Hensher, 2006), where agents are interviewed only once, but as well as the model including each agent's standard utility function, each shipper is also matched with a carrier and their group decision making is inferred.
  - Friesz et al. (2008) present a dynamic game-theoretic model with sellers and receivers of products and transporters in the context of an urban transport network, extending earlier models with shippers and carriers only. They provide the theoretical system of equations and illustrative numerical examples.
  - Holguin-Veras et al. (2008) and Wang and Holguin-Veras (2009) have developed models for commercial tours (series of trips by vehicles delivering at multiple receivers in a pre-planned sequence) organised by carriers, and empty trips, at the

aggregate level, making use of entropy maximization. In Holguin-Veras et al. (2006) interactions between carriers and receivers are studied in the context of deliveries outside the peak period (decision making on delivery times). Holguin-Veras et al. (2009) uses experimental economics (with students as participants) to study interactions between shippers and carriers in mode and shipment size choice.

- Models focusing on port competition:
  - These are models for the choice of maritime port, that connects origins and destinations on different continents. These models can consider a specific port range on the European continent (the Hamburg-Le Havre range, see Zondag et al., 2010; Posthuma, 2011) or have a global reach (Tavasszy et al., 2011). Typically they take into account different commodity classes, the costs of maritime transport to/from each of the ports, the cost of port operations and the hinterland transport cost from the sending zone to each port or from each port to the receiving zone. So far, these models work at the aggregate level (using aggregate logit models). The models mentioned are linked to worldwide trade models and the transport costs data base of the European Commission.

### 3. Recurring theme: the introduction of logistics

A recurring theme in the development of freight transport modeling since 2004 has been the introduction of logistics decisions into the models. In this section we describe the way logistics is incorporated into these models (this is summarised in Table 2).

Wigan and Southworth (2005) conclude that “current freight planning models reflect a limited understanding of the forces and agents involved” and that there is “limited attention to causes and dynamics underlying in both freight demand and supply”. Since then logistics behavioural modeling has been introduced into freight transport models in order to reduce these shortcomings and to increase policy-sensitivity and realism in the freight transport models. The inclusion of logistics has been one of the main recent developments in freight transport models. Before 2005 the Dutch SMILE-model (Strategic Model for Integrated Logistics and Evaluations, see Tavasszy et al. (1998), and also see below) was the only national freight model with endogenous logistics. Early efforts to combine decision-making on transport and on inventories into a single framework include Baumol and Vinod (1970) and Winston (1983).

The definition of logistics and logistics management is broad. “Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flows and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements”(CSCMP, 2011).“Logistics management activities typically include inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfilment, logistics network design, inventory management, supply/demand planning, and management of third party logistics services providers.”(CSCMP, 2011).

The logistics models that have been developed up to this point concentrate on the link between trade flows (of commodities) and physical transport flows (of vehicles). The distinction between production/consumption (PC) matrices and origin/destination (OD) matrices was introduced as a fundamental input to the analysis of logistics and transport systems (WSP, 2002). Transport flows are obtained from the PC-matrices that describe trade between producers and the consumers of these goods (which may be firms for further processing). These PC flows can consist of several OD flows, since every handling activity, whether for inventory or transshipment between vehicles or modes, leads to a new OD flow. A PC flow can thus be a chain of many transport segments, connected by inventory and/or transshipment activities (e.g. the PC flow or chain road-sea-road has three OD flows). Changes in PC-matrices are mainly influenced by changes outside the transport sector and changes inside the OD-matrices mainly by changes inside the transport sector. In most of the logistics models in transport, production and consumption is taken as given (also see section 4.2; these need to be predicted by an economic model).

The logistics models typically include all logistics costs and aim to describe the trade-offs between inventory and transport and the routing via “intermediate points”. These points can be *transshipment terminals* (road terminals, rail terminals, ports, airports) that are used for transfers between modes or different vehicle types of the same mode (allowing for consolidation and deconsolidation), or *distribution centres* (DC), warehouses where goods are stored, not necessarily labelled for their destination and where goods typically change consignment sizes. One difference is that distribution centres hold inventories while transshipment terminals do not have an inventory function. The different types of intermediate points are not easily observed separately (Grønland, 2004) as the underlying activities often appear simultaneously at the same logistics site.

The logistics models include one or more of the logistic decisions taken by different actors:

- shippers’ choice of number, location and size of distribution centres/warehouses
- shippers’ choice of shipment size (frequency of transports)
- shippers’ choice of loading unit (e.g. container or not)
- shippers/forwarders’ choice of mode(s) in a transport chain, which are built on the basis of distribution networks that take account of economies of scale in transport (larger vehicles, as used for instance for main-haul transport, have lower unit costs)
- forwarders/carriers’ choice of vehicle size/type
- forwarders/carriers’ choice of transshipment terminals
- carriers/drivers’ choice of routes(between P, C and “intermediate points”)
- forwarders/carriers’ choice of return transports (re-positioning of vehicles and of loading units), including empty returns (“empties”)

Below we list the models that were the first to include one or more of these logistic choices.

A useful taxonomy of choice problems is by aggregation level, as proposed by Liedtke (2009). The logistic choices are taken by firms at the *micro level*. Collaboration between firms and common use

of vehicles, terminals, warehouses and distribution centres in order to obtain economies of scale and scope cause the existence of a *meso level*. National and international models are often applied at the *macro (aggregate) level*: outputs from logistics model are used in assignment models (aggregated OD-matrices of vehicles) and aggregated economic/trade models (transport costs per zone-to-zone PC-relation and commodity). Thus different levels of aggregation are addressed. Usually meso level structures are described as emergent systems that result from interaction between firms. They can be modelled by using micro level models (de Jong and Ben-Akiva, 2007), or directly with aggregate models, without an explicit description of the underlying micro level decisions (Tavasszy, 1998). Models that operate exclusively at meso level are rare; the only example known to the authors is the model of colloidal structures, by analogy with physics, of intermodal transport networks, developed by Carillo-Murillo (2010).

#### *Aggregate (zonal) models*

The EUNET model (Jin and Williams, 2005) includes a logistics model that represents the stages of freight transport from producer to transshipment terminal for consolidation, from there to a transshipment terminal or warehouse for deconsolidation, and from there to the consumer explicitly. The complexities of the logistic chains and the handling factor (number of times the goods are lifted between initial sender and ultimate receiver) are calculated per commodity type. Consolidation, deconsolidation and the use of distribution centres are covered as well as the choice between road and rail and between different sizes of trucks.

The SMILE model (Tavasszy, 1998) includes Dutch freight flows and transit flows that use the Dutch infrastructure. In the step from trade to transport demand, alternative locations of distribution centres and chain types are calculated using characteristics of commodities, markets and transport services. One submodel calculates whether there will be inventories at the distribution centres, depending on the possibilities to consolidate goods from an origin to multiple destinations. This is done for “logistic families” built according to the commodities’ service requirements. Another submodel forecasts the locations of the distribution centres depending on attributes of the OD-relation and the regions. The model takes into account the way consolidation of freight flows influences the shipment sizes as well as the use of different vehicle types in the assignment. The costs of direct and indirect chains (using one continental, one national warehouse, or both) are determined. The usage of DC alternatives is estimated using a logit choice model.

The SLAM model (Spatial Logistics Appended Module; see SLAM; SCENES consortium, 2000) followed the SMILE development. The logistics module in SLAM was adopted as part of the European transport model Transtools version 1, TT1 (TNO , 2008) and version 2, TT2 (Tetraplan , 2009).

Maurer (2008) developed an integrated model for estimating emissions from freight transport in the UK. This model integrates modules for 1) policy, 2) freight transport demand, 3) logistics and 4) emissions. Direct delivery and different configurations of hub- and spoke concepts via distribution centers are simulated and their total logistics costs are compared to each other. The effect of logistics decisions on transport demand is illustrated for the commodity “food, drinks and agricultural products” (these commodities could not further be separated on the basis of the available data) with relatively small shipment sizes and potential for consolidation. Emphasis is put on outbound transports and road transport.

Port competition modelling including maritime, port, and hinterland characteristics was carried out by Zondag et al. (2010). In the port competition modelling approach, a port is considered to be a link in a transport chain. Therefore, modelling of transport chain choices is needed to forecast future freight flows by port. Due to data limitations the modeling cannot cover the full logistic chain between production and consumption of the goods. The transport chain in the model focuses on the part for which data is available and fortunately this is also the part for which the competitive position for import and export of the port alternatives differs most strongly. The Worldwide Container Model (Tavasszy et al., 2011) addresses the choices of service, port and route in the network of container service lines. It includes over 400 ports across the world and over 800 liner and feeder services. The model was formulated at a level of detail such that it could be based on publicly available databases on trade, transport and port transshipment. It applies a logit model to assign container flows between countries to a supernetwork including ports and inland transport links.

The tour formation models for road transport of Holguin-Veras (2008) and Wang and Holguin-Veras (2009) are based on entropy maximization. They also include the planning of empty return trips.

#### *Disaggregate (micro) models*

Disaggregate models take into account decisions of single firms (that maximise their profits) explicitly and apply disaggregate choice models, agent-based simulation models or normative rules.

In the Norwegian and Swedish national transport model systems the aggregate – disaggregate – aggregate (ADA) approach has been introduced (de Jong and Ben-Akiva, 2007 ; de Jong et al., 2008a, 2008b; Ben-Akiva and de Jong, 2008). Warehouses of wholesalers (W) are specified as a specific type of senders in the trade matrix (leading to a PWC matrix instead of PC): further inventories at intermediate points are not described. A three-step approach is applied:

- 1) Commodity specific PWC-matrices (zone to zone flows), in the Swedish model mainly derived from the national Commodity Flow Survey (CFS) (SIKA, 2004)) are disaggregated to virtual firm-to-firm flows. In the Swedish model flows between small, medium sized and large firms are modelled; senders and receivers of shipments are linked by simulating random draws using proportionality to the product of the production volume of the sender and the consumption volume of the receiver. Very large “singular” flows between large firms with direct access to the rail or sea network are described separately.
- 2) Shipment size and transport chains are optimised simultaneously at the firm level. The optimal shipment size is calculated starting from the economic order quantity (EOQ) formula. The order frequency is derived from the optimal shipment size and the annual flows. The choice between about 100 predefined transport chains uses exogenous information on the location of the ports, airports and road and rail terminals from the network. It is calculated which of the given terminals are used for transfers. Exploitation of scale economies in transport is taken into account using different vehicles sizes. Costs for transport chains using containers are compared to costs for conventional transport chains. In the Swedish model consolidation is assumed to take place inside commodities and in terminals. In the Norwegian model rules are applied for consolidation over

commodities and for consolidation and distribution along the route (Grønland and Madslien, 2009).

- 3) Shipments are aggregated over firms in the same zone (and possibly also over commodity types) to OD-flows in vehicle units that are assigned to the road, rail, sea and air networks. In both countries empty flows are calculated using the information of the loaded vehicle flows. It is assumed that overcapacity in an OD-relation returns empty to the starting point. The method used is based on (Holguin-Veras & Thorson, 2003)

In the operational versions of the Norwegian and Swedish model the logistic decisions at the firm level (step 2 above) are based on deterministic cost minimisation of the total annual logistics costs. Estimations on disaggregate data are planned. The estimated models have been applied to calculate mode/shipment size elasticities, but they have not been built into operational models.

Groothedde et al.(2005) elaborate how economies of scale and scope can be obtained in multimodal hub networks. The authors show how the total logistics costs can be reduced (and services levels maintained) by shifting consolidated flows from road to rail, inland waterway or coastal shipping, that are better suited for handling of large volumes. The total logistics costs are formulated taking into account the density of the flows and the location of the hubs. The approach is described through presenting the results of the design and implementation of collaborative networks for the distribution of fast moving consumer goods in the Netherlands using road and inland waterway transports. Combes and Leurent (2007) also stress the importance of scale economies as one of the main drivers of the organization of freight transport, on a larger scale, of companies' logistic choices.

Combes (2010a) investigates the microeconomic drivers underlying the choice of shipment sizes both for carriers (with technology constraints) and for shippers (with logistic constraints). He assesses the empirical validity of the Economic Order Quantity (EOQ) formulae with the national French shipment database ECHO from 2004 (Guilbault, 2008). The database contains detailed information for about 10,000 shipments about the sender and the receiver, the relationship between these firms, the shipment and the transport. Combes concludes that the EOQ formula contributes to a first promising step to model the shippers' shipment size decision and that the choice of mode is strongly consistent with the choice of shipment size.

Arunotayanun and Polak (2009) develop an approach to accommodating supply chain structures in discrete choice models for mode choice. The application of the approach is illustrated using the French ECHO database. The results indicate that some gains in model performance can be obtained in nesting by supply chain structure. The results indicate further that there exist a number of significant determinants of the demand related to logistical and supply chain attributes (like contract forms). Combes and Leurent (2007) also emphasize the strong influence of the relationship between the agents in the transport chain and their contracts on the elaboration of transport services and costs.

Liedtke (2006, 2009) integrates elements of normative logistics in a bottom-up simulation model of interregional freight transportation. The INTERLOG model distinguishes explicitly between the roles and logistic optimizations of the different actors involved. The model includes the following steps: 1) generation and location of heterogeneous actors, 2) simulation of the establishment of supplier-recipient relationships and 3) integrated transport market and shipment size simulation. Shippers

and carriers interact through simulated auctions of transport contracts resulting in the generation of truck tours. For some transport relations (e.g. intercontinental) this would need to be extended to include third-party logistics service providers and shipping lines. The model describes the freight flows operated by independent carriers (not company-internal transports). It has been applied to long-distance freight transport markets in Germany.

Friedrich (2010a, 2010b) applies optimisation procedures from operations research and logistics that were originally developed for individual firms, also at the sector level. Logistic decisions of food retailing companies and suppliers are simulated by optimising the total logistics costs. The output includes the number, location and level of warehouses and the allocation of food retailing stores to warehouses. The SYNTRADE model for the German food retail sector is divided into three phases: 1) generation of detailed data for the core model (types and locations of stores, turnover of different article types) and simplified data for the periphery model (location and production volume for producers, wholesalers and logistic service providers, demand for article types in each region), 2) determination of supply paths for flows between the producers and food retailing firms or regions (incl. shipment sizes on each link) based on existing warehouse structures. 3) determination of warehouse structures. Phases 2) and 3) are repeated if there are changes compared to the initial structure.

Samimi et al. (2010) develop the activity based microsimulation model framework FAME (Freight Activity Micro simulation Estimator) for the United States. The model structure comprises five modules: 1) firms are identified; 2) supply chains are generated, assuming that suppliers have to meet the requirements set by the inventory strategy of a dominant actor, using agent-based models, discrete choice models or machine learning models; 3) shipment sizes/ frequencies are calculated using an optimization model, a discrete choice model, machine learning or a rule based model; 4) mode, transport time and costs, warehousing and level of consolidation are calculated using a disaggregate mode choice model, a machine-learning-approach or rule based models; 5) impacts on the infrastructure networks are calculated. The authors discuss the gap between ideal and available data on national freight movements, business establishments, shipments and supply chains and the freight transportation networks in the United States.

Models 1-3 and models 5-8 in Table 2 are aggregate models, model 4 (the Norwegian/Swedish national model) is an aggregate –disaggregate-aggregate and models 9-13 are disaggregate models. The table gives an overview about the logistic choices covered in the models. Please note that these models have a different level of detail and different interrelationships between decisions.

#### 4. The road ahead

In the previous section we argued that the most important recent improvement in freight modeling was the introduction of logistics decision-making. While we are still far away from having solved this issue, in this section we consider what might be the next key developments for practical freight models. A discussion on this, mainly from the user perspective, can be found in the Dutch roadmap for freight model development (Tavasszy, 2011). There are several new developments in the very recent -largely academic- literature, each of which might become important for the next generation of freight transport models developed for national or state authorities and the European Commission. These are discussed below.

Table 2. Choices covered in in national and international logistics models

	Models developed for regional, national authorities or EU												
	EUNET	SMILE	SLAM/TRANSTOOLS 1, 2	Norwegian/Swedish models	Maurer (2008)	Port competition (Zondag et al., 2010, Posthuma 2011, Tavasszy, 2011))	Holguin-Veras (2009), Wang Holguin-Veras (2009)	Groothedde et al. (2005)	Combes (2010)	Arunotayanun and Polak (2009)	Liedtke (2006)	Friedrich (2010)	Samiri et al. (2010)
Choices:	1	2	3	4	5	6	7	8	9	10	11	12	13
identification of firms				X							X	X	X
use/location of warehouses/DC		X	X		X			X				X	
shipment size		X	X	X	X				X		X	X	X
consolidation	X	X	X	X	X			X				X	X
loading units	X			X				X					
mode(s)/chains	X	X	X	X	X			X	X	X			X
vehicle type		X	X	X	X			X					
terminals/ports	X	X	X	X	X	X		X					
routes		X	X		X	X	X	X			X	X	
return transports				X		X	X						
shippers' choice of carrier										X	X		
shippers' choice of supplier													X

#### 4.1 Modelling further decisions of logistics agents

Models that include logistics decisions concerning transport or inventory require knowledge of the PC flows. These result from the decision about trade, i.e. which sender will do business with which receiver. Trade relations can be determined heuristically (as in the models for Sweden, Norway and Flanders) but they can also be modelled as a decision taken by a receiver of the goods (for further processing or for sale to consumers) about the choice of supplier to supply these goods. Often many of these decisions are not taken for a one-off delivery, but for many deliveries over an agreed period. Ideas on how to model these vary from SCGE and gravity models at the aggregate level to disaggregate, agent based models. Oum (1979) gave an early warning against the use of multinomial logit choice models estimated on aggregate data, because of the many restrictions this imposes on the parameters (e.g. uniform cross elasticities and inconsistencies in the preference structure). Nevertheless, because of the relative ease of obtaining aggregate data, this model specification is still the one used most in modelling freight mode choice in practice (for a further discussion on this, see de Jong et al., 2004).

Recently, Roorda et al. (2010) provided a new example within the context of a micro-model on logistics choices for the Greater Toronto area. We include this here, even though this is not a national or international model, because the basic ideas might be relevant for future national and international models. They first distinguish commodity contracts (supply and demand of the good), which can be handled in a random utility maximisation model, with attributes of the suppliers and their prices as explanatory variables. Then there are logistics contracts, where a business establishment decides to carry out the transport or outsources to an external logistics firm. This again could be handled in a random utility model, with attributes of the logistics firm and their prices as explanatory variables. Arunotayanun and Polak (2009) show that this distinction between supply/demand and logistics service contracts is relevant for the mode choice problem. Another example of a disaggregate approach to modeling where a receiver of the goods also chooses a supplier to buy from (based on random utility maximisation) is Samimi et al. (2010). The utility function includes receiver characteristics (quantity required, budget, modes) and supplier characteristics (capacity to produce/stock, price, geographic location).

#### 4.2 Production, inventory and transport logistics and their integration

There are still various fundamental questions associated with the descriptive modeling of logistics considerations in transport, inventory and even production. Most of the literature in the field of freight modeling deals with mode choice modelling. Decisions concerning production and inventory systems, vehicle scheduling routing are usually treated only in optimization models and, apart from the examples mentioned in this paper, do not appear in freight models intended for public policy analysis. Research should be carried out into the theoretical and empirical understanding of the behaviour of companies in the following areas of decision-making:

- Configuration of production networks and local production systems, to represent changes in logistic demands of products in the supply chain.

- Spatial distribution structures including location and use of warehouses, to represent changes in handling factors, length of haul and shipment sizes.
- The acquisition, scheduling, routing and repositioning of vehicles, to represent changes in vehicle stocks, use of light goods vehicles and vehicle occupancy rates.

The logistics models used within freight transport model systems so far have treated inventory and transport logistics largely independently. Also, they have taken production logistics more or less as given. But in order to become real activity-based freight models (comparable with activity-based passenger transport models), various logistics decisions need to be considered together, and the core activity of firms – production – needs to be modelled. There are several trade-offs between production and inventory decisions. Production might for instance be cheaper during certain periods of the week than other periods, but this would lead to larger inventories than a more regular production schedule, unless the extra goods produced were shipped off right away. This would call for a model that jointly or sequentially explains the production schedule, storage and transport (of inputs and outputs). An integrated view on production, inventory and transport logistics is also important on the global level, where there is a trade-off between labour costs and logistics costs (Tavasszy et al., 2012). Although it is certain that not all companies are able to optimise their decisions in such an integrated manner, the joint modelling of these decisions could increase our understanding in this area and allow designing freight systems that support such an integration of areas of logistics decision making.

#### 4.3 Departure time modelling

A potentially important new development concerns the timing of freight trips. Some passenger transport models include, besides the usual four steps, a model for the choice of departure time (usually in broad periods of the day, such as the morning peak). In these models, this often turns out to be one of the most sensitive choices (to changes in the infrastructure or pricing) in the model. For (inter)national, regional or local freight transport analysis, models that deal with departure time (e.g. scheduling models) are practically non-existent. Nevertheless, certainly for shorter freight trips, the timing of the trips is important for congestion and this might also be sensitive to transport time and costs (Mahmassani et al., 2007). Holguin-Veras et al. (2006) have been studying this issue for the case of a charge for freight transport during normal office hours in New York City. They found that it is not easy to change departure time for carriers since the receivers have a large say in this, and keeping their premises open outside office hours costs much more than the office hours supplementary charge.

#### 4.4 Integration with urban freight models

All the final goods (i.e. not true for raw and intermediate goods) that are modelled in a national or international model eventually need to go to the consumers. Most of the consumers nowadays live in cities, and the urban share in the population is growing further. This means that the delivery of the goods to the places where the consumers come and buy them needs to be dealt with, also in a national model (unless there is a good reason to only model intercity trips in a model). In larger countries, especially those with well-separated industrial and commercial cities, it may be advantageous to separate national and local freight models, but in countries with more spatially integrated freight transport patterns, it might be imperative to include local distribution in the

national model. National models only do this in a very approximate way, if at all. On the other hand, the area of urban freight transport modeling and city logistics has seen exciting new developments recently, and marrying these with national models would provide a better representation of the 'last mile' of the transports (Boerkamps and van Binsbergen, 1999; Figliozzi, 2007; van Duin et al., 2007; Hunt and Stefan, 2007; Wisetjindawat et al., 2007; Taniguchi and Thompson, 2008; Marcucci and Danielis, 2008; Wang and Holguin-Veras, 2008; Russo and Comi, 2010; Arunatoyanun et al., 2011). These are micro-based models that depict the behaviour of senders (producers, wholesalers), receivers (retailers) and/or carriers. The decisions for the carriers can include the formation of multi-drop delivery tours. Usually this is exclusively for road transport. In an urban context, light goods vehicles (LGV) or vans are also very relevant. Vans are often not included in the freight transport statistics, but some areas have special surveys on vans (Wigan and Rockliffe, 1998). Many vans are used for both freight and passenger transport.

#### 4.5 Integration with passenger transport modelling

Some transport models have a simultaneous assignment of passenger and freight vehicles to the same network (e.g. de Jong et al., 2010), which is one form of integrating passenger and freight transport modelling.

Russo and Comi (2010) go one step further and also include the shopping trips of the consumers in the same model as the urban freight. The shopping behaviour of the consumers then also acts in a demand-pull fashion to trigger replenishment behaviour of the retailers (a similar mechanism, but only at the conceptual level, was proposed in de Jong et al., 2004). The retailers then organise truck tours from their suppliers to keep their inventory at the right level. Several retail companies now have real time replenishment systems based on actual consumer purchases in the supermarkets for optimising these flows and their inventories, but public sector models do not have access to these data and might use a shopping model instead. In addition, the increased use of e-commerce possibilities will induce delivery trips from retailers to consumers and may reduce the number of shopping trips. So the integration of freight and passenger transport modelling that we are discussing here goes much further than combining trucks and cars in the same assignment procedure (which in itself makes perfect sense). There is also a need for integration with passenger transport modeling for the other modes. Examples are the common assignment of passenger and freight trains, the common use of air planes (pax belly) and ferries (ropax). At the spatial economic level, models of freight and passenger activities can be tied together through the labour and product markets. Here, the Krugman-type SCGE models (Ivanova et al., 2007) provide a theoretical and empirical framework for the integration of aggregate passenger and freight transport models.

#### 4.6 Including latent variables

Freight transport models are usually quite sparse, in the sense that they contain only a few explanatory variables. Also these variables are 'hard' mainly economic attributes, like transport time and cost. From interviews with shippers we know that many other variables play a role in decisions on modes, shipment size, contracting out, etc.. These additional variables are often of a 'soft' nature (e.g. reliability of transport time, probability of damage, reputation of a carrier, flexibility) and in many situations they cannot be observed. They can be included through indicator equations in latent class models (for an application in freight transport modelling, see Ben-Akiva et al, 2008). One of the variables that usually scores as very important for shipper decisions is transport time

variability ('reliability'). The monetary value for this can be obtained through stated preference experiments. But including this variable in a demand forecasting model also requires forecasts of reliability on the basis of exogenous variables (that we can also predict).

## 5. Summary and conclusions

In recent years, several public sector national, international and regional freight transport models have been developed and improved in order to increase the understanding of the impacts of transport policies on shippers, forwarders, carriers, drivers, the environment and ultimately the whole society. The focus of this paper was on developments that have taken place in Europe.

The introduction of logistics has been one of the main improvements of the models. The logistics models calculate transport and vehicle flows based on a given production and given location of firms and annual trade flows and sometimes also warehousing. One or several decisions taken by the actors in the transport and logistics system are modelled. Different aggregation levels are addressed (micro, meso, macro) and aggregate as well as disaggregate models are developed. This paper described the progress made in including "logistics" in regional, national and international freight modeling. Nevertheless, most practical freight transport models are still lacking logistics choice making.

The development of the logistics models has only been possible due to the access to data beyond the (in the EU compulsory) aggregate freight transport statistics. For certain study areas, logistic models could be constructed owing to the availability of specific data from commodity flow surveys (Sweden and France), other detailed information (The Netherlands, UK and Germany) or separate data projects at the European level (ETIS, now ETIS+). McKinnon (2010) discusses problems related to the European freight transport statistics. Among the urgent data needs are indicators for logistics costs, operations and performance, at the firm and aggregate level (i.e. representative for industries, regions or commodity groups).

The logistics models that are part of the national models in Norway and Sweden have been applied for policy analysis (Kleven, 2011; Vierth, 2011). The elasticities for mode choice are generally lower than the elasticities calculated in models without logistics module and probably more realistic (Vierth et al., 2010). There is limited experience when it comes to the impacts of policies on logistics indicators like shipment size, load factors or percentage of empty trips. In the Netherlands one limitation for the use of logistics models was the challenge of model maintenance due to model complexity and lack of suitable data.

Other developments in freight transport models in the last decade have taken place at the "front" end (economics, trade) and concern multiregional input-output and spatial computable general equilibrium models. Also in this part of the freight models the access to data is crucial; regional input/output tables and similar data are often not available, let alone for a recent year. Also some models have begun to take explicit account of the fact that multiple decision-makers decide on the same commodity flows, by using interactive surveys, game theory and experimental economics.

We expect that all these developments will continue in the next decade. But there are also further innovations, which we also expect to be developed further in the next decade, possibly even up to the level of practical freight transport forecasting models:

- Models that include the choice of the location of the supplier or the receiver of the goods;
- Integration of production behaviour modeling with modeling inventory and transport behaviour:
- Modelling of the timing of freight trips;
- Integration of national/international freight transport models with urban models;
- Integration with passenger transport models that encompasses the joint assignment of passengers and freight to a common transport network;
- Inclusion of more explanatory variables than transport (and time), especially of 'soft' factors.

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## References

- Arunotayanun, K. (2009). Modelling freight supplier behaviour and response. PhD thesis, Centre for Transport Studies, Imperial College London.
- Arunotayanun, K., & Polak, J. (2009). Accounting for Supply Chain Structures in Modelling. European Transport Conference (ETC).
- Bates, J.,J. (2011).Freight modelling and policy analysis in The Unites Kingdom, Presentation at the CTS-Seminar on European and National Freight Demand Models, Stockholm.
- Barloworld Optimus. (2008). Retrieved from <http://www.barloworldscs.com/home/solutions/cast-supply-chain-modelling/cast-software.aspx>
- Baumol, W.J. and H.D. Vinod (1970). An inventory-theoretic model of freight transport demand, *Management Science*, 16, pp. 413-421.
- Ben-Akiva, M.E. and G.C. de Jong (2008).The aggregate-disaggregate-aggregate (ADA) freight model system, in *Recent developments in transport modelling: lessons for the freight sector* (Eds: M.E. Ben-Akiva, H. Meersman and E. van de Voorde), Emerald, 2008.
- Ben-Akiva, M.E., D. Bolduc and J.Q. Park (2008) Discrete choice analysis of shippers' preferences, in *Recent Developments in Transport Modelling* (Eds.: M.E. Ben-Akiva, H. Meersman and E. Van de Voorde), Emerald, Bingley, U.K.
- Beuthe, M.B.J. ,J.-F. Geerts, C. Koul a Ndjang Ha (2001).Freight transport demand elasticities: a geographic multimodal transportation network analysis, *Transportation Reseach part E*, 37, pp. 253-266.
- Boerkamps, J. and A. van Binsbergen (1999.) GoodTrip– A new approach for modelling and evaluation of urban goods distribution, *Urban Transport Conference, 2nd KFB Research Conference*, Lund.
- Bovenkerk, M. (2005). SMILE+: the new and improved Dutch national freight model system, Paper presnted at the *Europeana Transport Conference*, Strasbourg .
- Carrillo Murillo, D. (2010).Demand and supply interaction in transport models: the case of hinterland transportation, PhD thesis, Institute of Economic Policy Research (IWW), Karlsruhe Institute of Technology (KIT)
- Chen, M. (2011). ETIS and TRANS-TOOLS v1 Freight demand, Presentation at the CTS-Seminar on European and National Freight Demand Models. Stockholm.
- Chen, M. and P. Tardieu (2000). The NEAC model, answering policy questions in a European context, paper presented at THINK-UP seminar 1, Paris.
- Chow, J.Y.J., C.H.Y. Yang and A.C. Regan (2010). State-of-the art of freight forecast modeling: lessons learned and the road ahead, *Transportation*, vol. 37, no. 6, 1011-1030.

- Combes, P.F. (2010a). The choice of shipment size in freight transport (PhD). Paris: Université Paris-Est.
- Combes, P.F.; Leurent, F. (2007). Advances in freight transport demand modelling: An Assessment with research perspectives. European Transport conference (ETC) 2007.
- Combes, P.F. (2010). Estimation of the economic order quantity model using the ECHO shipment data base, paper presented at the European Transport Conference, Glasgow.
- CSCMP. (2011). Council of Supply Chain Management Professionals (CSCMP), Supply Chain Management Definitions. Retrieved from <http://cscmp.org/aboutcscmp/definitions.asp>
- CTS (2011). KTH - Centre for Transport Studies (CTS). Retrieved from [http://www.kth.se/abe/centra/cts/seminarier/temadagar/temadagar2011?l=en\\_UK](http://www.kth.se/abe/centra/cts/seminarier/temadagar/temadagar2011?l=en_UK)
- de Jong, G. , Gunn, H., and Walker, W. (2004). National and International Freight Transport Models: An Overview and Ideas for Future Development. *Transport Reviews*, Vol. 24, No. 1, 103 - 124.
- de Jong, G., and Ben-Akiva, M. (2007). A micro-simulation model of shipment size. *Transportation Research B* (41) 9, pp. 950-965.
- de Jong, G., Ben-Akiva, M., and Baak, J. (2008a). Method Report - Logistics Model in the Norwegian National Freight Model System (Version 2).Significance.
- de Jong, G., J. Baak, K. Ruijs, M. Pieters, T. Bellemans, D. Janssens and G. Wets (2010). Passenger and freight transport in Flanders 2010-2040 under three scenario's, Paper presented at the European Transport Conference 2010, Glasgow.
- de Jong, G.; Ben-Akiva, M.; Baak, J. (2008b). Method Report - Logistics Model in the Swedish National Freight Model System (Version 2).Significance.
- de Jong, G. , Johnson, D. (2009). Discrete mode and discrete or continuous shipment size choice in freight transport in Sweden, Paper presented at the European Transport Conference, Noordwijkerhout, The Netherlands.
- Duin, J.H.R. van, L.A.Tavasszy, E.Taniguchi (2007). Real time simulation of auctioning and re-scheduling processes in hybrid freight markets, *Transportation Research part B: Methodological*, Vol.41(9), pp. 1050-1066
- European Commission. (2011). Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system (White Paper) COM(2011) 144 final. Brussels: European Commission.
- Figliozzi, M.A. (2007). Analysis of the efficiency of urban commercial vehicle tours: data collection, methodology and policy implications, *Transportation Research B*, Vol. 41, Issue 9, 1014-1032.
- Fowkes, A.S., D. Johnson and A.E. Whiteing (2010). Modelling the effect of policies to reduce the environmental impact of freight transport in Great Britain, Paper presented at the European Transport Conference, Glasgow.

- Friedrich, H. (2010a). Simulation of logistics in food retailing for freight transportation analysis. Karlsruhe: Karlsruher Institut für Technologie (KIT).
- Friedrich, H. (2010b). Simulation of logistics in food retailing for freight transportation analysis. World Conference on Transport Research (WCTR), Lisbon.
- Friesz, T. R. Mookherjee, J. Holguin-Veras and M.A. Rigdon (2008). Dynamic pricing in an urban freight environment, *Transportation Research B*, Vol. 42, 305-324.
- Grønland, S. (2004). Logistical terminology (draft), SITMA, Oslo.
- Grønland, S.E.; Madslie, A. (2009). Konsolidering i logistikkmodellen, SITMA, Oslo.
- Groothedde, B., Ruijgrok, C., & Tavasszy, L. (2005). Towards collaborative, intermodal hub networks, A case study in the fast moving consumer goods market. *Transportation Research, Part E*, pp. 567-583.
- Guilbault, M. (2008). Enquête ECHO « Envois-Chargeurs-Opérateurs de transport ». Résultats de référence (Synthese no 58). INRETS (<http://www.inrets.fr>).
- Habibi, S. (2010). A Discrete Choice Model of Transport chain and Shipment size on Swedish Commodity Flow Survey. Stockholm: Kungliga Tekniska högskolan, Department of Transport and Logistics.
- Hansen (2010) Hansen, W. (2010). Developing a new spatial computable general equilibrium for Norway, Paper presented at European Transport Conference 2010, Glasgow.
- Hansen, C.O. (2011a). Trans-Tools version 2, Presentation at the CTS-Seminar on European and National Freight Demand Models, Stockholm.
- Hansen, C.O. (2011b). Freight modelling and policy analysis in Denmark, Presentation at the CTS-Seminar on European and National Freight Demand Models, Stockholm.
- HEATCO. (2006). Developing Harmonised European Approaches for Transport Costing and Project Assessment. Stuttgart: Universität Stuttgart (<http://heatco.ier.uni-stuttgart.de/>).
- Hensher, D.A. (2002). Models of organisational and agency choices for passenger and freight-related travel choices: notions of inter-activity and influence, Resource paper prepared for the 8<sup>th</sup> IATBR conference workshop on 'Models of organisational choices (freight and passenger)', Lucerne.
- Hensher, D.A. and S. M. Puckett (2005). Refocussing the modelling of freight distribution: development of an economic-based framework to evaluate supply chain behaviour in response to congestion charging, *Transportation*, Vol. 32, 573-602.
- Holguin-Veras, J., & Thorson, E. (2003). Modelling commercial vehicle empty trips models with a first order trip chain model. *Transportation Research B* (37)2, pp. 129-148.

- Holguín-Veras, J., M. Silas, J. Polimeni and B. Cruz (2006). An Investigation on the Effectiveness of Joint Receiver-Carrier Policies to Increase Truck Traffic in the Off-Peak Hours. Part I: The Behavior of Receivers, Networks and Spatial Economics, DOI 10.1007/s11067-006-9002-7.
- Holguín-Veras, J. and G. Patil (2008). A Multicommodity Integrated Freight Origin–destination Synthesis Model, Networks and Spatial Economics 8(2), 309-326
- Holguin-Veras, J. , E. Thorson and J.C. Zorilla (2008). Commercial vehicle empty trip models with a variable zero order empty trip probabilities, Networks and Spatial Economics, published online at <http://dx.doi.org/10.1007/s11067-008-9066-7>.
- Holguin-Veras, N. Xu, G.C. de Jong and H. Maurer (2009). An experimental economics investigation of shipper-carrier interactions on the choice of mode and shipment size in freight transport, Networks and Spatial Economics, DOI 10.1007/s11067-009-9107-x, <http://www.springerlink.com/openurl.asp?genre=article&id=doi:10.1007/s11067-009-9107-x>, 2009.
- Hunt J.D., R. Donnelly, J.E. Abraham, C. Batten, J. Freedman, J. Hicks, P.J. Costinett and W.J. Upton (2001). Design of a statewide land use transport interaction model for Oregon, Proceedings of the 9<sup>th</sup> World Conference for Transport Research, Seoul, South Korea.
- Hunt, J.D. and K.J. Stefan (2007). Tour-based microsimulation of urban commercial movements, Transportation Research Part B, Vol. 41, No. 9, 981-1013.
- Ibanez, N. (2011). TRANS-TOOLS developments and use of the model for EU studies, Presentation at the CTS-Seminar on European and National Freight Demand Models.
- Intraplan and BVU (2007). Prognose der deutschlandweiten Verkehrsverflechtungen 2025, ITP and BVU, München/Freiburg.
- Ivanova, O., C. Heyndrickx, K. Spitaels, L. Tavasszy, W. Manshanden, M. Snelder and O. Koops (2007). RAEM version 3.0, Transport Mobility Leuven, Leuven
- Jammernegg, W., Rosič, H., & Bauer, G. (2009). freightvision, Freight Transport Foresight 2020, Deliverable 4.2. , Logistics trends report.Vienna: WU Vienna University of Economics and Business.
- Jin, Y, I. Williams and M. Shahkarami (2005). Integrated regional economic and freight logistics modeling: results from a model for the Trans-Pennine Corridor, UK, Paper presented at the European Transport Conference 2005, Strasbourg.
- Jourquin, B. and M., Beuthe (1996) Transportation policy analysis with a GIS: The virtual network of freight transportation in Europe, Transportation Research C, 4(9), 359-371.
- Kleven, O. (2011). Freight modelling and policy analyses in Norway, Presentation at the CTS-Seminar on European and National Freight Demand Models.
- K+P Transport Consultants and Tritel (2006). Ontwikkeling van een multimodaal goederenvervoer-model voor Vlaanderen, rapport voor de Vlaamse Overheid, K+P Transport Consultants and Tritel, Freiburg/Mechelen.

- Liedtke, G. (2006). *An Actor-based Approach to Commodity Transport Modelling*. Baden-Baden: Nomos.
- Liedtke, G. (2009). Principles of micro-behavior commodity transport modeling. *Transportation Research Part E*, pp. 795-809.
- List, G.F. and M.A. Turnquist (1994). Estimating truck travel patterns in urban areas, *Transportation Research Record*, No. 1430, 1-9.
- Mahmassani, H.S., K. Zhang, J. Dong, C.C. Lu, V.C. Arcot and E. Miller-Hooks (2007). Dynamic network simulation-assignment platform for multiproduct intermodal freight transportation analysis, *Transportation Research Record*, 2032, 9-16.
- Marcucci, E. and R. Danielis (2008). The potential demand for an urban freight consolidation centre, *Transportation*, Vol. 35, issue 2, 269-284.
- Marzano, V. and A. Papola (2004). Modeling freight demand at a national level: theoretical developments and application to Italian demand, Paper presented at the European Transport Conference 2004, Strasbourg.
- Maurer, H. (2008). *Development of an Integrated Model for Estimating Emissions from Freight Transport (PhD)*. University of Leeds, Institute for Transport Studies.
- McKinnon, A. (2010). *European Freight Transport Statistics: Limitations, Misinterpretations and Aspirations*, Report prepared for the 15th Scientific Advisory Group Meeting - Brussels 8th September 2010. Brussels: ACEA.
- MDS-Transmodal (2003). *The GB freight model documentation project: methodology*, MDS-Transmodal Ltd, Chester.
- Minderhoud, M., L.A.Tavasszy, J.F.Perrin (2009). A strategic port choice model for worldwide container flows, *Proceedings of the 88th Annual meeting of the Transportation Research Board*, Washington: TRB.
- MVA and Kessel+Partner (2006). *MODEV – Modèle Marchandises, Note Méthodologique*, MVA and Kessel+Partner, Paris/Freiburg.
- Nestear (2010). *Note méthodologique détaillée – Transport de marchandises*. NESTEAR, Paris.
- Newton, S. (2008). *Worldnet: Applying transport modelling techniques to long distance freight flows*, Paper presented at the European Transport Conference, Noordwijkerhout, The Netherlands.
- Nielsen, O.A. (2011). *Transtools 3*, Presentation at the CTS-Seminar on European and National Freight Demand Models, Stockholm.
- Oum, T. (1979). A warning on the use of linear logit models in transport mode choice studies, *Bell Journal of Economics*, 10, pp. 374-388.

- Pekin, E., C. Macharis, A. Caris, G.K. Janssens, T. Crépin and B. Jourquin (2007). Integrated decision support tool for intermodal freight transport, Vrije Universiteit Brussel, Universiteit Hasselt and Les Facultés Universitaires Catholiques de Mons.
- Perrin, J.-F.; Tavasszy, L.; van Meijeren, J.; Minderhoud, M.; Burgess, A.; Bowden, N. (2008). Worldwide Container Model. European Transport Conference (ETC) 2008. Posthuma, C. (2011) Towards a competitive and socially responsible port of Rotterdam using port competition modelling, MSc thesis, Delft University of Technology.
- Puckett, S. M. and D.A. Hensher (2006). Modelling interdependent behaviour as a sequentially administrated stated choice experiment: analysis of freight distribution chains, Paper presented at the International Association of Travel Behaviour Research Conference, Kyoto.
- Reynaud, C. (2011). LOGIS European Model, Presentation at TRANS-TOOLS 3 workshop, Copenhagen March 25 2011.
- Roorda, M.J.,R. Cavalcante, S. McCabe and H. Kwan (2010). A conceptual framework for agent-based modelling of logistics services, *Transportation Research E*, vol. 46, no. 1, 18-31.
- Russo, F., and A. Comi, A. (2010). A modelling system to simulate goods movement at an urban scale, *Transportation*, vol. 37, no. 6, 987-1009.
- Samimi, A., Mohammadian, A., & Kawamura, K. (2010). Freight Demand Microsimulation in the U.S. World Conference on Transport Research (WCTR): Lisbon.
- SAMPLAN. (2004). The Swedish National Freight Model - A critical review and an outline of the way ahead. Stockholm: SIKa, SAMPLAN 2004:1.
- SCENES Consortium (2000). SCENES European transport forecasting model and appended module, Technical description, SCENES deliverable 4 for the European Commission DG-TREN, ME&P, Cambridge.
- Significance, NEA and DEMIS (2010). Schatting BASGOED, Rapportage DP1; A report for DVS-Rijkswaterstaat, Significance, The Hague.
- SIKA (2004). Commodity Flow Surevy (SIKA-report 2004:3). [http://www.sika-institute.se/Templates/FileInfo.aspx?filepath=/Doelib/Import/104/sr\\_2003\\_4e.pdf](http://www.sika-institute.se/Templates/FileInfo.aspx?filepath=/Doelib/Import/104/sr_2003_4e.pdf) .
- Taniguchi, E. and R.G. Thompson (2008). Innovations in city logistics, Nova Science Publishers, Haippauge, NY.
- Tavasszy, L.A. (1996). Modelling European Transport Flows, PhD Thesis, Delft University of Technology
- Tavasszy, L.A., Smeenk, B., C.J. Ruijgrok (1998). A DSS for modelling logistics chains in freight transport systems analysis, *International Transactions in Operational Research*, Vol. 5, No. 6, pp. 447-459
- Tavasszy, L.A. (2011). Freight modelling and policy analysis in The Netherlands, Presentation at the CTS-Seminar on European and National Freight Demand Models, Stockholm.

- Tavasszy, L.A., M. Minderhoud, J-F. Perrin and T. Notteboom (2011). A strategic network choice model for global container flows: specification, estimation and application, *Journal of Transport Geography*, 19 (6), 1163-1173.
- Tavasszy, L.A., Ruijgrok, K., & Davydenko, I. (2012). Incorporating logistics in freight transportation models: state of the art and research opportunities. *Transport Reviews: a transnational transdisciplinary journal*, DOI: 10.1080/01441647.2011.644640.
- Tetraplan (2009). TENCONNECT. Copenhagen: Tetraplan A/S.
- TNO (2008). TRANS-TOOLS, Deliverable 6: TRANS-TOOLS Final Report, WP 6. Delft : TNO Inro (The Netherlands).
- Vierth, I. (2004). Applications, weaknesses and development issues of the Swedish National Freight Transport Model System SAMGODS (SIKA Document 2004:1). Stockholm: SIKA (<http://www.trafa.se/Publikationer/>).
- Vierth, I. (2011, 3 1). Freight modelling and policy analyses in Sweden, Presentation at the CTS-Seminar on European and National Freight Demand Models. Stockholm.
- Vierth, I., Hylén, B., Mellin, A., de Jong, G., & Bucci, P. (2010). Priselasticiteter som underlag för konsekvensanalyser av förändrade banavgifter för godstransporter, VTI Notat 10-2010. Linköping: VTI.
- Vold, A, V. Jean-Hansen, PINGO (2007). A model for the prediction of regional and interregional freight transport in Norway, TOI, Oslo
- Wigan, M., & Southworth, F. (2005). What's wrong with freight models? Paper presented at the European Transport Conference, Strasbourg.
- Wang, Q. and J. Holguin-Veras (2009). Tour-based entropy maximization formulations of urban freight demand, paper presented at the 88<sup>th</sup> Annual Transportation Research Board Conference, TRB, Washington.
- Wigan, M. and N. Rockliffe (1998). Freight survey requirements for urban areas, Proceedings of 19<sup>th</sup> ARRB Conference, Sydney, Vol. 1, 109-131.
- Williams, I, (2011) Fundamentals of modelling goods vehicles in urban areas, WSP, Cambridge.
- Windisch, E. (2009). A disaggregate freight transport model of transport chain and shipment size choice on the Swedish Commodity Flow Survey 2004/05. Delft.
- Winston, C. (1983). The demand for freight transportation: models and applications, *Econometrica*, 49, pp. 981-1006.
- WSP (2002). Feasibility Study of SCGE Models of Goods Flows in Sweden - report prepared for Swedish Institute for Transport and Communications Analysis SIKA. Cambridge.
- WSP (2011). Base Year Freight Matrices: final report, report prepared for the ITEA Division of DfT, WSP, Cambridge (forthcoming).

Wisetjindawat, W., K. Sano, S. Matsumoto and P. Raathanachonkun (2007). Micro-simulation model for modeling freight agents interactions in urban freight movements, Paper presented at 86<sup>th</sup> Annual Meeting of the Transportation Research Board, Washington DC.

Zhong, M., J.D. Hunt and J.E. Abraham (2007). Design and development of a statewide land use transport model for Alberta, Journal of Transportation Systems Engineering and Information Technology, Vol. 7, Issue 1, pp. 79-91.

Zondag, B., P. Bucci, P. Gützkow and G.C. de Jong (2010). Port competition modeling including maritime, port, and hinterland characteristics. Maritime Policy & Management (37)3, pp. Maritime Policy & Management, Volume 37, Number 3, May 2010.