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Seven Fat Years or Seven Lean Years for Freight Transport Modelling?

Developments Since 2013

Gerard de Jong, Michiel de Bok, and Sebastiaan Thoen

Address for correspondence: Gerard de Jong is at Institute for Transport Studies, University of Leeds, 36–40 University Road, Leeds, LS2 9JT, UK (g.c.dejong@its.leeds.ac.uk). Michiel de Bok and Sebastiaan Thoen are at Significance, Grote Markstraat 47, 2511 BH De Haag, The Netherlands (debok@significance.nl and thoen@significance.nl).

Abstract

Freight transport modelling has seen many developments in this century. A key trend was the inclusion of more aspects of logistics thinking in freight transport models for the public sector. In de Jong *et al*. (2013) is a list of topics that were expected to be the main areas for further development in freight transport modelling in the next decade. The current paper describes the developments that have actually taken place in modelling freight transport, at the international, national, regional, and urban level, and compares these to the list in the 2013 paper.

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1.0 Introduction

For a long time, freight transport modelling was an under-researched topic and most of the applications to freight transport borrowed heavily from passenger transport modelling. Only occasional innovative work took place. This includes Bayliss (1988) and especially Bayliss and Edwards (1970), who already had a probability model at the level of individual consignments. Other examples of early innovative papers in freight transport modelling are Baumol and Vinod (1970), which combined transport and inventory considerations, and the applications of random utility modelling (albeit transferred from passenger transport) in Chiang *et al.* (1981) and Winston (1981). Since the start of the new millennium, freight transport modelling has been receiving much more attention and seen more development.

A paper published in 2013 (de Jong *et al.*, 2013) reviewed the freight transport models that were available at the time, with a focus on the national and international level and on Europe. It concluded that in the decade up to 2013, the main development in the freight transport models at these levels was the inclusion of more logistics components (such as inventory considerations and use of multimodal transport chains, consolidation, and distribution, instead of a single main mode). This paper also included a list of key developments that were expected to take place in freight transport modelling in the years to come. Even though some of these developments had already begun, predictions of which new topics would be studied and which new methods developed were highly uncertain. The actual developments in freight transport modelling depend on many different researchers with their own research interests and skills, and also on the topics that are debated in transport policy making, which may shift over time.

The key developments expected for the following decade, mentioned under 'The road ahead' in de Jong *et al.* (2013), were:

- integration of production, inventory, and transport logistics;
- modelling of further logistics decisions, especially supply chain formation;
- departure time modelling;
- integration of (inter)national (intercity) freight models with urban freight models;
- integration of freight transport models with passenger transport models; and
- including latent variables (for example, on attitudes) in freight transport models leading to hybrid models with hard (for example, time and cost) and soft (for example, attitude towards the environment) variables.

The current article will review developments in applied freight transport modelling since the 2013 paper — that is during, the past seven years. Unlike the 2013 paper, we will also discuss urban freight transport models, since many of the developments in recent years have occurred in freight models at this level. We also include developments that have taken place outside Europe. Similar to the 2013 paper, we will not discuss models used in the private sector to optimise a firm's transport activities, but restrict ourselves to freight transport models developed for transport authorities or to study freight transport in some geographic study areas in academia.

In Section 2, the paper will first review international freight transport models, followed by Sections 3, 4, and 5 on national, regional, and urban models, respectively. Then in Section 6, we will take each of the expected developments from de Jong *et al.* (2013), and discuss whether the expected changes have actually taken place. Section 7 will look at other important developments in freight transport modelling, which were not foreseen in the list of 2013 but can be observed to be happening. A summary and conclusions on whether the past seven years have been fat or lean for freight transport modelling, and also including a future outlook, will be provided in Section 8.

2.0 Developments in International Freight Transport Models

Most of the freight transport models at the European level that were mentioned in de Jong *et al.* (2013) have been superseded by newer models. More recently developed models that operate at the European level are HIGH-TOOL, Transtools3, TRUST, and TRIMODE. All these models include both passenger and freight transport. Below, we briefly discuss each of these.

HIGH-TOOL (Szimba *et al.*, 2018) is a strategic transport policy assessment instrument, developed for the European Commission. It is relatively easy and fast to use and is open-source, so as to allow policy makers to apply the model for themselves to strategically evaluate the impacts of transport policies on transport, environment, and economy. The model is broad (it also includes an ‘Economy and Resources’ module following spatial computable general equilibrium (SCGE) principles, vehicle stock models, demography, the environment, and safety), but to remain fast had to compromise on spatial detail (it uses 314 zones, corresponding to NUTS2 in the EU and coarser outside) and network assignment was excluded.

The freight transport model within HIGH-TOOL is an aggregate model that follows the conventional four-stage approach in several ways (please note that step four, the network assignment, is missing here). However, there are some important aspects where the model goes beyond what is standard in four-stage models:

- The trade projections are produced by the Economy and Resources module, and these refer to the flows from the producing zone to the consumption zone of the goods (PC flows, not origin-destination OD flows, which are used in most conventional freight models). There are several advantages of a PC-based approach for modelling trade over an OD-based approach (Ben-Akiva and de Jong, 2013). In a PC-based model, the forecasts of the trade flows will be based on economic development in the producing and consuming regions, not on what happens in intermediate regions where transhipments take place. However, when it comes to network assignment, OD-flows are the relevant measure. In practice, many transports go through transhipment points, and assigning the OD trips within these transport chains is more accurate. The data available for transport flows (for example, from traffic counts and interviews with carriers) are also at the OD level.
- The freight transport between the production and consumption zone is modelled by multimodal transport chains, considering the transport modes air, rail, road, inland waterways, and maritime transport. The distribution of mode chains follows a multinomial logit model and distributes the freight flow across multimodal transport chains (routed through transhipment points) for up to two transhipment points.

The Transtools3 model also follows the distinction between PC flows and OD flows. It differs from other European models in that the central component of its freight transport component — namely, the sub-model for the choice of (possibly multimodal) transport chains — was estimated on disaggregate data (Jensen *et al.*, 2019). These data sources are the Swedish Commodity Flow Survey 2009 and the French ECHO survey that was carried out in 2004. The modes that can be part of these transport chains are road, rail, inland waterways, and sea transport. The transport chain models are nested logit models and different kinds of non-linear cost functions, including spline functions, were tested. The Transtools3 freight model also contains aggregate models for the prediction of the PC flows, with logsums from the chain choice model influencing the trade patterns (de Jong *et al.*, 2017), and for network assignment. Unlike HIGH-TOOL, it uses a zoning system that resembles the NUTS3 classification (more than 1,500 zones).

TRUST is a network assignment model (TRT, 2018) developed for assessing EU transport policies. It uses a fixed OD matrix for passenger and freight traffic at the NUTS3 level. However, by combining this network module with the older ASTRA passenger and freight transport demand model (which is a system dynamics model), feedback to transport demand can be taken into account to change the OD matrices. TRUST carries out assignments for road, rail, and maritime transport.

TRIMODE (Nöckel *et al.*, 2017; Martino *et al.*, 2018) is the latest transport model developed for the European Commission. It comprises passenger and freight transport. Like HIGH-TOOL and Transtools3, the TRIMODE freight transport model also starts from the basic distinction between PC and OD flows. It uses an SCGE Economy model to determine the PC flows, and allows for multimodal transport chains between the production and consumption locations. Unlike Transtools3, the transport chain model is based on aggregate data; this is a nested logit model with main mode, feeder mode, and some vehicle type choice. TRIMODE models not only multimodal transport chains but also intermediate storage along the distribution channel, where the storage can take place at national, regional, and/or local distribution centres, based on transport and warehousing costs. The spatial level is that of NUTS3, and the modes included for freight transport are road, rail, inland waterways, maritime, air, and pipeline.

Besides freight transport models for Europe, there are also other international models, especially global transport models. In this respect, the WorldNet model that was mentioned in de Jong *et al.* (2013) is still in use, and there is also a global model, based on transport costs minimisation, for international container transport (Halim, 2017). ITF also has its own transport forecasting tool, which includes a global freight transport model for both domestic and international flows, with components for trade patterns, value-to-weight ratios, mode choice, and route choice, all at the aggregate (zonal) level (ITF, 2019). Models that focus on cross-border transport of two countries are discussed under regional models below.

Konstantinus (2019) and Konstantinus *et al.* (2020) developed a mode choice model for the choice between road transport and short-sea shipping (SSS) for the Southern African Development Community (SADC), an intergovernmental organisation wherein the 16 southern African countries work together. The model was based on stated preference interviews with shippers and freight forwarders. The models estimated include multinomial and mixed logit but also latent class models, where the unobserved heterogeneity between respondents/shipments was linked to characteristics of the product shipped. In addition, in this research project the integrated choice and latent variable (ICLV) model or ‘hybrid model’ was employed to assess the attitudes of shippers towards employing SSS.

3.0 Developments in National Freight Transport Models

BasGoed is the strategic Freight Transport model for the Netherlands. The initial model that was developed almost a decade ago applies the conventional four-step approach, where route choice is handled in already existing individual assignment models for each mode: road, rail, and inland waterways (de Jong *et al.*, 2011). Freight generation is modelled in the 'Economy' module, which applies economic make/use patterns for the national economy to simulate regional freight demand; international trade scenarios are used to calculate international freight patterns.

The functionality of the BasGoed model was further extended by the implementation of a multimodal transport chain model for container transport (de Bok *et al.*, 2018), which can be used to evaluate the impacts of new multimodal terminals. In the absence of good quality multimodal transport data, this model was calibrated by linking unimodal data for different transport modes.

In the latest model improvement stage of BasGoed, the functionality of the Economy module was improved to be able to include the impact of climate transition on freight transport demand. This transition to a more sustainable energy mix is simulated using a shift functionality that modifies the use of resources in the production function. In addition, the sectoral industry growth scenario and investment assumptions were modified consistently (Wesseling *et al.*, 2020). Such an application requires specific scenario input on the energy mix, and an input/output growth scenario.

The aggregate-disaggregate-aggregate (ADA) model is a framework for freight transport models at the international, national, or regional level, which was originally developed in the first decade of the 20th century (de Jong and Ben-Akiva, 2007; Ben-Akiva and de Jong, 2013). It distinguishes three model steps:

- the PC model, which explains trade between the location of production and the location of consumption;
- the logistics model, which explains logistics decisions such as transport chain choice and shipment size choice, and in this way translates the PC flows into mode-specific OD-flows; and
- the network model for assignment of origin-destination matrices to the transport networks.

The ADA philosophy is that it is most important that the logistics choices (the 'middle part') are modelled at the level of the individual decision makers (disaggregate level), because decision makers on all goods flows between two zones per commodity type do not exist, and this would assume a greater level of coordination and optimality than what happens in reality. Modelling the PC flows and the network assignment at the aggregate (zone-to-zone) level on the other hand is acceptable for reasons of data availability and computation time. In order to have a disaggregate logistics model, the outcomes of the PC model have to be allocated to individual firms at both ends (firm-to-firm flows), and before network assignment flows have to be aggregated into OD matrices. The ADA model has been worked out in practice in a number of countries, where gravity models, input-output models, or SCGE models are used to obtain the PC matrices, deterministic minimisation of the full logistics costs (including transport, inventory, and capital cost) is used to yield the logistics outcomes at the micro-level, and existing commercial packages are used for network assignment. Applications of the ADA model at the national level to date are as follows:

- The Norwegian national freight transport model. This uses the PINGO SCGE model for the generation of PC flows, a deterministic logistics cost minimisation approach, and a commercial assignment package.
- The Swedish national freight transport model Samgods, which uses a gravity approach for the PC flows, deterministic logistics cost minimisation, and commercial assignment software (also for steering the model as a whole).
- The Danish national freight transport model; this uses a similar approach to the Norwegian and Swedish models (also with deterministic logistic choices), but a special component of the model — the Fehmarn Belt model — that can be run separately was estimated on disaggregate stated and revealed preference (SP/RP) data.
- Development of an ADA national freight transport model has started in Austria (Grebe *et al.*, 2020). The PC flows will come from an input-output model, the logistics model will be estimated as far as possible on new SP/RP data collected as part of the project, and the network assignment and overall model steering will use a commercial package.

The Swedish Commodity Flow Survey (CFS) has been used in several projects to estimate discrete choice models of the choice of transport chain and shipment size in the Swedish freight market (Abate *et al.*, 2014, 2018; Lindgren *et al.*, 2019). The purpose of this set of projects has been to promote the development of a so-called stochastic logistics module in Samgods, where the logistics choices are based on a logit-formula and coefficients are estimated on observed choices by shippers, to replace the currently operational version of Samgods that uses a deterministic logistic costs minimisation for transport chain and shipment size choice. These projects show that estimation of a transport chain and shipment size choice component for a national model system is feasible, and leads to more plausible elasticities and forecast in general than a deterministic approach.

The USA also has several national freight transport models that have been developed in the recent past, such as the FAME microsimulation model (Samimi *et al.*, 2010), or the nationwide disaggregate mode and shipment size choice models that have been estimated on the US CFS by Holguín-Veras and colleagues at Rensselaer Polytechnic Institute (for example, Holguín-Veras *et al.*, 2019) or that are under development, such as the national model for the developed by a consortium led by RSG. In another project for the Federal Highway Administration, a national freight traffic assignment model for the USA, also including conversion from 132 Freight Analysis Framework (FAF) zones to OD matrices for 3,500 zones and from tonnes to vehicles, was developed (Rabinovicz and Slavin, 2020).

4.0 Developments in Regional Freight Transport Models

The strategic Flemish freight model (SVRM) is used by the Flemish authorities to forecast the demand for freight transport in the future, and to support the decision-making process for large infrastructure investments or the implementation of a kilometre charge for heavy goods vehicles (Grebe *et al.*, 2016). The model simulates all national and international flows of goods for road, rail, and inland waterway transport for the region of Flanders (northern part of Belgium). It has a classical four-step structure including detailed network models for road, rail, and inland waterways, with several additions such as a time-period choice model, and the choice between direct transport and the use of logistic hubs by mode.

The time-period choice model in the SVRM only applies to road transport (de Jong *et al.*, 2016). It determines the choice of when to carry out the transport, distinguishing seven periods during the day (for example, the morning and the afternoon peak). It was estimated on SP data collected among receivers of the goods, given that the existing literature had indicated that the receivers are the most important agents on the period choice in freight transport by setting the delivery time or time window (for example, Holguín-Veras *et al.*, 2012). This time period model can be used to simulate the impact of changes in the level of congestion on the roads or of kilometre charging schemes with variation in the charges between time periods. Time period choice in road freight transport was also investigated in Australia using latent curve models, a form of structural equations modelling (Ellison *et al.*, 2015).

The SVRM also distinguishes multiple vehicle types within each mode (three types for road and rail, and six for inland waterways). The calibration took place on aggregate data, due to the absence of disaggregate data on transport flows.

The de Jong *et al.* (2013) review also mentioned some pioneering freight transport models from North America (for example, for Oregon, Calgary, Toronto, or the FAME national US model). Since then, North America has been at the forefront of new developments in freight transport modelling.

Florida's FreightSim model (RSG, 2015a) is part of the Florida Statewide Model (FLSWM). It simulates the transport of goods between supplier and buyer (receiver) firms in the USA — within, into, out of, and through Florida. This model also makes the distinction between PC and OD flows. Another similarity with the ADA models is that various components work at the disaggregate level (microsimulation). FreightSim includes a firm synthesis, which synthesises all firms in the USA and a sample of international businesses. Then each buyer firm (by type) selects supplier firms in the supplier firm selection module (unlike the ADA approach, this step is handled at the disaggregate level, letting the model evolve into a DDA approach). The distribution channels between these firms are modelled as well, for example, whether a shipment is transported directly or passes through one or more warehouses, intermodal centres, distribution centres, or consolidation centres, as is the choice of shipment size, primary mode (road, rail, air, waterway), and transfer locations. This leads to the determination of trips at the OD level by mode, which for road transport are assigned to the network.

Just as the model for Florida, the freight transport model for the Chicago Metropolitan Agency for Planning (CMAP) uses a firm synthesis, supply chain, and logistics microsimulation, as well as truck tour formation models (Cambridge Systematics, 2011; RSG, 2015b). The first elements are modelled at the national scale; the latter at the regional scale (the Chicago region).

The national scale portion of the CMAP model focuses on how firms that buy goods select suppliers (DDA) and how suppliers ship goods to their buyers, resulting in PC flows. Multinomial logit choice models determine the supply chain type (direct, 1, 2, or 3+ types of intermediate stops). Furthermore, there are sub-models for shipment size, mode, and intermediate transfer choice, based on full logistics costs functions as in de Jong and Ben-Akiva (2007). For the supplier selection, for each commodity market, an iterative procurement market game (PMG) is played in which a pool of buyers attempt to procure inputs from a pool of sellers in the market, depending on, for instance, shipping times, unit costs (transport and non-transport), and risks.

In de Jong *et al.* (2020), a mode and route choice model for north-east India and Bangladesh is developed and used to answer the question of what the transport consequences will be of implementing bilateral and multilateral agreements to facilitate cross-border trade in South Asia. The model is largely based on stated preference (SP) interviews among more than 500 shippers and road haulage firms in north-east India and Bangladesh. The modes included in the model are road, rail, inland waterways, and coastal shipping, and the model also contains the choice of port (either Kolkata/Haldia in India or Chattogram in Bangladesh).

Holguín-Veras *et al.* (2020) developed a regional freight model for trucks in Bangladesh using novel methods for building OD matrices for different commodity types. The freight trip distribution for trucks is estimated from secondary data sources, such as traffic counts, GPS data on network travel times, and truck payload data, using a technique called Freight Origin-Destination Synthesis (FODS). This technique is applied here for the first time in the form of both a single-commodity and a multi-commodity model.

Nugroho *et al.* (2016) also used SP data, in this case referring to the choice of hinterland mode (road or rail) and port (distinguishing four ports) by exporters and forwarders for exports from Java, Indonesia. The data were analysed using various forms of discrete choice models (multinomial logit, nested logit, mixed logit) and they were applied to study the impact of policies on emissions.

In the PhD thesis of de Tremerie (De Tremerie, 2018), a model is developed for the choice of mode for goods flows going through the port of Ghent in Belgium. The models were estimated on within mode and between mode (road, rail, inland waterways, short-sea shipping) SP experiments with shippers in the port area. The attributes also include the CO_2 emissions of the transport. The estimated models are the multinomial logit and mixed logit model, but hybrid models (ICLV models) have been estimated as well, using additional information collected in the survey on the level of agreement of the shippers with statements about making transport greener. On the basis of this information, latent variables were identified for the attitude of the firm and/or the individual respondent towards the environment, which helped explain the choice between modes.

Tapia *et al.* (2020) similarly did an SP on mode (road versus rail) and port choice (unlabelled port alternatives), in this case for specific agricultural products in Argentina. In this paper, not only were discrete choice models estimated but also multiple discrete-continuous extreme value (MDCEV) models (MDCEV). These latter models were appropriate, because the choice experiments asked for the percentage allocated to each alternative instead of a single discrete choice. There were also joint SP/RP models with disaggregate consignment bill data.

5.0 Developments in Urban Freight Transport Models

In order to support urban planners to optimise city logistic solutions, urban freight transport models are gaining interest.

In the Netherlands, a new urban multi-agent simulation model was developed, called MASS-GT (de Bok and Tavasszy, 2018), which was adopted in the EU H2020 HARMONY modelling framework as a tactical freight simulator. It is agent- and shipment-based, and uses a novel high-density data collection of truck trip diaries as an empirical basis. Logistic choices are simulated using discrete choice models, such as the formation of trips into multiple-drop tours (Thoen *et al.*, 2020a) or simultaneous vehicle and shipment size choice (Mohammed *et al.*, 2019). The scope of the model is urban freight transport demand and the modelling focuses on road transport.

The tour formation model is a random utility model, estimated on disaggregate data for more than 2 million shipments, which are gathered automatically from the planning systems of carriers transporting goods in the Netherlands by road. This choice model is embedded in an algorithm that works iteratively by incrementally allocating each shipment to a specific tour, taking account of differences between commodity types, vehicles, and types of locations (Thoen *et al.*, 2020a).

The model can be applied for the impact assessment of urban logistics policies, such as zero-emission zoning schemes (de Bok *et al.*, 2020), and calculate numerous key performance indicators, such as vehicle kilometres and emissions (Thoen *et al.*, 2020b). The level of detail in the multi-agent model also permits the implementation of detailed urban freight scenarios, and makes it possible to account more effectively for heterogeneity in responses of different actors in city logistics. International and inter-regional freight demand patterns at NUTS3 level are input to the simulator and can be derived from strategic models such as BasGoed for the Netherlands, or HighTool, TransTools, or TriMode at a European scale. This top-down approach allows the integration of modal split, or shifts in inter-regional trade patterns into the regional simulation. The current implementation of this model is for the Province of Zuid-Holland in the Netherlands.

SimMobility Freight is another example of a recent urban freight simulator (Alho *et al.*, 2017; Sakai *et al.*, 2020). It is developed as part of SimMobility, a multi-scale agent-based urban transport simulation platform. SimMobility Freight is capable of simulating commodity contracts between firms (encompassing supplier choice), inventory and transport logistics, and vehicle operation planning and parking decisions in a fully disaggregate manner. Logistic decision making is simulated on three distinct temporal dimensions: long-term (freight generation, supplier selection, shipment size); mid-term (transport logistics and vehicle planning); and short-term (dynamic traffic assignment). It simulates the behaviour of individual agents, using discrete choice models based in part on vehicle tracking and establishment data. It has been implemented in Singapore.

In the mid-term component of SimMobility Freight, freight activity schedules are generated for each vehicle in the fleet of the carriers. SimMobility Freight handles the conversion of shipment demand (in terms of a list of commodity contracts between senders and receivers) to vehicle tours. This step includes the selection of time-window, and of carrier and shipment-to-vehicle allocation and tour formation for an average day. The output consists of vehicle operations plans, with information on stop locations, arrival, and departure times, and stop purposes (overnight parking, pickup, or delivery). These plans, essentially outlining vehicle tours, are then used in the mesoscopic or microscopic traffic simulations.

Currently, work is underway to include firm strategy as a determinant of vehicle fleet decisions, for which latent class discrete choice models are estimated using a novel data analysis methodology on existing firm strategy documents, instead of carrying out new surveys that often attain a low response rate (Stinson and Mohammadian, 2020). This research project has also studied the possibility of moving parcels in passenger vehicles (in this case for autonomous mobility-on-demand vehicles; Alho, 2020); in this way also further integrating passenger and freight transport modelling.

The POLARIS model is a forecasting tool that can be applied at different spatial levels (from a small neighbourhood up to the regional scale of a metropolitan area) and for different areas. It was developed by the US Department of Energy's Argonne National Laboratory. The freight model that was recently integrated into the POLARIS platform simulates the decisions that businesses and other agents make at the micro-level, just as do some of the regional models in the USA discussed above (such as Florida's FreightSim). It includes the formation of the supply chain. For this, POLARIS distinguishes between push and pull supply chains: in push environments, manufacturing is driven from the producer down to the retailer based on forecasts of demand; in pull environments, it is driven by information on consumer demand. POLARIS captures push-pull dynamics by establishing information links to represent which producers have information about demand and which do not. In this way, it can predict demand for last-mile just-in-time deliveries (Stinson, 2020a). This framework can be used to compare traditional shopping trips against commercial vehicle e-commerce delivery trips (Stinson, 2020b), also because it includes both passenger and freight transport.

Nuzzolo and Comi (2014) developed a simulation model for urban freight transport in Rome, Italy. This model consists of three main parts. First, the commodity flows between zones are determined per transport type (retailer own-account, retailer third-party, wholesaler own-account, wholesaler third-party). Second, the commodity flows are divided into discrete shipments based on an average shipment size, and each shipment is assigned a delivery time period based on a discrete choice model. Third, the shipments are assigned to vehicles using a discrete choice-based algorithm for tour formation (Nuzzolo *et al.*, 2012). While not as agent-focused as MASS-GT and SimMobility Freight, this model provides another good example of more disaggregate shipment-based modelling of urban freight transport. The issue of the timing of the last-mile delivery under delivery time windows is also studied in Pahwa and Jaller (2020).

The TRABAM model for Flanders, Belgium, focuses on the decisions made by carriers (Mommens *et al.*, 2016). A freight generation model determines the zonal productions and attractions, which are divided into individual shipments based on the economic order quantity formula, as is done by Ben-Akiva and de Jong (2013). Each shipment is assigned to a carrier based on the size and the location of the carrier's depots. These carriers optimise a set of tours to transport all the shipments. The set of carriers in the model is based on rich data on Belgian third-party carriers, and their vehicle fleet and depots. One innovative aspect of this modelling framework is the inclusion of 'learning' by the carrier agents. If the success rate of delivery of shipments is considered too low, the carriers can react to this by, for example, expanding their vehicle fleet. Finally, the model also includes an emission calculation that considers the diffusion of pollutant gases, which leads to a better estimation of the local exposure to these gases (Mommens *et al.*, 2019).

The above-mentioned urban modelling frameworks show a clear development towards more disaggregate modelling of urban freight transport through shipment-based and agent-based features. Another development we can identify is an increased effort to include transport resulting from e-commerce in urban freight models. MASS-GT (Thoen *et al*., 2020b), TRABAM (Mommens *et al*., 2020), and POLARIS and SVRM (Grebe *et al*., 2016), for example, were all expanded with a module for parcel deliveries in recent years. Llorca and Moeckel (2020) use the FOCA model of Munich to simulate the effects of different shares of cargo bikes and densities of local micro depots. Le Pira *et al*. (2020) analyse e-groceries and consumers' preferences for home deliveries versus store pick-up.

Recent literature also shows a vast body of research on applying dynamic agent-based models in the urban freight context (Roorda *et al*., 2010; Marcucci *et al*., 2017; Anand *et al*., 2019). These models study dynamic behaviour between and within agents (negotiation, learning), and are behaviourally more realistic and complex than the standard city logistics models. This complexity, however, creates great challenges for the calibration of these models, due to absence of data for such strategic decision making and the computational burden involved with the simulated behaviour.

6.0 Looking Back at the Expected Developments

Since the start of this century, there has been a tendency to include more logistics aspects in freight transport modelling. This tendency, which had already manifested itself before 2013, has continued in the past seven years: many new models at the international, national, and regional level distinguish between PC and OD flows, and explain the multimodal transport chain for the PC flow (HIGH-TOOL, Transtools3, TRIMODE, BasGoed container model, new ADA models, FreightSim, CMAP model). Some of these models also distinguish the choice of intermediate storage location along the distribution channel (for example, TRIMODE, FreightSim). For urban freight transport, multimodality is usually of less importance, road transport until very recently often being the only game in town, but there is a tendency to include more logistics aspects at this level as well (for example, shipment size, tour formation).

There has also been considerable progress since 2013 on most of the expected additional areas for developments from the list in de Jong *et al*. (2013):

- Modelling of further logistics decisions, especially supply chain formation.
  This is included in FreightSim, the CMAP model, POLARIS, and SimMobility Freight.
- Integration of (inter)national (intercity) freight models with urban freight models.
  The CMAP model, POLARIS, and MASS-GT are examples of this.
- Integration of freight transport models with passenger transport models.
  POLARIS goes some way in this respect (dependence of freight flows on consumer demand) and so does SimMobility (for example, crowd-sourcing of parcel deliveries). The importance of this integration, given the increasing importance of online ordering and home deliveries replacing conventional shopping trips, is widely acknowledged.
- Including latent variables (for example, on attitudes) in freight transport models, leading to hybrid models with hard (for example, time and cost) and soft (for example, attitude towards the environment) variables.

Several discrete choice models based on SP data use transport time reliability, or the probability of damage or theft (for example, de Jong *et al*., 2020; Konstantinus *et al*., 2020; Tapia *et al*., 2020). Latent variables in the ICLV framework are used in De Tremerie (2018), Konstantinus (2019), and Stinson and Mohammadian (2020). The general popularity of the ICLV model has decreased since Vij and Walker (2016) warned that this model might have difficulty in properly identifying the latent variable coefficients from other influences on choice. Another issue with these models is the difficulty of predicting the future values of the attitudinal variables.

The other expected developments from de Jong *et al*. (2013) have not taken off in a major way:

- Integration of production, inventory, and transport logistics.
  POLARIS goes somewhere in this direction (demand-led versus top-down supply chains), but further than that, we are not aware of attempts to model production decisions jointly with transport and inventory logistics decisions in forecasting and policy evaluation models for the public sector.
- Departure (or rather delivery) time modelling.
  As far as we are aware, this has not been taken up in any international or national freight transport model. This is not so surprising, since much transport in these models is multiday, and the precise timing of the delivery on the delivery day in this context is difficult and highly uncertain. The only regional freight transport model we know of with a component for time period choice is SVRM, the model for Flanders (and then only for the road mode). In the urban context, there might be more scope for delivery time modelling. Time period is an endogenous variable in the model of Nuzzolo and Comi (2014), in SimMobility Freight, and it was studied by Pahwa and Jaller (2020). A time period choice sub-model seems most relevant in congested urban areas and in situations where the authorities are considering truck charges with variation by time of day.

7.0 Other Developments Since 2013

Notwithstanding the progress that has been made in recent years in regional to international freight transport models, the area where most progress had been made since 2013 seems to be urban freight transport modelling. This development has at least partly been driven by policy-relevant issues that are especially important at the urban level, such as harmful emissions, congestion, limited parking space, growth of e-commerce and direct deliveries to consumers, and the (possible) introduction of new modes of freight transport, such as cargo-bikes, drones, crowdsourcing of parcel deliveries, and automated vehicles.

The recent development in urban freight transport models include:

- more modelling at the level of shipments: microsimulation (to a lesser degree this development is also taking place at regional and national level — for example, in the ADA models);
- explicit consideration of carriers, sending firms, receiving firms (to a lesser degree this is also taking place at the regional level, such as Florida's FreightSim model);

- dynamic agent-based aspects: negotiation of contracts, learning (also at the regional level: Florida's FreightSim and the CMAP model);
- explicit consideration of tour formation;
- specific models for parcel deliveries; and
- more detailed emission calculations.

These are developments that were not included in the list of expected developments in de Jong *et al.* (2013). This is partly due to the fact that the 2013 paper focused on regional to international models, not on the urban case. Modelling the formation of multi-sender and/or multi-receiver tours, for example, had already started before 2013 (for example, Wang and Holguín-Veras, 2009), but was considered to be too detailed and computer-intensive for (inter)national and regional models in 2013. Most new developments on tour formation have indeed taken place at the urban level, but it is now also done at the regional model (in the CMAP model).

A development that was not on the list of 2013, and that is not specific for urban models, is the use of other model specifications than standard regression and the discrete choice model (such as the joint discrete-continuous model, including MDCEV; see Tapia *et al.*, 2020), although as before this is an adaptation from passenger transport modelling. Another unlisted development is the explicit modelling of port choice as a separate step in the freight transport model, especially on SP data (Nugroho *et al.*, 2017; de Jong *et al.*, 2020; Tapia *et al.*, 2020).

8.0 Summary, Conclusions, and Future Outlook

In the biblical story, the seven fat years in Egypt were followed by seven lean years. Freight transport modelling has long been a field where only a limited amount of research took place, and the research that was done largely borrowed its key concepts from passenger transport modelling. More or less since the beginning of this century, freight transport modelling has been receiving more attention and has seen more original development, notably the inclusion of more logistics concepts into the models.

In 2013, freight transport modelling had already seen two periods of around seven years that can be regarded as fat. Our conclusion from the review above is that the period 2013–20 can be regarded as seven fat years as well. In a longer time perspective, the lean decades before 2000 have been followed by a series of two decades of fat years for freight transport modelling.

We see every reason to assume that these fat years will continue in the coming decade. Especially at the urban level (see Section 7), many problems, but also many potential solutions, exist related to freight transport. New developments in passenger transport modelling may be relevant for freight as well, such as discrete-continuous models and latent variable models in the recent past, and maybe models with endogenous choice sets and explicitly dynamic models in the near future.

We expect that the general tendency towards more shipment-level micro-simulation models will continue, in spite of the difficulty of obtaining disaggregate data, and that this will also go for the shift towards agent-based models with several interacting agents and the possibility of learning behaviour. We also expect that the expansion of choices modelled (from generation, distribution, mode, and route choice towards supplier and receiver, distribution channel, shipment size, port, consolidation and distribution, fleet size, and composition choice, as well as tour formation, including failed deliveries, returning ordered goods, and empty vehicle trips) is here to stay and become more mature. Further integration with production choices does not seem to be high on the research agenda, and this may also apply for time period choice in freight transport. The integration of freight models at different spatial levels, and of freight and passenger transport models, is also very likely to continue.

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