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Opportunities of sectoral freight transport demand modelling

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ABSTRACT

This paper discusses the opportunities of sectoral freight transport demand models. The work is based on literature and insights from interdisciplinary research in the field of production, logistics and transport. First, current and future factors influencing freight transport are discussed. Next, a brief summary of the traditional transport modelling approach and recent extensions and adaptations of freight transport models is given. As interdisciplinary research has shown, the impact of the identified factors on the development of freight transport is strongly dependent on the sector under investigation. As a consequence, this paper proposes the application of a sectoral modelling approach. The automotive and food sectors in Germany are used as examples to further examine the opportunities of sectoral freight transport demand models.

1. Introduction

The transport system plays a key role in national and international economic prosperity. To begin with, it offers mobility to people. It also bridges the spatial gap between locations of production and consumption for materials and goods. With today's multi-tier, minimum-inventory supply chains, the reliability of the transport system has become a competitive advantage for national economies. Given the budgets and strict environmental regulations, public authorities have limited options for creating and maintaining sustainable transport systems that fulfil the arising requirements. In order to cope with this challenge, reliable prognoses and policy assessments are needed. These are the key areas for the application of transport models. The question then arises: what are the most important factors governing freight transport demand?

Since freight transport demand is a derived demand resulting from the systems of production, logistics and trade, we will extend our view and also address potential influences from these systems in the following sections.

The paper is organized as follows: First, trends influencing the development of freight transport demand are described. Next, existing approaches and recent developments in freight transport modelling are discussed. Building upon these two sections, the concept of sectoral freight transport modelling is introduced and exemplified by referring to the German food and automotive industry. In the end, a brief conclusion is drawn.

2. Trends influencing future freight transport demand

Trends influencing future freight transport might originate from the demand side for transport, e.g. trade and production, the supply side for transport, e.g. logistics and transport systems, as well as regulation.

Trade and production are responsible for fulfilling the demand of households as well as companies. Here, the development is closely connected to innovations in products and production technology as well as trade patterns. For example, affordable small- to mid-scale automation solutions make it possible to establish smaller production facilities in close proximity to demand locations instead of operating single centralised production plants, thereby reshaping the spatial flow of intermediates and final products.

The transport system itself also faces changes. Especially in developing countries, there are plans for massive investments in new infrastructure. These new connections will foster accessibility, in many cases especially that of remote regions, and therefore directly impact national as well as international freight flows.

Advances in information technology are another source of change. For example, real-time analytics in combination with big data will allow for better traffic control and better information for transport system users, e.g. freight carriers. In addition to this, the broad application of new technology on the user side, e.g. automated guided vehicles, may lead to radical changes in the transport system. The impact of navigation systems on infrastructure usage can already be observed today.

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Last but not least, regulation will have an increasingly strong influence on freight transport. After focussing on passenger mobility, public authorities are beginning to put more effort into freight transport demand management in order to balance the requirements of businesses with traffic-oriented objectives. This trend is intensified by the need for measures that help achieve sustainability targets, especially those related to environmental protection, since existing agreements require major reductions in greenhouse gas emissions. Another focus of governmental action will have to be on the security of supply chains and risk prevention since international supply chains are increasingly vulnerable to disruptions caused by political instabilities or extreme events caused by nature, epidemics or technical failure.

3. Freight transport modelling

New freight transport demand models, attempting to forecast freight transport, should explain the impact of trends, like the ones described in the previous section, on freight transport. In practice, however, the traditional four-step-approach is used most frequently. This approach was originally developed to explain passenger transport demand (Martin et al., 1965; Hutchinson, 1974). Directly applied to freight transport modelling, the steps are as follows:

1. Generation: How much freight is generated where?
   ⇨ freight volume per zone (O_i and D_j)
2. Distribution: Where does this freight go?
   ⇨ freight volume per zonal relation (X_{ij})
3. Modal Choice: Which means of transport are chosen?
   ⇨ trips per relation ij and mode v (T_{ijv})
4. Assignment: Which route is chosen?
   ⇨ vehicles per network section

Emphasizing how the interaction between activity system and transport system leads to flows, Marvin Manheim made a major contribution to the development of transport models (Manheim, 1980). In the very same work, he already described several limitations of the four-step-approach. In our opinion, the most severe restraints are the absence of decisions of actors, especially those related to logistics (e.g. transport lot size, distribution structures), the absence of interaction between modelling steps due to sequential modelling (e.g. increased costs caused by congestion, synergies from bundling transports) and information loss caused by aggregation (supply chains/networks, transport markets).

Since then, the freight transport modelling research community has put a large amount of effort into overcoming these shortcomings of the traditional approach. As a consequence, there have been advances, in particular in the following areas of modelling:

- Large (extended) trade models (multi-regional input-output, e.g. Cascetta et al., 2008; spatial computable general equilibrium, e.g. Bröcker et al., 2010).
- Elaborate discrete-choice models (total logistics costs, latent classes, e.g. Park, 1995).
- Additional logistics steps within the traditional aggregate sequential model framework (tours in trip-based models, e.g. FRETURB, Routhier and Toilier, 2007; lot sizes and transport chains, e.g. ADA, de Jong and Ben-Akiva, 2007; logistics locations, e.g. Davydenko and Tavasszy, 2013).
- (Micro) simulation of logistics decisions / interactions (multi-agent frameworks, e.g. Roorda et al., 2010; interaction of shippers and carriers, e.g. INTERLOG, Liedtke, 2006 integration with passenger transport model, e.g. MATSim, Schröder et al., 2012; simulation of warehouse structures for food retailers, e.g. SYNTRADE, Friedrich, 2010).

All these different approaches have contributed significantly to the improvement of freight transport modelling with regard to the wide variety of modelling or evaluation purposes. From our interdisciplinary point of view and corresponding research questions, we developed a sectoral modelling approach that attempts to combine developments from the areas depicted above. Sectoral modelling offers significant advantages during the model creation and data collection phases as well as new areas of model application. We will explain this approach in the following section.

4. Sectoral freight transport modelling

The idea of limiting a freight transport model's scope to a single industry has its origin in the main challenges of transport modelling, i.e. data availability, homogenous groups of actors and decisions, and complexity. We propose to define sectoral models as follows:

> Sectoral models limit their scope to one sector. Their objective is the analysis of a sector's system behaviour. For this purpose, they focus on a single sector's characteristics, i.e. system elements, interrelations and especially actors and their decisions.

The general development process of sectoral freight transport models starts with choosing the sector that is going to be captured in the model. The process is also outlined in Fig. 1. The next step then will be to conduct a system analysis for the sector of interest. This can be done based on literature and explorative expert interviews. The system analysis will foster an understanding of the actors in the sector, their interrelations, and their planning scopes.

Based upon this knowledge, it must be decided which aspects of the sector should be analysed. After the relevant aspects have been chosen, the required data can be identified. Structural data, like detailed spatial employment statistics, can often be provided by federal statistics offices. For the economic integration of the sector, it is often necessary to join different sectoral production and consumption statistics, published for example by organisations like industry associations, in order to capture the physical flows in form of enhanced sectoral physical input-output-matrices. Behavioural data can be found in sector studies and accompanying

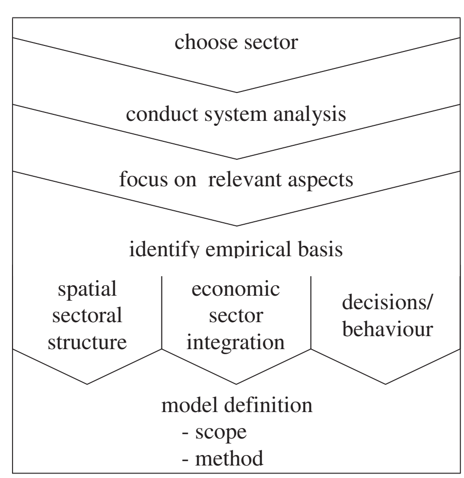

Fig. 1. Design process for sectoral freight transport demand models.

surveys. Finally, the available data, the aspect of interest and the system analysis define the model to be built especially regarding the model scope and methods to be applied.

Since the composition of actors in a sector and their decisions are different, sectoral freight transport demand models must also focus on different aspects as described in the previous section. In order to give a more vivid understanding of this, we now discuss the analysis of two sectors: the food sector and the automotive sector in Germany. Certain characteristics might be specific to the German market but the general insights are transferable to other regions.

When analysing a sector's behaviour, in this case its freight transport demand, it is advisable to include the overall supply chain, starting from a final product (e.g. cars) or a distinguishable group of products and then following the related supply chains upstream until a certain system boundary is reached (e.g. imports for a spatially defined border or the production step of agriculture for a product-based scope). In Table 1, the supply chains of food and automobiles are characterized.

Obviously, the two sectors differ in the nature of their products. In comparison, vehicles are highly complex and customizable due to the wide variety of technical systems they include. As a result, they are of high value and often customer-specific. By contrast, food products usually contain one or a few ingredients with low value and without any customer-specific variations. If there is no customer waiting for a specific car, it can potentially be stored. Food products are often perishable and can only be stored for a limited amount of time.

In order to efficiently produce vehicles, the car-manufacturing companies (original equipment manufacturer, OEM) rely on highly specialised, multi-tier supply chains which are centrally controlled in order to secure the continuous supply of the OEM's final assembly lines. Therefore, well-organized supply chains are the key to success in cost efficiency and technological leadership. By contrast, the food retailing companies buy final products from suppliers that are at the end of fairly short supply chains with very few intermediate stages.

Contact to vehicle buyers is often established by OEM- or brand-specific local (regional) trading establishments with rather large catchment areas. By contrast, the food retailing companies have established a dense network of points-of-sale, providing their customers with a wide range of differentiated products. As a result, the retailers make use of warehouses close to the final demand for bundling, buffering and commissioning purposes. By contrast, vehicle manufacturers try to avoid storing the finished car on the way to the customer. This means that outbound logistics in the automotive sector are mainly transport-optimized. As a result, inbound as well as outbound logistics are outsourced to logistics service providers. For the food retailing industry, the inbound logistics into the warehouses is usually organized and carried out by logistics service providers. The outbound logistics from the warehouse to the points-of-sale is optimized by the retailer since its efficiency is a significant competitive factor in this sector.

The high number of products and points of sale in the food sector leads to a large number of commodity flows with low volumes. The shipment sizes between two locations are smaller than or at best equal to a full truck-load. As a result, the food sector is entirely reliant on road transport. By contrast, the automotive sector is well known for using all modes of transport, especially rail, road and water transport. Rail transport is extremely efficient, especially for large material flows, e.g. those that occur between car plants exchanging preassembled intermediates.

Comparing the described overall characteristics of these two sectors, it is questionable whether one model can adequately capture the significant development factors of freight transport demand for both sectors. For the food sector, the strongest impact on freight transport originates in the distribution systems (Friedrich, 2010) while in the automotive sector, the spatial setup and structure of the supply chains upstream from the car plants has the strongest influence on freight transport demand. Sectoral freight transport models can address such sectoral specifics.

Limiting the scope of a model to a single sector's most important factors helps reduce model complexity in general. As a result, it is possible to model the identified relevant factors in a more detailed way, e.g. warehouse structures of food retailing companies. In addition to offering improved insight in terms of freight transport, this high level of detail also allows the developed models to be applied in new ways. An example for the food sector is the assessment of risks and vulnerability including scenarios such as shortfalls due to breakdowns in production, the logistics system or on the infrastructure level. For this application, the focus has to be on the dynamics of flows, necessitating simulation methodologies such as system dynamics (e.g. Kumar and Nigmatullin, 2011). Due to its vital importance, the food sector gets a large amount of attention from companies and politics as well as governmental regulation, leading to a large number of potentially available data

Table 1
Characteristics of the food and automotive sectors.

	Food	Automotive
Product	• Low value • Perishable • Interchangeable	• High value • Storable • Customized
Production	• Simple production chain (few inputs and actors) • Driven by retailers	• Complex supply networks with many actors • Driven and coordinated by OEM
Trade	• Large retailer networks • Many products • Warehouses close to customers	• Distribution of final products by OEM • Few products • Distribution networks hierarchical with intermediate stages mainly for transport
Logistics	• Many small commodity flows (maximum: one truck between two locations) • Outbound: optimized by retailer • Inbound: outsourced to logistics service provider • Mode: purely HGV	• Frequently large material flows between locations (unit trains) • Logistics outsourced to service provider • Modes: ship, rail, HGV

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sources, e.g. on agriculture, production and consumption of goods, international trade, etc. from statistics offices, industry associations and commercial data providers. By combining these different sources, it is possible to obtain detailed data with categories corresponding to homogeneous groups of actors within the sector. If we transfer the sectoral modelling approach to a different industry, the modelling focus changes.

As previously described, the major parameters of freight transport in the automotive industry are determined by the setup of the multi-stage supply chains that are applied. In the traditional four-step approach, this is covered in aggregate in the first two steps, freight generation and distribution. In order to trace potential freight transport effects resulting from changes in the supply chain, e.g. vertical (dis) integration, models on the level of business establishments and the material flows between them are required. Focusing on the automotive industry, it is possible to create such a model, as we can take apart the produced cars into modules, components, parts and finally raw materials, leading to simplified bills of materials. For the different types of intermediates, the sourcing strategies that may be applied are documented in literature. Precise data on the location of car plants and the number of vehicles produced is available from industry associations as well as from commercial data providers. Trade and production statistics contribute additional information. Existing scientific surveys can fill gaps in data, especially regarding the behavioural parameters of business establishments, completing the sectoral picture.

The example of these two sectors makes the advantages of sectoral freight transport models obvious, in terms of data availability, integration of behavioural components/decisions and managing complexity. As a result, we consider further research based on the concept of sectoral modelling to be a fruitful approach in order to foster the further improvement of freight transport models.

5. Conclusion

We have shown that there are a wide variety of developments in freight transport that cannot be explained with the traditional four-step approach of passenger-transport modelling. We have presented sectoral freight transport modelling as an approach that can contribute to current advances in this area and open up possibilities for new applications. As we have shown for the automotive and food sectors, sectoral models can unleash the potential of data sources that are already available. The sectoral approach also benefits from the homogeneity of planning problems along supply chains. By comparing the automotive and food sectors, we demonstrate that such models will have different focuses depending on sector-specific development factors of freight transport.

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