Application of a multi-level freight transport demand model
to estimate the effects of political measures

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Abstract

The paper describes the multi-level freight transport demand model WiVSim (Wirtschaftsverkehrs-Simulation) and its application in a project to estimate the effects of various political measures on freight transport in Germany until the year 2030. The concept of a multi-level model positioned between macroscopic models dealing with zones and aggregate values and microscopic models dealing with individual businesses and shipments is explained. While maintaining the concepts and resolution of a micro model because of a lack of crucial behavioral data WiVSim uses several methods from macro modeling and calibration to advance the treatment of political measures inside the simulation.

1 Introduction

Freight modeling is increasingly giving attention to the fact that the development of both production systems and logistics is having a fundamental influence on the amount and structure of freight transport demand (see [Zo2004], [Re2000], [Ta1998]). In this context, a trend towards experimental microscopic models of commercial transport has come up in recent years (see [Lie06], [Wis06, Spa05] for examples). Traditional macroscopic models of commercial transport (e.g. [BVU et al., 2001]) are based on traffic zones and goods categories, while these newly developed microscopic models put the emphasis on the actors of commercial transport demand. Shippers and forwarders are incorporated explicitly in these models.

The similar trend towards microscopic, activity-based models in personal travel demand modeling has benefited greatly and was made possible by the availability of survey data which describes directly the processes influencing travel demand, e.g. personal activity planning, location choice and travel behavior of large numbers of surveyed persons. Freight transport demand is as well an induced effect influenced by economic behavior, e.g. supply chain formation, production allocation and logistics behavior of individual businesses. Unfortunately at present direct surveys of this transport-related economic behavior of large numbers of individual businesses are largely unavailable for transport models.

On the other hand concepts of microscopic modeling like the direct incorporation of shippers and forwarders and individual shipments would offer great advantages for the determination of effects of political measures with freight transport demand models. Representing the actors whose behavior is influenced by the measures directly in the model allows a natural integration of the reaction of individual actors to the measures and the estimation of the resulting effects on aggregate transport demand. The usage of macroscopic data and model calibration techniques to construct a microscopic model of freight transport demand could therefore be described as a multi-level approach. This approach of modeling also offers a starting point from which to integrate detailed transport-related behavioral data of businesses as it hopefully becomes available in the future.

The ability of microscopic models to represent reactions of actors is specifically
useful to determine the effects of political measures on commercial transport\(^1\). Microscopic models allow for the computation of the effects of political measures which are considered appropriate to help reach particular goals, so for instance the goal of sustainable mobility. For goods transport these measures may be changes to road use charges, permitting longer and heavier trucks, enhancing the infrastructure for goods transport with trains, the promotion of alternative fuels and engines or regulated mixing of bio fuels with traditional fuels.

2 Mode of operation of WiVSim

Based on the process diagrams of WiVSim (Figures 1 and 2) the operation of the model WiVSim to determine the actors’ reaction on measures will be presented in this section. In the course of the description of each process step the encountered challenges and their solutions will be discussed.

![Figure 1: Process diagram (1 of 2) of WiVSim; from structural data up to the list of shipments. Rounded boxes in the middle column signify results of process steps during the course of the simulation. The boxes in the left and right column signify data sources used in the process steps.](image)

The first step in the simulation with WiVSim is the generation of a synthetic economy. The goal is to build a list of businesses in a way that the statistical properties of this synthetic economy are identical to the structural data for the region under consideration – at present this has been done for the case of Germany. The level of detail and quality of the input data determine the quality of

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\(^1\) This is currently done with the DLR-model WiVSim (Wirtschaftsverkehrs-Simulation = simulation of commercial transport) in a project about the development of traffic and the introduction of alternative fuels in Germany up to the year 2030. The objective of the project RENEWbility (see [www.renewbility.de](http://www.renewbility.de)) financed by the German Ministry of the Environment) is to foster sustainable mobility for individuals and goods. To this end the development of transport demand is analyzed and the question is raised how it can get together with a sustainable energy and fuel policy to advance climate protection. In the project team the DLR-Institute of Transport Research (DLR-IVF) is responsible for determining the personal travel demand as well as commercial transport demand. For goods transport the model WiVSim is used.
the synthetic economy. To achieve the best result a combination of several input data sources can be used.

Commercially available data from „infas GeoDaten GmbH“ are used as the starting point to generate the list of businesses. In this dataset the number of businesses is given separately for each municipality („Kreis-Gemeinde-Schlüssel“ - district-municipality-key KGS8). The 50 biggest municipalities are further divided into statistical zones. The city of Berlin for example is divided into 287 zones.

Additionally the dataset from infas GeoDaten resolves the number of businesses further on the basis of business sectors. The classification of the German federal statistical office is used, differentiating 400 sectors of economic activity. Apart from the spatial resolution and the different sectors the dataset contains the size of businesses in three categories: less than 10 employees, between 10 and 100, and more than 100 employees.

Despite the already detailed information contained in the data from infas GeoDaten this is not enough to generate the list of individual businesses. The next step to make this dataset usable for WiVSim is therefore the computation of explicit business sizes for each business instead of the three size categories. For the assignment of an individual number of employees for each business data for the distribution of business sizes in the German economy from the Federal Statistical Office is used.

This data is only spatially differentiated on the level of the 15 German Bundesländer and the sector information is not as detailed as in the dataset from infas GeoDaten. Nevertheless the combination of both sources results in a more detailed synthetic economy with statistical properties identical to the available data from each source.

To represent the spatial distribution of businesses the location information is further detailed starting with the municipalities and zones contained in the data from infas GeoDaten. The additional data used in this step is the network of streets and highways which is used further along for the route assignment. With the help of a GIS each zone of the infas GeoDaten dataset is assigned a list of links (street and highway segments) of the transportation network which are in this zone. For each individual business in the zone one of these links is chosen randomly. While the level of spatial resolution is not improved in this step there are some useful applications of the direct connection to the underlying transport network. For each business the distance to the next highway exit and access point to the train network can be computed and is used as a determining factor for the mode choice. Errors caused by the random assignment are to some extend averaged out when looking at all businesses in the zone. Nevertheless this offers direct possibilities for further improvement. Land use and location choice algorithms can be incorporated to model the behavior of the real economic actors.

The result of this generation of a synthetic economy is a list of individual businesses with a known location, a business sector and the number of employees which, while containing random elements, is the best combination of several data sources.
The next process step (see figure 1) is the computation of the amount of production measured in monetary values for each business. The input for this computation is the number of employees for the business. In this step federal statistics on labour productivity are used which are differentiated by sector and contain information on sector production and the number of employees working in this sector. To account for future changes of these labour productivity parameters until 2030 economic forecasts done by the Institute for Economic Research Halle (IWH Halle) are incorporated ([IWH06]). These economic forecasts will be used in the federal transport forecast until the year 2025 as well. It is a goal during the current application of WiVSim to be compatible to this forecast in the basis scenario. The data from IWH Halle contain forecasts on the output of 14 business sectors in the 99 German planning regions until 2025.

The conversion of production amounts measured in values to those measured in physical units (weight, volumes or number of pieces) is the next process step. This is done with coefficients denoting specific values of goods categories (Euros per kilogram / litre / piece). These coefficients have been determined at the University of Karlsruhe from federal production statistics data. To account for the change in the coefficients up to 2030 data from IWH Halle are used. A trend prognosis based on the development in the years 1995-2005 ([IWH06]) is made, using 38 different goods categories. At this point further integration with the work of economists on structural change in the economy is a good enhancement for the future. The modeling with WiVSim is able to accommodate these results directly in the model.

A correct linkage on the level of economic interrelations of suppliers and customers of goods is an important element of an actor-based model. The necessary data for our model was gathered in a survey of shippers done by the DLR-Institute of Transport Research (see [Var05] for a report on the qualitative part of the survey). In the quantitative part of the survey 907 industry businesses were investigated using computer-assisted telephone interviews (CATI). The survey was stratified in the properties business size, industry sector (NACE code) and spatial location in Germany. The survey form consisted of 44 questions on several topics from logistics and goods transport ([Men06]), for example the most important preliminary products, the number of suppliers of those and the number of customers of the business. A detailed recording of the whole supply chain was not possible due to the limited length of the telephone interviews in this survey. A difficulty arose in the inhomogeneity of different businesses of the same sector. A possible solution for the future is a greater sample size as in [Wis06]. Another possibility is a direct treatment and stratification by sector relations (see [Fri07]).

The results of the DLR shipper survey are used as indications to generate interrelations between businesses of the synthetic economy on the basis of input / output statistics. In this way it is determined for each sector which other sectors supply goods to it. Accordingly each business is assigned a demand of goods of these other sectors. The usage of input / output tables in this way is a method which is also used in other freight demand models (e.g. the Commercial Travel Module in TLUMIP, a model for Oregon; see also [Wis06]). A possible problem here is that for a process step which is critical for the transport demand model data has to be used which is generated solely for economic applications. A solution is freight transport statistics which record the industry sectors of shipper of recipient
of the transport.

To model the distance for freight shipments distance distributions are integrated from the federal transport forecast up to 2025. The compatibility of WiVSim with this forecast makes a separate distance distribution change forecast unnecessary in the current context. Such a forecast would be very challenging over the long period until 2030, dealing with structural changes such as globalization and outsourcing.

The next process step is the determination of lot sizes to split the goods flows between businesses. This is done depending on the type of goods and their transport characteristics as well as with data from the DLR shipper survey on shipment frequencies. The assumptions used have to be calibrated with freight transport statistics which is possible for the base year 2002. Further advances are to be expected from using results from shipment tracking surveys (e.g. the French ECHO study) which follow the shipment from consignor to consignee. Another area of current study is the analysis of distinct combinations of goods type, shipper sector and customer sector ([Fri07]).

At this point in the simulation process (the connection between figures 1 and 2) we have a list of shipments between businesses of the synthetic economy. Each shipment is assigned with a goods category and a lot size. The further process steps in WiVSim are detailed in Figure 2.

![Figure 2: Process diagram (2 of 2) of WiVSim: from shipment properties to vehicle kilometers, which are then further processed in other modules. Round boxes signify data, cornered boxes process steps.](image)

Based on the shipment properties a logistics group is assigned with a rule based system which takes into account the good type, shipment lot size and the distance between shipper and recipient. Logistics groups are e.g. express and parcel delivery, piece goods, whole truck loads, liquid fuels, container transports etc. (18 groups). The parameters for these rules are based on informed assumptions which incorporate the transportation characteristics. This is justified because for any given combination of goods category and transport distance there are indeed only a few logistics groups possible. Trends e.g. a higher importance of piece goods transport are taken into account based on historical data. The assignment of
logistics groups provides segmentation into different transport markets similar to other microscopic models of freight transport demand ([Lie06]).

Separately for each logistics group a mode choice model is used which is a combination of a rule-based model and a discrete choice model. Considered transport modes are road, rail, combined transport of road and rail, ship and air cargo. Parameters for the rules and the discrete choice model are the goods category, the transport distance, the transport cost, the lot size and the distance to highway exits and access points to rail, ship and air modes. The parameters of the discrete choice model are estimated with the federal transport statistics for Germany. For the development up to 2030 in the base scenario the parameters are estimated based on the freight transport forecasts in the German freight traffic forecast.

Taking into account data on empty tour ratios and tour patterns as the last process step of WiVSim, itself the result is a list of separate trips for the different modes of transport. Using commercially available software for route assignment the volume of freight transport measured in kilometers is computed and further processed with the method of material flow analysis to determine ecological and economical effects.

3 Determination of the effects of political measures

One particular goal of the application of WiVSim can be the determination of the effects of political measures on freight transport demand. The actor-centered method allowing for detailed representation of individual shipments offers many integration points for reactions to those measures.

A major process step influenced by measures is the generation of shipments and their properties. Permitting longer and heavier trucks as currently under discussion in Germany will change the parameters for whole truck load transports and the capacity for piece goods transport with changes to shipment bundling. The German automobile industry advocates the measure of permitting trucks with a length of 25.25 meters and a maximum gross weight of 60 tonnes estimating 2.2 billion truck kilometers less freight traffic and 15% less fuel needed per ton of freight ([VDA07]). A government agency (Bundesanstalt für Straßenwesen – Federal Agency for Roads) on the other hand argues that there will be significant additional strain on roads ([Gla06]). The exact assumptions regarding the reactions to the measures in the current model application will be determined in discussion with stakeholders. The number of road freight traffic trips will be reduced and higher efficiency will lead to reduced costs for transportation with trucks. This will facilitate a further shift of freight transport from trains to trucks ([KB06]). In the model this will be integrated with changes to the cost parameters for modal choice and a change to load factors of trucks.

While it is possible to integrate a measure of this kind in a macroscopic freight transport demand model this would involve estimating the effects of several reaction mechanisms as mentioned above outside the model and changing a single or a few parameters describing the handling of goods flows. The external effects estimation in this fashion is of the same complexity as the separate changes at
different process steps in WiVSim. We believe that a multi-level model like WiVSim offers advantages of transparency, straightforward mixing of several measures and comprehensibility, because the reactions are represented in the model at the same points as they are observed in reality.

Another integration point for the reactions on measures is mode choice. Changes to road use charges influence the costs for road transport and shift mode choice towards alternative modes depending on the transport characteristics of the goods and transport distance. Empirical results from Germany and other countries and forecasts on the effects of the already introduced German heavy trucks road use charge inform parameter changes for the individual mode choice models for the different logistics groups.²

4 Outlook

After the described application of WiVSim as a multi-level approach to determine scenario effects on freight transport demand in Germany several further applications are possible. The effects of technological changes in logistics like new vehicle concepts on aggregate freight transport demand can be determined when knowledge or assumptions regarding the reactions of individual shippers and forwarders is available and can be integrated. Another further application is to consider a greater spatial region. For freight transport a consideration of Europe in contrast to a single country is a natural enhancement only currently limited by computational requirements.

Another exciting prospect and the long-term direction of the DLR-Institute of Transport Research is the use of multi-level models such as WiVSim as the starting-point towards true microscopic models incorporating transport-related economic and logistics behavior of individual business. The DLR-Institute of Transport Research is currently working towards this goal which will require intense collaboration with logistics, computational economics, land use and transport scientists.

References

² The participative scenario process in RENEWbility is taking place in the year 2007 and the exact measures under consideration have not yet been defined. Results from the determination of effects will be available according to the schedule for the scenario process early in 2008. At this point the integration of a broader range of measures in WiVSim can be described.

[IWH06] Institut für Wirtschaftsforschung Halle, Bearbeiter U. Ludwig et.al.: Regionalisierte Wirtschafts- und Außenhandelsprognose für die Verkehrsprognose 2025 i.A. des Bundesministerium für Verkehr, Bau und Stadtentwicklung, Halle 2006


[VP2025] Verkehrsprognose 2025, currently running project granted by the German Ministry of Transport, results for freight transport expected in 2007; the project is done by e.g. IW Halle, ProgTrans