SIMULATION OF LOGISTICS IN FOOD RETAILING FOR FREIGHT TRANSPORTATION ANALYSIS

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ABSTRACT

Logistic systems are crucial to understand the conversion of economic activity into freight transportation. However, until recently, transportation models did not explicitly consider logistics. But still, transportation models do not include the emergence of complex logistic structures characterized by economies of scale. In most cases only the choice of lot sizes and transportation paths represents the logistic part of these models. Fixed costs are generally transformed into variable cost. This paper shows that it is also possible to model complex logistic structures for the purpose of transportation analysis.
The paper starts with a literature review of freight transportation models, focusing on the question of which logistic aspects they include. It will be shown that the emergence of logistic locations is not yet part of freight transportation models. A description of the SYNTRADE simulation model shows how this can be addresses. It is able to simulate the emergence and dynamic development of warehouse structures in the food retailing sector for Germany. The results show significant congruence between the modeled and the real spatial warehouse structures. SYNTRADE includes a detailed logistic optimization of food retailing companies as well as simplified optimizations of adjacent logistic systems. Thus, the model can describe dependencies between logistic systems, which are important to explain differences of warehouse structures. The modeling of forward looking decisions in the simulation enables SYNTRADE to avoid local optima on the level of individual companies. Thus, the dependencies on the overall system state, which is not unique in freight transportation, can be limited. Some model results and an application example demonstrate the new capabilities of such a model.

1. INTRODUCTION

Logistic systems are crucial to understand the translation from economic activity into freight transport demand. They are part of the economic entities like trading, logistic or production companies, and, at the same time, part of the overall freight transportation system. Therefore, logistic systems represent the interface between economic activity and transportation.

An example from food retailing can illustrate that: the production of consumer products may be located close to a retail store where the products are sold. In most cases, however, the products will first be transported to the retailer warehouse, and then be distributed to the individual stores. The driving factor that makes this economically reasonable for the retailer, are economies of scale, in form of the bundling of goods for transport and warehousing. This example shows that freight transport demand can sometimes be more driven by the shape of the logistic structures than by the locations of production and consumption.

The rising proportion of freight in overall transportation and the increasing importance of logistics for many economic sectors lead to a higher attention of politics for logistics. This is documented in logistic action plans on the European (EU, 2007) and the national level (BMVBS, 2006). Therefore, there is a need to assess effects of political measures on logistics and freight transportation, like the effect of rising fuel prices or toll introduction. These questions cannot be answered by traditional freight transportation models.

In recent years, many transportation researchers realized this necessity to include logistics in freight transportation models (Tavasszy (2006), Ben-Akiva and De Jong (2008), Rothengatter (2008)). The importance of the interface between economic activity and transportation has always been a main focus of transportation researchers (see Manheim (1979), p.5). However, logistics was not part of transportation models until recently. A main reason for this lies in the fact that logistic structures emerge out of the optimization of individual actors who often have concave cost functions caused by economies of scale. This is different to modeling traffic flows in networks, where cost functions are convex and therefore a unique solution exists, since user optimum is equal to system optimum. For aggregate approaches that describe logistic structures only as external input, the heterogeneity of economic actors and logistic systems is difficult to handle. Therefore, disaggregate approaches have emerged that include elements of logistic optimization. However, complex structures usually are not included yet, mostly only the choice of lot sizes and transport paths represents the logistic part of the models. An exception is the work of Liedtke which simulates tours of transport service providers. The emergence of complex logistic structures including locations, like warehouse structures of food retailing companies, are not yet modeled in transportation research.

Optimization procedures from logistic research, on the other hand, usually concentrate on the optimization of individual logistic systems. While they are able to optimize complex logistic systems like warehouse structures and networks, they are not designed to be applicable to logistic systems of different actors, to model many logistic systems in parallel or to consider system interaction.

The model presented in this paper contributes to fill this gap between transportation and logistic research. It will be shown that it is possible to artificially reproduce and explain the emergence of complex logistic structures on a large scale, meaning for an overall sector and region, taking the example of the food retailing sector in Germany. This sector is most suitable for this experiment, since complex logistic structures exist, a significant part of overall freight transport demand is caused by this sector, and sufficient data sources are available.

The designed simulation system includes detailed logistic optimization of food retailing companies as well as simplified optimizations of adjacent logistic systems. Thus, the model can describe effects that are important to explain differences of warehouse structures. The simulation of forward looking decisions enables the model to avoid local optima on the level of individual companies. Thus, the dependencies on the overall system state, which is not unique, can be limited and simulation results are stable.

The resulting simulation model, called SYNTRADE, is able to reproduce logistic structures in food retailing in Germany, as shown by comparison to real world data. With SYNTRADE it is possible to analyze the effect on logistic structures and transport demand caused by macroeconomic changes, like an increase in fuel price, as well as microeconomic changes, like a merger of two companies.

The paper is divided into five chapters. After these introductory remarks, a short literature review of existing freight transportation models and their representation of logistic aspects is given. This discussion shows the motivation to develop the simulation model. In chapter three the simulation model SYNTRADE will be described. Chapter four shows some model results and a possible application example before conclusions are drawn in the last chapter.

2. LITERATURE REVIEW

In the following, the inclusion of logistic aspects in a selection of models will be analyzed briefly. Discussing each model in adequate detail and comparing every model based on a standardized framework is beyond the scope of this paper. Also, for many cases it is difficult to "press" models in frameworks that do not correspond to their structure and objective. This review will be oriented at the hierarchy of logistic choices, shown in figure 1.

2.1 Hierarchy of choices leading to freight transport demand

There is a number of decisions going down from economic activity to vehicle flows on transport infrastructure. The idea of introducing a sort of hierarchy originates from Manheim (Manheim (1979), p. 62). He lists levels of choices in the activity system that lead to passenger and freight transport demand. For freight transport demand, this list is very focused on the economic activity, it therefore was extended by logistic decisions for this paper (see figure 1).

The first three levels are purely related to economic and non-logistic activity: There is the choice of overall aspirations for the companies, describing for example if the company is profit oriented. Then there is the choice of the activity, i.e. which products should be produced and which markets they should be produced for. Finally, the locations for the activity are chosen. It can be differentiated between the choices of business locations, logistic locations, and sourcing locations. On the first three levels, considerations on logistic systems have only a limited influence, they are probably driven by considerations on business activity like the questions which products are in demand, where to locate this demand (geographically) and where to find production resources. But nevertheless, especially for the third level, factors like accessibility and availability of compatible transport services determine the spatial environment and might therefore play a role. On the fourth level (sourcing) logistic considerations have already influence, since the costs for transport will be an influencing factor for the choice.

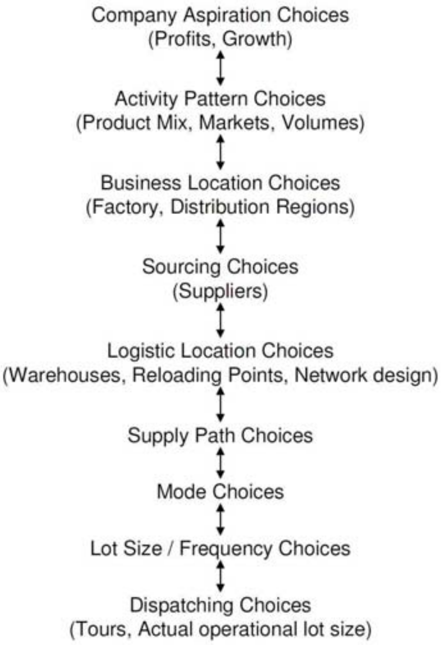


Figure 1 – Levels of choice for a firm (Top three levels based on Manheim (1979))

The bottom five levels represent pure logistic choices. For this paper, it was tried to order them in an hierarchical way: On the fifth level there are the choices of logistic locations for warehouses and reloading points. Taking these as given, there are different supply paths that can be chosen for the commodity flows, including for example which warehouse to use. Having assigned commodity flows to paths, one can think of the choices that can be taken for bundles of commodity flows on parts of the paths like choices of mode and delivery frequency or lot size. Finally, there are choices that have a more operational character on the actual dispatching level, as the choice of tours and order size. This list is a simplified hierarchy of choices. In practice, decisions often integrate several choice levels.

2.2 Selection of existing models

Different methods are used in transportation modeling, and scopes or objectives of the models differ as well. Therefore, it is very difficult to compare models. This also accounts for the representation of logistics in freight transportation models. Choice of lot sizes, for example, can be modeled in detail, by using lot size models that consider inventory and transport costs explicitly, or it can be modeled by a simple linear relationship with distance.

Therefore, the overview shown in figure 2 has to be handled with care since it is very simplified. It shows which kind of logistic choices are represented in a selection of models.

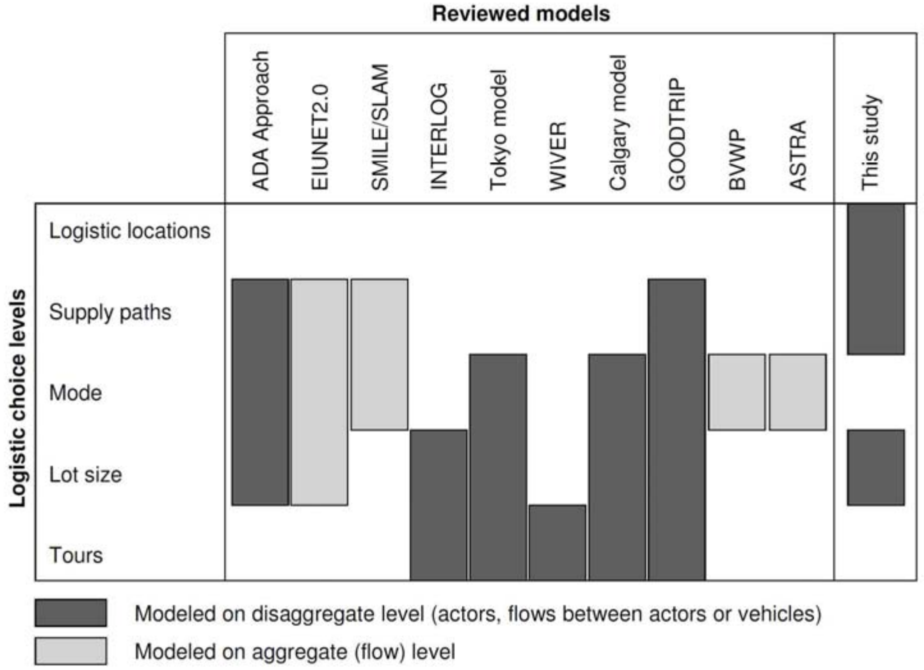


Figure 2 – Simplified view on logistic choices in freight transportation models (Sources: De Jong and Ben-Akiva (2007), Williams et al (2005), Tavasszy et al. (1998), Liedtke (2006), Wisetjndawat (2007), Sonntag (1996), Hunt and Stefan (2007), Boerkams and Van Binsbergen (1999), BVU et al. (2001), Schade (2005))

Following insights can be taken from the overview:

- The emergence of tours is often modeled by urban commercial traffic models, mostly however not out of a perspective of a logistic decision taker. In this context, the INTERLOG model is special in two ways: its focus is national (not urban) and the logistic decision is modeled out of the actors' perspectives.

- The choice of lot sizes is already part of many models, however the details of representation differ significantly.

- The modal choice traditionally is part of transportation models, therefore already well captured by many models and also analyzed in separate models with logistic frameworks.

- The supply path decision, or at least the decision on transport paths, is part of new partly aggregate modeling approaches (ADA or EUNET2.0) that interpret this as main logistic component. Logistic locations are assumed as given or available in each region for each flow.

- The explicit modeling of complex logistic structures containing logistic locations is not yet part of transportation models.

Two reasons why complex logistic structures (containing locations) are not yet modelled on a large scale within transportation models are high data demand and computational complexity of underlying problems: As introduced at the beginning of this chapter, systems can be described by modeling their behavior or their functioning. In the first case, the heterogeneity in logistic systems (and actors) leads to high data demand. In the second case, the underlying combinatorial problems lead to problems in computational capacity, if optimization is done for a large number of systems.

SYNTRADE, addresses both dimensions: new data sources get available because of a detailed sectoral modeling and second, simplified optimization heuristics are defined that can reproduce real-world logistic structures.

3. SYNTRADE – MODEL DESCRIPTION

3.1 Model overview

The objective of the model is to demonstrate that it is possible to artificially reproduce and explain the emergence of complicated logistic structures on a large scale, meaning for an overall sector and region. The SYNTRADE model reproduces warehouse structures of the German food retailing sector. The generated information on warehouse structures includes number, location and level of warehouses, as well as the allocation of food retailing stores to warehouses. To reproduce these structures in a realistic way, underlying logistic decisions of microeconomic actors are simulated. Besides the decision on the warehouse structures itself, these are supply path decisions and lot size decisions for bundled commodity flows on transport links. Actors are mainly food retailing companies and suppliers.

Decisions of microeconomic actors are simulated by optimizing total logistic costs. Solution procedures from the area of Operations Research (OR) and from logistic research are employed for the underlying optimization problems.

The decisions are simulated in a forward looking way, including all future changes caused by the decisions. For the warehouse structure decision this includes future changes of supply paths and lot sizes, for the supply path decision this includes future changes in lot sizes on the related transport links. These complex decision scopes have to be modelled to reach stable solutions in the simulation process.

The model can be differentiated into a model core and a model periphery. The food retailing sector is the core of the model, here more detailed input data is used, including for example data on company turnover and article data. The periphery is modeled in a simplified fashion, data is generated based on statistics and only establishments, no company structures are represented. The periphery is modeled to cover the dependencies on logistic systems surrounding the food retailing sector: food and other consumer products can also be distributed via other distribution channels. To model their attractiveness alternative supply paths have to be represented. Therefore, the periphery includes the production location and simplified logistic systems for distribution of all consumer products.

SYNTRADE can be divided into three phases as shown in figure 3. In the first phase, the data needed for the simulation is generated. Data for food retailing companies includes the types and locations of stores and the disaggregation of turnover to article types. Data of the periphery includes an artificial economic establishment structure with locations and production volume for each establishment, based on statistical data on employment and establishment sizes. Wholesalers and logistic service providers are not covered within this generation but represented simplified in each region. Demand for consumer products is modeled for each NUTS-3 region, imports on the level of countries.

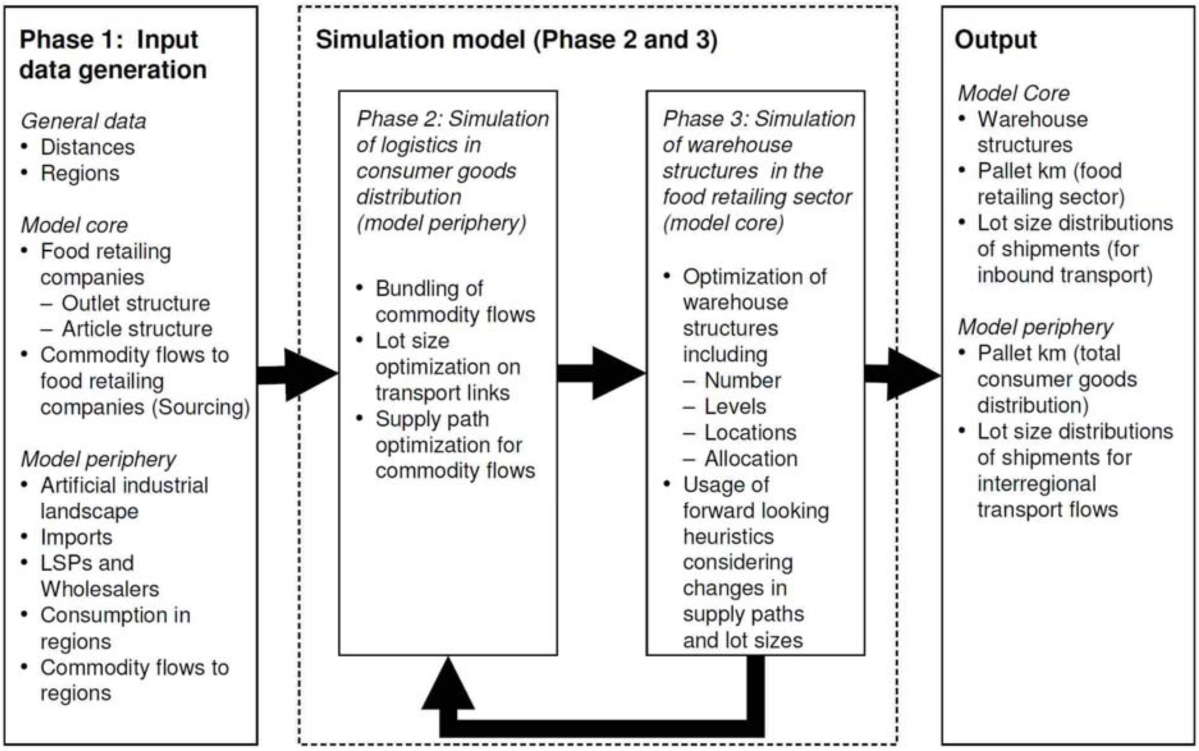


Figure 3 – Levels SYNTRADE overview

The generation of commodity flows from producing establishments to food retailing companies is explicitly modeled by a sourcing procedure, the remaining demand for consumer products in regions is distributed with a gravity model.

In the second phase, the periphery is established: supply paths are determined for flows between producing establishments and food retailing companies or regions. On each transport link the lot sizes are determined for the flow bundle including all flows on this link. The supply paths can change with the bundling level. Therefore, supply path choices are repeated until a stable state is reached, meaning that no improvement can be reached by changing supply paths of single commodity flows. This represents an equilibrium for commodity flows. This simulation includes assumptions on existing warehouse structures of food retailers to calculate the costs of supply paths.

The explicit determination of warehouse structures for food retailing companies happens in the last phase. This includes the determination of number, level and location of warehouses as well as the allocation of stores to warehouses. If warehouse structures change, compared to the initial assumed structures, phases two and three are repeated.

Numbers of generated objects and detail of classifications can further describe the scope of the model. The model generates following objects:

- About 17.000 establishments in 78 sectors
- 481 regions, thereof 439 NUTS-3 regions in Germany and 41 regions representing European countries

- Logistic Service Providers (LSP) of three categories and wholesalers of 16 categories in each region
- 31 retail companies with up to four store categories each, about 51.000 stores in total, 50 article types in 5 assortments and about 210 warehouses in total
- About 150.000 commodity flows between producing establishments and retail companies and about 2.5 million flows between producing establishments and regions.

The main result of the model are simulated warehouse structures of the German food retailing companies. In the next chapter simulated warehouse structures are shown and compared to real structures. Besides the warehouse structures, also data on commodity flows results from the simulation. This data includes transport volumes of transports through the warehouse structures of food retailing companies (measured in pallet kilometers - pkms) and lot size distributions for inbound transports. This information can be aggregated to transport volumes between regions. Similar information also results from the simulation of commodity flows outside the food retailing sector in the model periphery. However, this data has to be handled with care, since it results from a simplified modeling. Another side product, especially interesting for analysis on company level is cost data. An analysis, conducted with the model, shows for example the cost savings in logistics of a merger of two food retailing companies.

In the following a more detailed description is given for the modelling of the supply path decision and the warehouse structure decision.

3.2 Supply path decision

The supply path alternatives in the model are shown schematically in figure 4.

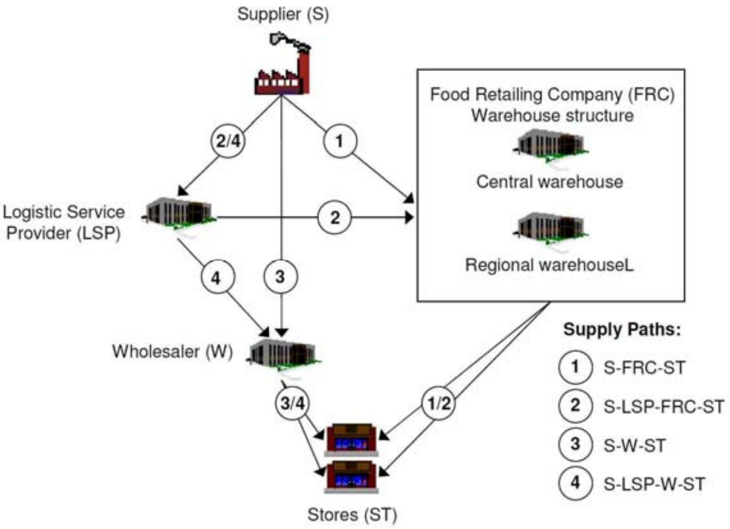


Figure 4 – Supply paths alternatives

The model distinguishes four supply paths: the first and the second describe the distribution via the food retailing sector, the other two the direct delivery. For both distribution types, the warehouse of a logistic service provider can be used to bundle flows from different suppliers. All four alternatives are determined for commodity flows into food retailing, for the remainig flows into the regions only two direct alternatives apply. Logistic service providers (LSP) are only modeled in a simplified way: only three types of LSPs are represented in the model (cooled/frozen food, dry food and non food), in each region one of each type is present, each supplier can only use the corresponding LSP in his region. The LSPs are included into the model to describe the outsourcing of distribution activity of goods for low demand regions. Further bundling for transport, for example by mixed cargo load networks, is not explicitly modeled but included in the transport price matrix within the lot size model. Also wholesaling is modeled in a simplified way: 16 wholesaling sectors exist. In each region, wholesaling of each type is represented. The distribution area of a wholesaler is limited to the region where he is located. The number of wholesalers varies depending on the demand in the region.

The decision on supply paths is taken based on logistic costs. Only long term marginal costs are considered for calculation. The costs are calculated as follows:

$$\begin{aligned}
C_1 &= TC_{S-FRC} + SC_{FRC} + HC_{FRC} + (CDC_{FRC}) + DC_{FRC} \\
C_2 &= TC_{S-LSP} + SC_{LSP} + HC_{LSP} + TC_{LSP-FRC} + SC_{FRC} + HC_{FRC} + (CDC_{FRC}) + DC_{FRC} \\
C_3 &= \sum_i \left(TC_{S-W_i} + SC_{W_i} + HC_{W_i} + DC_{W_i}\right) \\
C_4 &= TC_{S-LSP} + SC_{LSP} + HC_{LSP} + \sum_i \left(TC_{LSP-W_i} + SC_{W_i} + HC_{W_i} + DC_{W_i}\right)
\end{aligned}$$

C_x = Costs of alternatives x
TC_{x-y} = Transport costs from x to y
i = Regions with different wholesalers W_i
SC_x = Storage costs at warehouse x
HC_x = Handling costs at warehouse x
DC_{FRC}/DC_W = Costs for distribution of food retailing company or wholesaler
CDC_{FRC} = Cross docking costs at food retailing company

The costs modeled include transport costs, storage costs, handling costs and distribution costs. Storage costs include costs for the storage space as well as capital costs, they are determined together with transport costs in the lot size model for flow bundles. The calculation of handling costs is limited to costs for throughput, meaning costs for movement in the warehouse, from the truck to the storage space and vice versa. Commissioning and ordering costs are not included in the model. A further cost component is included to define extra costs for cross docking in case of a two level warehouse structure of the retailing company. Finally distribution costs of the wholesaler or the retailing company include transport and handling costs for the last transport from the last warehouse to the stores.

For the two alternatives of direct delivery, costs have to be differentiated by regions since the operations of wholesalers in the model are limited to their regions. This offers the possibility to reflect differences in distribution costs for regions, depending on their demand structure. These distribution costs, however, have only to be considered for the supply path choice of commodity flows. Region flows are distributed via wholesalers anyway so that distribution costs do not have to be considered.

3.3 Warehouse structure decision

Figure 5 gives an overview on the optimization heuristic for warehouse structures.

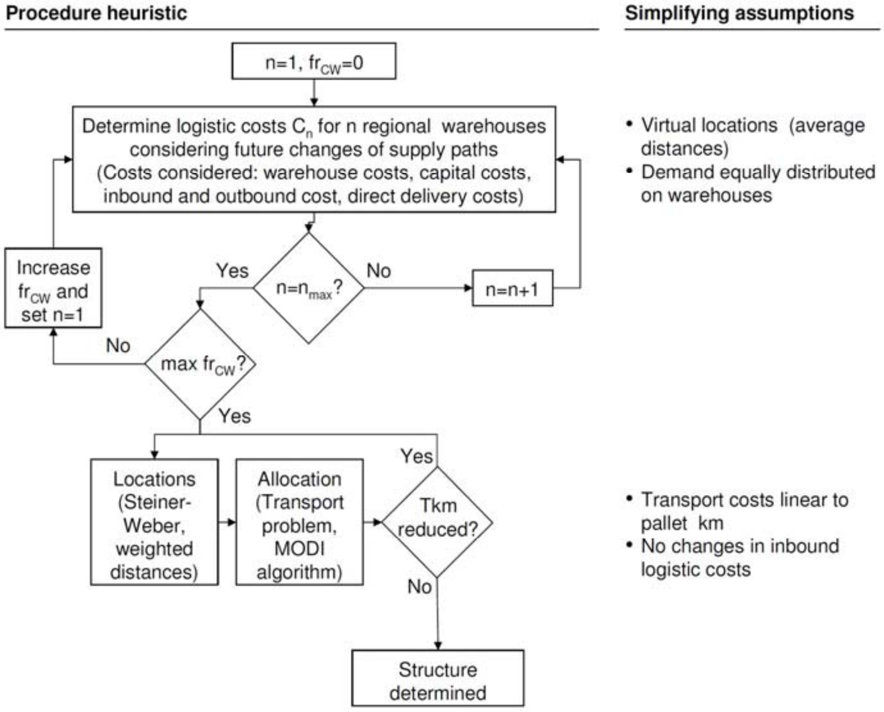


Figure 5 – Heuristic for determination of warehouse structure

In a first phase, the number of warehouses and the warehouse levels are optimized. Then locations of warehouses and allocations of stores to warehouses is determined in a second phase. The optimization in the first phase is done by full enumeration, meaning that costs for all possible warehouse structures are calculated. Different kinds of central levels are distinguished by the weekly frequency (fr_{CW}) of transports between central and regional warehouse level. The alternatives include no central level, central level with weekly, biweekly or daily delivery. Depending on this frequency, different goods can be handled in the central level. The costs considered within the calculation include warehouse costs, capital costs inbound and outbound costs as well as costs for direct delivery. All these costs are dependent on the structure. The calculation considers all changes, caused by a "new" warehouse structure. Besides new lot sizes for inbound transports this includes possible changes of supply paths. Thus, costs are calculated in a forward looking way. It has to be noted that the heuristic uses some simplifying assumptions to keep the problem solvable. For the determination of the number of warehouses these are the assumptions of virtual locations and equal demand for all warehouses. The locations are assumed to be distributed equally in space, thus, average distances can be used for calculation. Equal demand of warehouses is assumed to avoid a combinatorial problem which needs more time to be solved. The detailed modeling of this first part differentiates the heuristic from standard problems in operations research like the warehouse location problem or the facility location problem. Contrary to these problems, warehouse costs are modeled in a very detailed way. This is needed to differentiate companies in food retailing.

The allocation and location problem are solved integrated in an iterative procedure. The choice of locations corresponds to the Steiner Weber problem. The allocation problem corresponds to the standard transport problem in operations research and can be solved by the MODI algorithm. By repeated solving of the two problems, the solution is constantly improved. The heuristic terminates if no improvement can be reached through changing warehouse locations or allocation of stores. The implicit assumption, taken in this part, is that inbound costs do not change and thus, no recalculation of the first part is necessary. Also the procedure assumes that the minimization of tonnes kilometers corresponds to the minimization of costs.

The general form of the warehouse structure, including number of warehouses and existence of central level, is determined based on all logistic costs dependent on this structure:

$$TLC(n_{RW}) = n_{RW}\, WC_{fix} + \sum_{cf \in CF_{FRC}^{RW}} (C_{cf}^{LSP} + TC_{cf} + SC_{cf} + HC_{cf})$$
$$+ TLC_{FRC}^{CW} + \sum_{St} DC_{ST} + \sum_{cf \in CF_{direct}} (C_{cf}^{direct})$$

Warehouse costs include fix costs (WC_{fix}) and variable warehouse costs (SC_{cf} and HC_{cf}). The variable costs have to be determined together with inbound transport costs TC_{cf}, based on the lot size optimization model and individually for all commodity flows that are handled within food retailer warehouses. By calculating these costs in this detail differences between retail companies caused by number of articles and turnover per article can be modeled.

In case of delivery via a LSP, additional costs C^{LSP} have to be considered, including the transport costs and costs within the warehouse of the LSP. Costs for a central warehouse level TLC^{CW} include costs for individual flows, as for the flows on the regional level, as well as costs for cross docking. Costs for distribution DC by store are a key driver for the number of warehouses since distances decrease with increasing number of warehouses. Also the volume distributed can change, if supply paths change. Finally, the potential change of supply paths connected to a different warehouse structure leads to a change in costs for direct delivery C^{direct}.

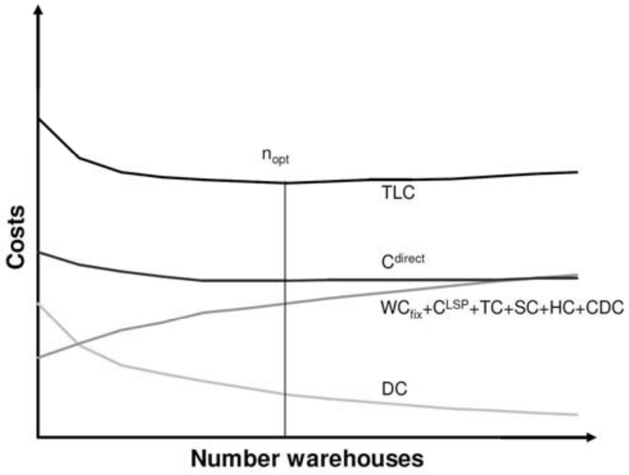


Figure 6 – Cost components for different warehouse numbers

The optimal warehouse structure is determined by enumeration of all alternatives of warehouse numbers and central warehouse level.

A typical course of the costs components - taken from the model results for Full Assortment Retailer 1 - is shown in figure 6.
It corresponds to the pictures drawn in other logistic publications (see for example Toporowski (1996), p. 104). Costs for distribution decrease with a declining rate whereas the other costs of the retailer increase. The costs of direct delivery are very stable, the course shows that more flows are delivered directly, if few or many warehouses are assumed.

4. MODEL RESULTS

4.1 Calibration and verification

For model calibration and validation data on all warehouses of the German food retailing sector was available. Data of five companies was used for calibration, the data of the remaining 26 companies could be used for validation.
The model is calibrated by stepwise adapting the variable model paramteters in a way that warehouse structures, chosen for calibration are met. The five warehouse structures chosen are marked with a star (*) in figure 9. Different types of retailing companies are included:

- A national and a regional discounter with less than 2000 articles
- A national discounter with more than 2000 articles
- A national full assortment retailer
- A regional full assortment retailer

Besides these warehouse structures, some orientation points from the expert interviews are used to calibrate the proportions of direct deliveries, resulting from the supply path decisions in the second model phase. These orientation points are:

- The direct delivery proportions of a full assortment company: about 40% of articlesof the store type "SB-Warenhaus" are delivered directly (supply path 3/4).
- Discounters are usually delivered via food retailer warehouses.
- Beer and non alcoholic drinks of large full assortment stores are often delivered via a wholesaler, because of the bottle return system in Germany.

The calibration process for the model is time consuming since for the test of each parameter value combination a whole simulation run is necessary. One simulation run can include several repetitions of the second and third model phase and takes about 30 minutes.

The outcome of the second model phase is shown in figure 7.

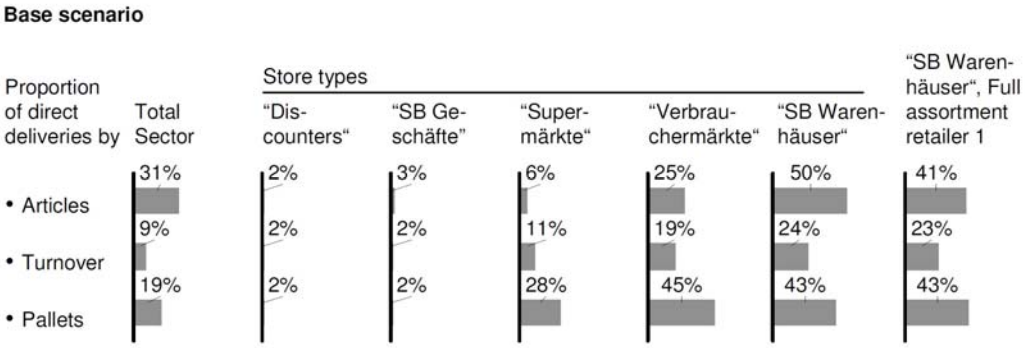


Figure 7 – Proportions of direct deliveries from the second model step in base scenario

This is the result of the calibration by the above listed observation points: the known proportion of full assortment retailer is at 40%, no direct deliveries for discounters and delivery of beverages via wholesalers for large full assortment stores. The high proportions of pallets delivered directly, results from beverages that represent about 30 percent of overall pallets. Considering this, it can be seen that for stores with large number of articles ("SB-Warenhäuser" and "Verbrauchermärkte") mainly commodity flows with low number of pallets are delivered directly which corresponds to the observations in expert interviews.

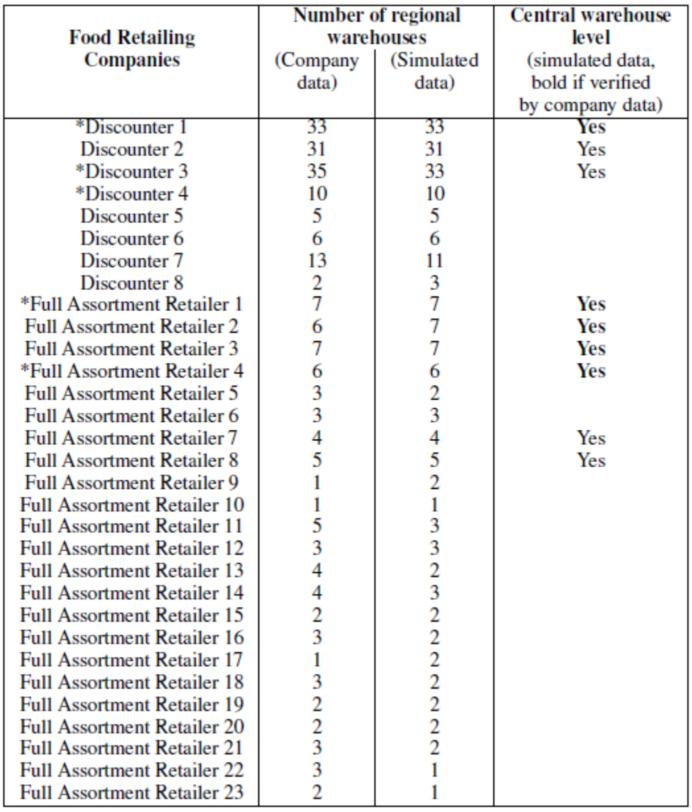

Food Retailing Companies	**Number of regional warehouses** (Company data)	(Simulated data)	**Central warehouse level** (simulated data, bold if verified by company data)
*Discounter 1	33	33	**Yes**
Discounter 2	31	31	Yes
*Discounter 3	35	33	Yes
*Discounter 4	10	10	
Discounter 5	5	5	
Discounter 6	6	6	
Discounter 7	13	11	
Discounter 8	2	3	
*Full Assortment Retailer 1	7	7	**Yes**
Full Assortment Retailer 2	6	7	**Yes**
Full Assortment Retailer 3	7	7	**Yes**
*Full Assortment Retailer 4	6	6	**Yes**
Full Assortment Retailer 5	3	2	
Full Assortment Retailer 6	3	3	
Full Assortment Retailer 7	4	4	Yes
Full Assortment Retailer 8	5	5	Yes
Full Assortment Retailer 9	1	2	
Full Assortment Retailer 10	1	1	
Full Assortment Retailer 11	5	3	
Full Assortment Retailer 12	3	3	
Full Assortment Retailer 13	4	2	
Full Assortment Retailer 14	4	3	
Full Assortment Retailer 15	2	2	
Full Assortment Retailer 16	3	2	
Full Assortment Retailer 17	1	2	
Full Assortment Retailer 18	3	2	
Full Assortment Retailer 19	2	2	
Full Assortment Retailer 20	2	2	
Full Assortment Retailer 21	3	2	
Full Assortment Retailer 22	3	1	
Full Assortment Retailer 23	2	1	

Figure 8 – Number of warehouses and warehouse levels

In figure 8 the simulated data for warehouse numbers is shown and can be compared to the existing company data. There is a high degree of similarity, not only for the structures used for calibration but also for the rest. While the numbers do not meet every single data point, the tendency is very clearly met. Besides differences resulting from historic structures or from estimations in input data, some cases exist that result from simplifying assumptions. The model assumes that regional warehouses have the same size and that the distribution area is connected. Especially the second aspect leads to the differences for the full assortment retailer 13 and 22.

Finally, the average distance between existing and simulated warehouses, is about 60km (distances on road network - not direct).

Apart from individual differences for some companies the overall structures are very well met as can be seen in figure 9 that gives an overview on all existing and simulated warehouse locations.

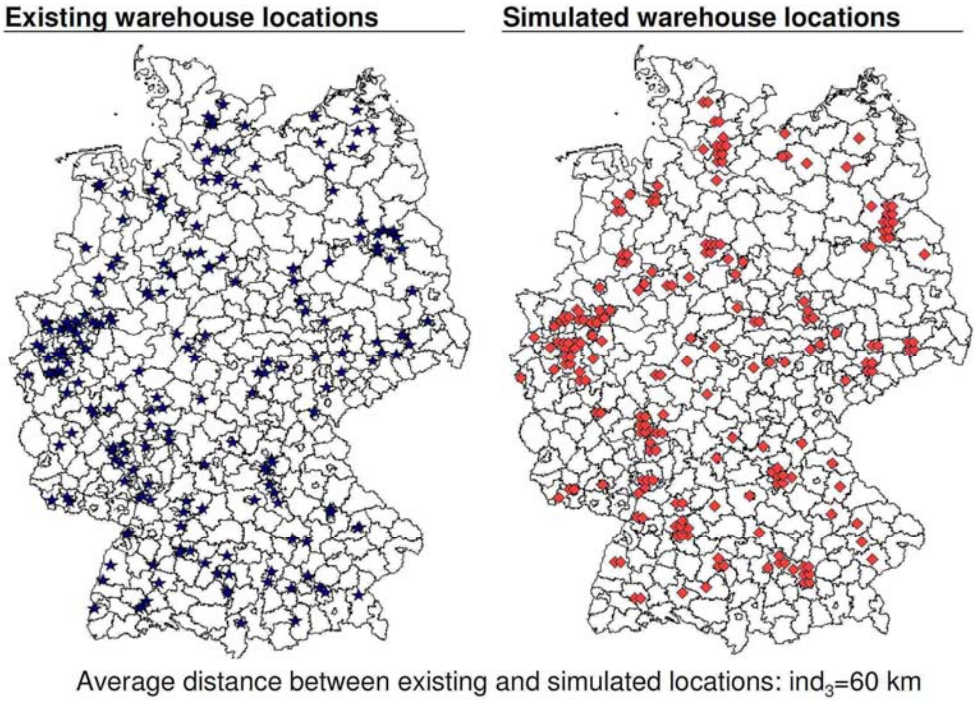


Figure 9 – Regional warehouses real data (left) versus simulated data (right)

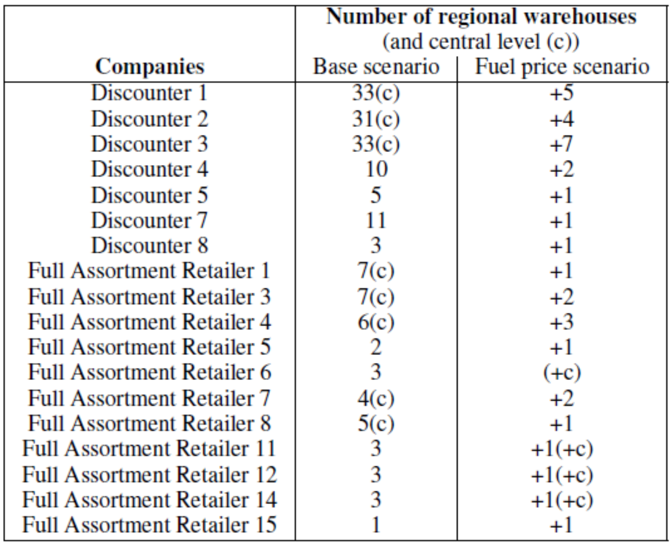
4.2 Application example – fuel price scenario

The fuel price scenario is defined by a change of all parameters connected to fuel prices. In the model, these are:

- The general transport costs for incoming transports
- he interregional distribution transport cost rate of retailers
- The local distribution transport cost rate of retailers
- The (local) distribution transport cost rate of wholesalers

A fuel price raise of 100% is analyzed, which translates into a raise of 25% in these parameters, given that fuel costs make about 25% of total truck costs (BGL, 2009). It is assumed that all parameters are affected the same way. The differences in value between the parameter values in the base scenario result mainly from higher detour factors in regional transport and urban traffic (slower traffic with many stops) which both are fully affected by a fuel price raise.

The scenario is implemented as a "future" scenario, meaning that it bases on the stable state of the base scenario and describes the "future" development with changed parameters.



Companies	Number of regional warehouses (and central level (c)) Base scenario	Fuel price scenario
Discounter 1	33(c)	+5
Discounter 2	31(c)	+4
Discounter 3	33(c)	+7
Discounter 4	10	+2
Discounter 5	5	+1
Discounter 7	11	+1
Discounter 8	3	+1
Full Assortment Retailer 1	7(c)	+1
Full Assortment Retailer 3	7(c)	+2
Full Assortment Retailer 4	6(c)	+3
Full Assortment Retailer 5	2	+1
Full Assortment Retailer 6	3	(+c)
Full Assortment Retailer 7	4(c)	+2
Full Assortment Retailer 8	5(c)	+1
Full Assortment Retailer 11	3	+1(+c)
Full Assortment Retailer 12	3	+1(+c)
Full Assortment Retailer 14	3	+1(+c)
Full Assortment Retailer 15	1	+1

Figure 10 – Changes in number of warehouses and warehouse levels

The number of warehouses changes for many companies (figure 10). Mainly discounters as well as Full Assortment Retailers that have a certain number of warehouses react. Besides a higher number of regional warehouses, also the usage of the central level increases. These are the first two "evasion strategies" of food retailers.

For full assortment companies, the increase of number of warehouses is only affordable for those companies that are large enough. Besides the opening of regional warehouses the second evasion strategy, the increased usage of the central level, is applied of those that have enough load to open a central level.

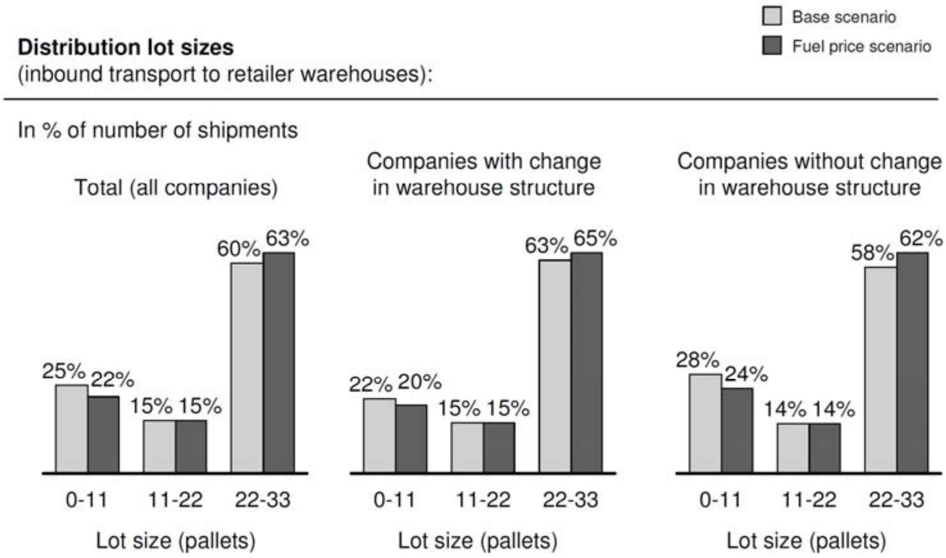


Figure 11 – Distribution of lot sizes for base and fuel price scenario

For those full assortment retailers that neither do increase the number of regional warehouses nor have a central warehouse level a third "evasion strategy" exists as can be seen, if lot size distribution is analyzed in detail (figure 11). A differentiation of companies, in those that increase the number of warehouses or the usage of the central level and the others, reveals a difference: the change of lot size distribution is stronger for the second group. For the first group, smaller changes occur since the effects of increased lot sizes and smaller flows due to more warehouses overlap. For the second group lot sizes increase more significantly. By doing so, they try to avoid the higher transport costs by accepting higher stock which is not more expensive than in the base scenario.
Finally figure 12 shows the overall estimation for transport demand in form of pallet kilometers.

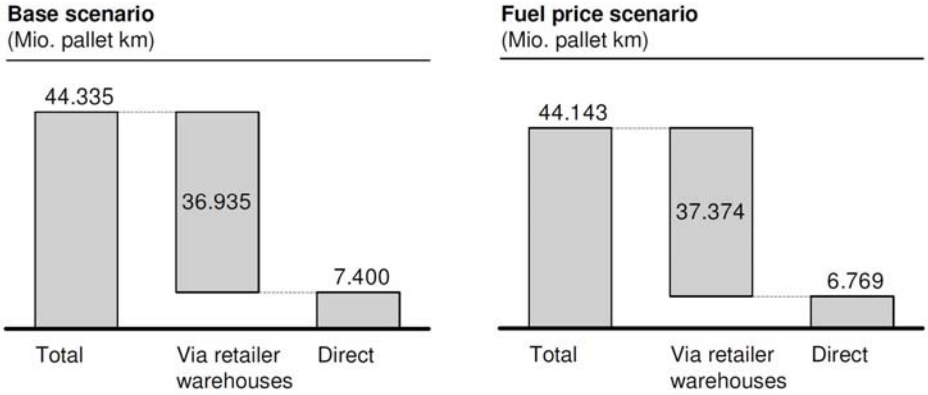


Figure 12 – Estimation pallet kilometer for base and fuel price scenario

In total it decreases slightly. The effect of more regional warehouses (leading to less detours) is almost equalized by a higher usage of the central warehouses level and a decrease of direct deliveries.
The translation of this result into vehicle kilometers is not part of SYNTRADE. It depends on the utilizations reached by the transport service providers. It can be expected that a higher bundling for long distances will also influence the utilization positively.

This analysis shows the capabilities of SYNTRADE and of modeling logistic mesostructures in transportation analysis in general. Forecasts can include consequences for logistics that are not yet covered by existing models. In the case described the analysis shows the adaptability of logistic structures. The more logistic aspects are represented in the model the more "evasion strategies" can be identified. This underlines the necessity to model logistic mesostructures. In classical transportation models, this logistic diversity is often neglected, leading to an overestimation of modeled interrelationships. The modelling of mode choice without consideration of other logistic decisions is an example for this.
The enhanced capabilities of the new modeling approach are also reflected in a more detailed picture of consequences for transport. Besides the forecast of pallet kilometers, the model shows the change in logistic locations and lot size distributions that can be expected. Thus, consequences on the logistic sector become visible. In the case of increased fuel prices, the usage of "logistics" is strengthened, more warehouses are built and the usage of

logistic service providers increases. In the context of logistic master plans these effects are of interest.

5. CONCLUSIONS

Models using activity patterns of individuals and households to explain transport demand, are state of the art in passenger transportation models. However, for modeling freight transportation such approaches are still at the beginning of their development. A possible reason for this is that the transition from transport demand of individual companies in form of commodity flows (micro level) to vehicle flows on the network (macro level) is very complex. Economies of scale in logistics, that occur through bundling for transport or by a shared usage of warehouses, cause the existence of a meso level and logistic mesostructures like warehouse structures or vehicle tours. Aggregation or disaggregation between the macro and the micro level can only be done by modeling these structures. Besides the high requirements for data and processing capacity, a major difficulty for modeling these structures is the identification of system characteristics that can be reproduced. Since economies of scale within logistic systems cause concave cost functions, multiple possible system states exist. To produce stable solutions, system characteristics resulting from logistic decisions with convex cost functions can be modeled.

These complications are probably a reason that, despite the awareness of the necessity to include logistics in freight transportation models, recent developments only include basic logistic decisions. A progress has been achieved recently in Liedtke (2006) who manages to simulate the emergence of vehicle tours by modeling the interaction between shippers and forwarders. Unlike in urban commercial transportation models, his simulation includes the explicit modeling of logistic optimization of these actors. The emergence of logistic locations has not been part of freight transportation models, although optimization procedures from logistic research exist for these problems as well.

However, these optimization procedures are manifold. All different sorts of details can be included, reflecting that many different logistic situations may exist. The optimization of lot size, for example, can include a range of different characteristics like fluctuations, complex cost functions or dynamic conditions. To use logistic optimization for the modelling of complex logistic structures in freight transportation models, a detailed analysis of the economic activity under consideration is necessary. This includes the identification of logistic decisions taken, including scope and objective.

The approach chosen in this paper builds on a detailed analysis of the food retailing sector. Based on this, the SYNTRADE model is defined, that is capable to describe the emergence of warehouse structures in this sector.

The simulation in the SYNTRADE model consists of phase two and three of the model that are repeated several times within a simulation run. The second phase generates a realistic logistic environment of the food retailing sector, the third determines warehouse structures of the food retailing companies.

In the second phase, the supply path decision is simulated for the overall distribution of consumer goods, including the food retailing sector, as well as all other sectors in its "logistic environment". This represents the overall system within the model, where interactions between individual logistic system can take place through combining flows for interregional transport and distribution in the target region. The supply path decisions are repeated until a stable state is reached, meaning that no supply path is changed anymore. This system state represents an equilibrium: no actor can improve his situation through changes in supply paths of individual commodity flows or combined flows from supplier to region. This equilibrium is not unique, but it is calibrated based on proportions of direct deliveries to food retailing companies.

The third phase of the model consists of the optimization of warehouse structures of individual food retailing companies. The scope of this decision is much wider, including all commodity flows of the company. Also, a forward looking decision is assumed, considering future changes in supply paths. Thus, the formulated optimization problem has a convex cost function and the overall solution of the simulation is stable.

In both phases the decision scopes reflect very closely the logistic decisions in reality. Model results show a high fit with existing structures. Also, sensitivity analysis shows a plausible behavior of the model. The dependency of resulting warehouse structures on initial system states, including allocation of flows to supply paths and initially assumed warehouse structure, is minor. This can be explained by the described optimization procedures for warehouse structures including forward looking elements.

The scenarios that can be simulated with SYTHRADE demonstrate the new possibilities of such models. Multiple reactions of logistic systems can be described including changes in warehouse structures. A scenario simulating a rise in fuel prices shows an increased usage of logistic systems that are more complex: the number of warehouses, as well as the usage of the central warehouse function increase.

With the SYNTRADE model it can be proved that it is possible to simulate warehouse structures of the overall food retailing sector for the purpose of freight transport demand modeling. This is based on a detailed analysis of the sector, including the identification of additional data sources, and the usage of adapted logistic optimization procedures.

There is still research to do for a complete freight transportation modeling system that explains overall transport demand by connecting the micro with the macro level. The SYNTRADE model is an important step in this direction and contributes to fill the gap between transportation and logistic research.

REFERENCES

Ben-Akiva, M. and G. De Jong (2008). The Aggregate-Disaggregate-Aggregate (ADA) Freight Model System, In: Recent Developments in Transport Modelling. Emerald, 2008, Chapter 7. – ISBN 978-0-08045-119-0

BGL (2009). Kosteninformationssystem für die leistungsorientierte Kalkulation von Straßengütertransporten.

BMVBS (2006). Masterplan Logistik. Bundesministerium für Verkehr, Bau und Stadtentwicklung (German ministry of transport and housing). 2006. – URL: http://www.bmvbs.de/Anlage/original_1058871/Masterplan-Gueterverkehr-und-Logistik.pdf

Boerkamps J. and A. Van Binsbergen (1999). GoodTrip, A New Arrpoach for Modelling and Evaluation of Urban Goods Distribution. Paper presented at the 2nd KFB-Research Conference, Lund.

BVU, IFO, ITP, PLANCO (2001). Verkehrsprognose 2015 für die Bundesverkehrswegeplanung. Bundesministerium für Verkehr-, Bau- und Wohnungswesen. Available online, April 2001. – Reserach report. – URL http://www.bmvbs.de.

De Jong G. and M. Ben-Akiva (2007): A microsimulation model of shipment size and transport chain choice. In: Transportation Research Part B: Methodological 41 (2007), No. 9, p. 950–965

EU (2007). Freight Transport Logistics Action Plan. Communication from the European Commission, URL: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0607:FIN:EN:PDF

Hunt, J.D. and K.J. Stefan (2007). Tour-based microsimulation of urban commercial movements. In: Transportation Research Part B: Methodological 41 (2007), No. 9, p. 981–1013

Liedtke, G. (2006). An Actor-based Approach to Commodity Transport Modelling, University of Karlsruhe, Institut fürWirtschaftspolitik undWirtschaftsforschung (IWW), Dissertation.

Manheim, M. (1979). Fundamentals of Transportation Systems Analysis. The MIT Press, Cambridge, Massachusetts

Rothengatter, W. (2008). Marvin Manheim: Founder of the World Conference on Transport Research Society and Spiritus Rector of the Integration of Human Resources and Technological Systems in Transport. In: Recent Developments in Transport Modelling. Emerald, 2008, Chapter 7. – ISBN 978-0-08045-119-0

Schade, W. (2005). Strategic Sustainability Analysis: Concept and Application for the Assessment of European Transport Policy, University of Karlsruhe, Institut für Wirtschaftspolitik und Wirtschaftsforschung (IWW), Dissertation.

Sonntag, H. (1996). Entwicklung eines Wirtschaftsverkehrsmodells für Städte. In: Berichte der Bundesanstalt für Straßenwesen, Verkehrstechnik.

Tavasszy, L.A. (2006). Freight Modelling - An overview of international experiences. (2006). – Presented at the TRB conference 2006

Tavasszy, L.A., M. Van de Vlist, C. Ruijgrok, J. Van de Rest (1998). Scenario-wise analysis of transport and logistic systems with a SMILE. Paper presented at the 8th WCTR Conference

Toporowski, W. (1996). Logistik im Handel, Optimale Lagerstruktur und Bestellpolitik einer Filialunternehmung. Universität Köln, Dissertation.

Williams I., Y. Jin, G. Deane, Y. Zhu (2005). The EUNET2.0 Freight and Logistics Model - Final Report / WSP. 2005. – Research report. Project for Department for Transport, England (DFT) Contract PPAD 8/134/24

Wisetjindawad, W., K. Sano, S. Matsumoto and P. Raothanachonkun (2007). Micro-Simulation Model for Modeling Freight Agents Interactions in Urban Freight Movement. Paper presented at the 86th annual meeting of Transportation Research Board, Washington DC.