Simulation of logistics in food retailing for freight transportation analysis

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List of Abbrevations

BAG	Bundesamt für Güterverkehr
BAST	Bundesanstalt für Straßenwesen
BBR	Bundesamt für Bauwesen und Raumordnung
CC	Capital Costs
CDC	Cross Docking Costs
CPA	Classification of Products by Activity
DC	Distribution Costs
DIN	Deutsches Institut für Normung
DIW	Deutsches Institut für Wirtschaftsforschung
EAN	European Article Number
EHI	Europäisches Handels Institut
EU	European Union
FRC	Food Retailing Company
GFK	Gesellschaft fü Konsumforschung
GP	Klassifikation der Güterproduktion
GS1	Global Standard One
HC	Handling Costs
IO	Input Output
IRI	Information Resources Inc.
ISIC	International Standard Industrial Classification
KBA	Kraftfahrt Bundesamt
km	Kilometer
LSP	Logistic Service Provider
LZ	Lebensmittelzeitung
m3	Cubic Meter
MODI	Modifizierte Distributionsmethode

MRIO Multi Regional Input Output

NACE Nomenclature Generale des Activites Economiques

NSTR Nomenclature Uniforme de Marchandises pour les Statistiques de Transport

NUTS Nomenclature of Terratorial Units for Statistics

OHC Ordering and Handling Costs

OR Operations Research

PC Production Consumption

pkm Pallet Kilometer

POS Point of Sale

PWC Production Wholesaling Consumption

RC Risc Costs

SC Storage Costs

SCGE Spatial Computable Equilibrium

SCM Supply Chain Management

t Ton

TC Transport Costs

TLC Total Logistic Costs

UN United Nations

WC Warehouse Costs

WZ Klassifikation der Wirtschaftszweige

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. 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. Complex logictic structures usually are not modeled yet, mostly only the choices of lot sizes and transport paths represent the logistic part of transportation models. An exception is the work of Liedtke ((Liedtke, 2006)) which simulates tours of transport service providers. However, a model that includes the choice of warehouse structures has not been developped. While on an aggregate level the SMILE model ((Tavasszy et al., 1998)) already includes warehouse locations, the choice of warehouse structures on the company level has not been part of models 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.

This study 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. The food retailing sector in Germany serves as an application example. It 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.

To be able to fill the gap between transportation and logistics, three important aspects are addressed within this study: Firstly, a detailed analysis of the sector under consideration is carried out. It includes the identification of new data sources not yet used by transportation modeling and expert interviews that help to explain logistic behavior in this sector. Secondly, 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. And finally, 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 study is divided into seven chapters. After these introductory remarks, a short overview of SYNTRADE is given to clarify the objective of the discussions in the following chapters.

Then, chapter three carries out an analysis of the freight transportation system in general, as well as the food retailing sector and its logistic systems. Besides this analysis, the second part of the chapter also contains a description of data sources used, as well as a discussion on research methods that explains the motivation for expert interviews carried out for this study. With this chapter the empirical basis for the SYNTRADE model is laid.

In the fourth chapter methods of freight transportation modeling are presented. A special focus is laid on experiences from logistic optimization that are used within SYNTRADE. The chapter concludes with a review of existing freight transportation models and their representation of logistic aspects. This discussion shows the motivation to develop the simulation model in this study.

In chapter five a formal definition of the simulation model SYNTRADE will be given. This description includes three parts of the model. The generation of input data, the simplified simulation of the logistic environment of the food retailing sector and the optimization procedures for warehouse structures within the food retailing sector.

Chapter six shows the model results. A base scenario is presented and compared to real world data. Sensitivity analysis are defined and carried out for the base scenario, including changes in parameters, as well as changed system states at the beginning of the simulation process. Furthermore, two future scenarios are defined and analyzed, one assuming a merger of two companies and one assuming a raise in fuel prices.

Finally, the last chapter summarizes the results and modeling experiences. Based on this, potential directions for future research are identified.

2 SYNTRADE - model overview

This chapter gives a short overview of the SYNTRADE model which is developed in this study. This is done at this place to clarify the objectives of discussions in the following chapters, where the basis for the model will be laid in terms of system understanding, data used and methodologies employed.

The objective of this study 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[1]. 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 modeled to reach stable solutions in the simulation process. A detailed analysis of logistic decisions in general, as well as logistic decisions in food retailing, can be found in chapter 3.

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 2.1:

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. 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.

[1] Chapter 3 gives an exact definition of the food retailing sector in Germany

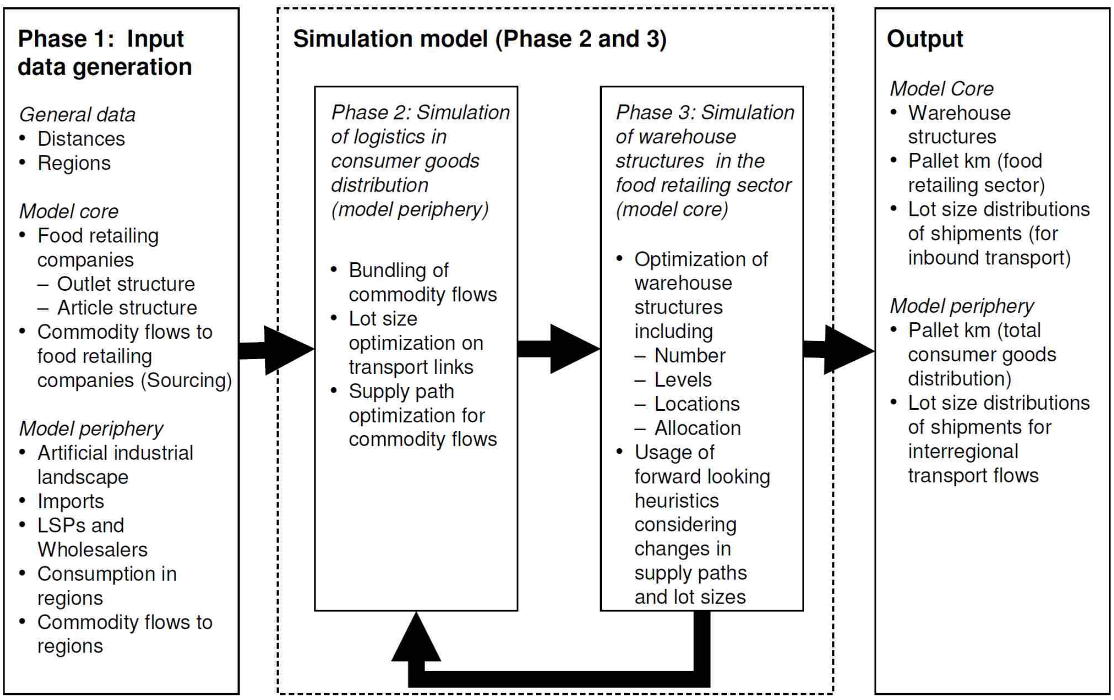

Figure 2.1: SYNTRADE overview

The second and third phase of SYNTRADE are the logistic simulation.

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
- 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 chapter 6 simulated warehouse structures are shown and compared to real structures. Figures show for example warehouse locations for the overall sector (see figure 6.4), as well as for individual companies (see figure 6.2 and 6.3). 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 within this study, shows for example the cost savings in logistics of a merger of two food retailing companies.

This chapter only contains a very general overview of the SYNTRADE model. A formal definition of the model and a detailed discussion of model results will be given in chapters 5 and 6. But before discussing the model and its results, a detailed basis will be laid in this study by analyzing the systems under consideration, freight transportation system and logistic systems in food retailing, and presenting existing modeling experiences and methodologies from literature in the next two chapters.

3 Analysis of freight transport demand

In this chapter, transport demand in food retailing is analyzed. This analysis is the basis for the SYNTRADE model developed later in this study. In the first section, a system analysis of freight transport demand in general is carried out. The second section will give an overview on the empirical bases, including data sources and methods to collect data like expert interviews that were carried out for this study. Finally, the characteristics and structure of the food retailing sector in Germany will be described in more detail.

3.1 General system analysis of freight transport demand

In a general sense a system is defined as an object that fulfills a certain purpose. It is composed out of a number of components and relations between these components that determine the functioning. The system will not fulfill its purpose any more, if it is split up (translated and simplified from Bossel (1994)).

The analysis of a system tries to understand the system. This can either refer to the behavior (purpose) of the system or the functioning of the system. Looking at the behavior, the analyst can consider the system as a black box and concentrate on the inputs and outputs of the system - Ritchey (1991) calls this an analysis. Looking at the functioning of the system, means to try to examine the components, their relations, and therefore the structure of the system - Ritchey (1991) calls this a synthesis.

If considering a system whose components are also systems (subsystems), the synthesis of this system can be done in two ways. Either starting with the system and then decomposing it to subsystems, called top-down analysis, or to start at the smallest subsystem, analyze its behavior (analysis) and relations to other subsystems and thus, at some point, arrive at the overall system, called bottom-up analysis.

For the systems analysis of freight transport demand, both, a qualitative top-down analysis describing the overall transportation system and the economic activity system as well as a qualitative bottom-up analysis, will be started. Then, the concept of mesostructures representing structures of subsystems on a meso level will be introduced to close the gap between the top-down (macro) view and the bottom-up (micro) view. Finally, decisions leading to the composition of the systems and system states in transportation and logistic systems will be discussed.

3.1.1 Top down analysis

Transportation system analysis focuses on the interaction of the transportation system with the economic activity system. It can be used as a starting point for the top-down analysis of freight transport demand. Manheim (1979) defines the transportation system by listing all components and movements connected to transport [1]. The economic activity system on the other hand is defined by "the totality of social, economic, political, and

[1] "All mode of transport modes must be considered.", "All elements of the transportation system must be considered: the persons and the things being transported; the vehicles in which they are conveyed; and the network of facilities through which the vehicles, passengers, and cargoes move, including terminals and transfer points as well as line haul facilities.", "All movements through the system must be considered, including passenger and goods flows from all origins to all destinations.", "For each specific flow, the total trip, from point of origin to final destination, over all modes and facilities must be considered."(Manheim (1979), p.11,12)

other transactions taking place over space and time in a particular region" (Manheim (1979) p. 17). Following this definition, the transportation system is also part of the economic activity system.

The basic relation between these systems is shown in figure 3.1. The flow pattern (F) in the transportation system ("origins, destinations, routes, and volumes of goods and people moving through the system" Manheim (1979), p. 12) results from the interaction between the activity system and the transportation system. The flow pattern on the other hand will over time influence the transportation system as well as the activity system.

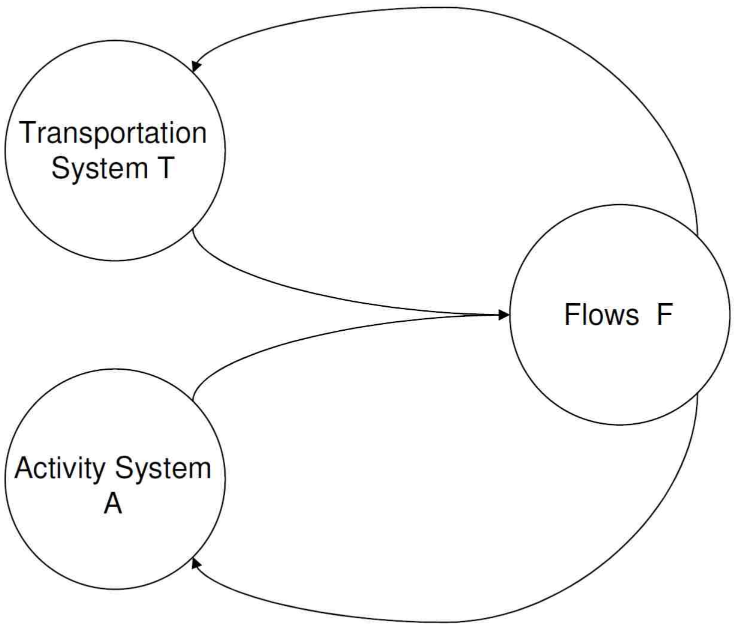

Figure 3.1: Basic relations in freight transportation analysis (adapted from Manheim (1979), p.13)

Following this framework, freight transport demand can be derived from an activity system interacting with the transportation system. Most freight transport demand is connected with economic activity. Therefore, the focus of this study will be on economic activity in the activity system. The economic activity system can be subdivided by geography into regions or by activity into sectors.

In national accounting, economic activity is represented in form of monetary values. The "Input-Output" (IO) analysis (in Germany Statistisches Bundesamt (2008d)) represents the linkage between the economic sectors, including state and consumers. It shows the input and output (goods or services) that are consumed or produced in each sector. Of interest for freight transport demand is the movement of goods between locations. This is different to the "flows" within the IO analysis, since between the location of production and the location of consumption the good may have passed other locations. Especially the activity in the sectors trade and logistics include movements of goods, but the values within the IO analysis for these sectors only represent the goods and services consumed during this activity or the value of the service "produced".

The flows of goods between the sectors can be called PC (production-consumption) flows. To include the movement caused by trade as well, this can be extended to PWC (production-wholesale-consumption) flows (Tavasszy et al., 1998). To arrive at the original demand for freight transport one has to add the geographic dimension resulting in a multi-regional input-output table (SCGE and MRIO models try to reproduce this data, see chapter 4). This can be seen as the origin of (top-down) freight transport demand.

But there is still a gap between flows connecting regions or sectors and the actual vehicle flows on transport infrastructure. As shown in figure 3.2, that was originally used to describe market levels from a logistic perspective, one can distinguish a logistic level that has to be considered when decomposing the system further.

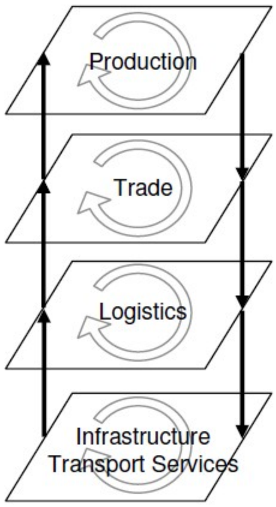

Figure 3.2: Market levels in a logistic system perspective (adapted from Oestlund et al. (2002))

Definitions of logistics change over time:

- There are definitions focusing on the company (translated from Schulte (2005)): market oriented, integrated planning, design, operation and control of the whole material (commodity) flow and the corresponding information flow between the company and its supplier, within the company and between the company and its customers.
- There are definitions including the overall supply chain (definition for supply chain management translated from Arndt (2004) (p. 46ff): cross-company-coordination and optimization of material, information and financial flows of the overall value added process from the sourcing of row material along the different stages of refinement to the final customer, with the objective to design the overall process in a cost and time optimal way.
- And there are even definitions emphasizing the network view (translated from Gudehus (2004), p.1): Today, logistics is the network of transport infrastructure, warehouses and reloading points, established to connect companies and consumers.

This development of the understanding of logistics from a company centered to a network view is described by many researchers (see for example Sjoestedt (2004), p. 208, Tavasszy

(2008) or Gudehus (2004), p. 1). All these definitions have in common that they take the perspective of goods and see logistics as a system assuring the provision of goods. Logistic systems hence have the purpose of providing goods in space and on time, they can be seen as subsystems of the overall activity system, their components are warehouses, reloading points and transport links.

On the other hand, the definition of the transportation system lays the focus on the system that provides the transport service. Sjoestedt (2004) shows this relation between the logistic system and the transportation system (see figure 3.3).

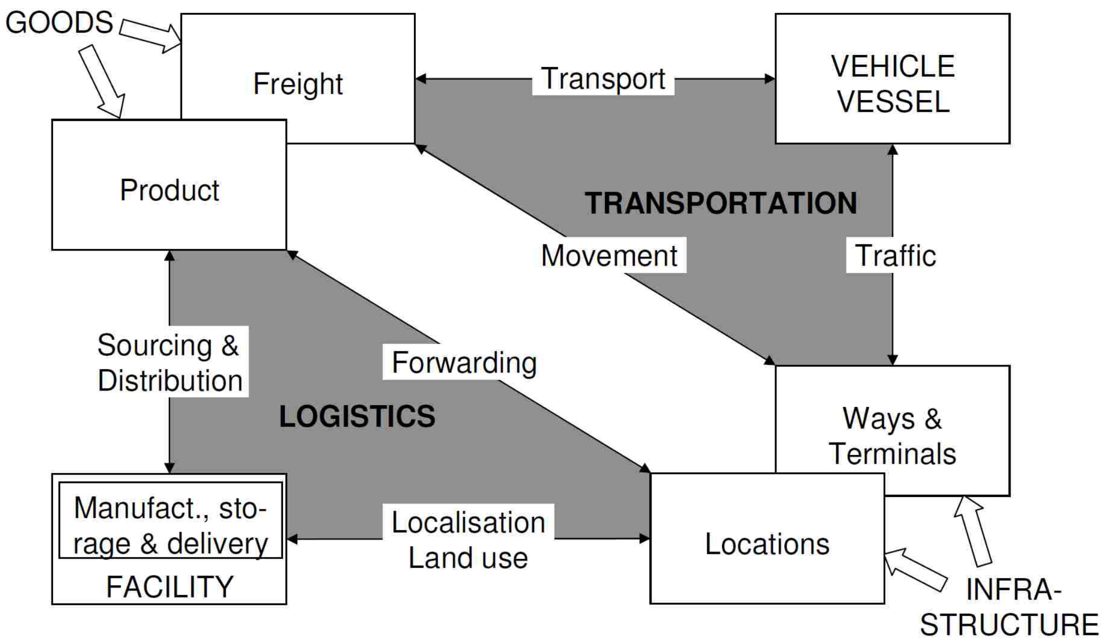

Figure 3.3: Relation between logistics and transportation system (Sjoestedt, 2004)

The systems overlap but the transportation system incorporates more than the transport of goods (particularly passenger transport) and the logistic systems incorporate activities like storing or commissioning of goods besides the pure transport.

In the context of the economic activity system, logistics can be seen as subsystems generating freight transport and therefore explaining the generation of freight transport related to economic activity. In this study all systems that have the provision of goods as a goal are referred to as logistic systems. This includes also systems that focus purely on transportation. The transportation system on the contrary stands for the overall transportation system including all sorts of traffic (see definition of Manheim).

Thus, the distinction between transportation system and logistic systems ought not be along the market for transport services: the subsystems on both sides are logistic systems.

It is important to note that logistic systems and the transportation system as a whole cannot be seen as independent but are very integrated, since transport cost are influenced by the amount transported. Bundling of flows within logistic systems therefore can change these costs. This is contrary to passenger transport, where the parameters of the transport services supplied by the transportation system are rather stable (at least short-term). In freight transportation logistic systems are part of the activity system and of the transportation system at the same time. Thus, there is an immediate (short-term) interaction between activity system and transportation system. The relation between activity system and transportation system described by Manheim (see figure 3.1) is therefore very dynamic and the reaction of the activity system and transportation system have to be considered describing both the short-term equilibrium as well as the long-term equilibrium. Logistic systems are the connecting element between both systems and incorporate this interaction.

The logistic system and thus the interaction must be the focus of the analysis of freight transport demand. This is in line with the requirement already formulated for overall transportation analysis by Manheim (Manheim (1979), p.5): "The focus of transportation system analysis is on the interaction between the transportation and the activity system."

To continue the top-down analysis, PCW flows between sectors and regions have to be connected with logistic systems. This is not straight forward, since flows can be part of many logistic systems and logistic systems can include many PCW flows. But primarily, it seems difficult, since logistic systems are part of companies and thus result out of a microeconomic logic. Therefore we will continue with the bottom-up analysis.

3.1.2 Bottom-up analysis

This bottom-up analysis tries to describe systems involved in the generation of freight transport, starting from small components.

Goods

A good can be described by general characteristics like weight, volume or value. Additionally there are specific requirements that are also important since they influence the way they have to be transported, reloaded or stored. In food retailing this is for example the temperature level required or time limitation due to perishability of the good.

A shipment (goods sent from one to another location) mostly is composed of an amount of goods not just one entity. This amount can be expressed in weight or volume or in entities describing the entity in or on which the goods are transported like packages, pallets or containers. The dominating entity in food retailing are pallets, so in this study shipments of goods will be measured in pallets.

Companies and establishments

The locations between which goods are transported are establishments belonging to companies or households.

The focus of this study will be on establishments belonging to companies.

It is important to distinguish between establishments and companies. Establishments do not act, the acting institutions that take economic decisions are companies. Nevertheless, establishments belong to companies and represent the locations where companies are active. The allocation of an establishment or a company to an economic sector can be difficult. Even if an establishment has a clear economic activity (for example retailing), the main activity of the company to which it belongs can be different (for example consumer product manufacturing). Companies or even establishments might have activities in different areas. As a result in practice (e.g. statistics), simplifications are undertaken. In statistical surveys, the main economic activity is taken to classify a company or establishment.

Companies can be seen as systems whose objective is defined by their business activity, establishments are components of these systems. For freight transport demand, it is important to understand the relation between these systems (companies and their business activity) and logistic systems that themselves are part of companies. Goods are produced and consumed during economic activity that takes place in establishments at specific locations. Therefore the goods have to be provided to these locations at specific times. This provision of goods is the purpose of logistic systems. The requirements for this and the integration of company systems and logistic systems is different, depending on the economic activity, a detailed picture for the retailing sector will be drawn later in this study. Demand for goods in business establishments and the output of goods in business establishments is the starting point for logistic activity.

Reloading points and warehouses

Reloading points and warehouses are establishments that are components of logistic systems. They can be seen as individual systems with following purposes:

- Reloading: unloading goods from one transport vehicle and reloading them to another.
- Consolidating/commissioning: Bundling goods from different origins together.
- Deconsolidating: Splitting a bundle of goods to different destinations.
- Storing: Keeping goods at warehouse locations over a certain time period (only in warehouses, not in reloading points).

The activities can be described by parameters that at the same time show the level of service and capacity of establishments like "picks per hour" for commissioning or number of pallet slots in the warehouse for storing.

Concerning the analysis of the functioning of these systems, there are different techniques of warehouses, starting from a block storage warehouse up to a high bay warehouse. But this will not be analyzed at this point. More detailed descriptions of warehousing can be found in Bartholdi and Hackman (2008) or Gudehus (2004).

Warehouses, or the functionality of warehouses, often is also present in establishments of companies where goods are consumed or produced.

Commodity Flows

Looking more closely at the exchange of goods between two locations, the concept of a commodity flow is defined as:

> The **commodity flow** between two locations (establishments) of companies is the amount (measured in weight, volume and value) of a certain commodity, delivered over a certain time period.

Note that this flow may not be constant, therefore to describe the reality in detail, the distribution of the commodity flow over time is needed. Assuming constant flows over time in models is a simplification, but depending on the objective of the analysis, it can be acceptable. Models in the area of transportation system analysis usually assume constant flows (see Liedtke (2006) or Ben-Akiva and De Jong (2008)).

There are two main differences between the concept of commodity flows and PC (production-consumption) or PWC (production-wholesale-consumption) flows as for example mentioned by Ben-Akiva and De Jong (2008) and originally introduced by Tavasszy et al. (1998):

1. A microscopic commodity flow refers to economic actors and is therefore anchored on the micro level, in contrast to that the notion of PC or PCW flows is of macroeconomic nature describing flows between regions and sectors.

2. A microscopic commodity flow is defined by two locations, that do not have to be a source or sink (production or consumption location). A microscopic commodity flow can as well take place between two reloading points.

The microscopic counterparts of PWC flows are those flows that do not start or end at logistic locations and are the result of the sourcing decisions of economic actors (see paragraph 3.1.4). To explain the existence of other flows that start or end at logistic locations, the corresponding logistic systems have to be analyzed.

A commodity flow has by definition a starting and a destination location. The goods can pass additional warehouses or reloading points between them. The path through which the goods of a commodity flow pass, is called "supply path" in this study.

This is different to the supply chain (definition translated from Beckmann (2004), p.1): "The supply chain incorporates all companies, that take part in the development, production and distribution of a product." The supply chain refers to companies not to locations and to the overall chain from raw material to consumer.

If a supply path contains more than two locations, the corresponding commodity flow can be cut in parts that again represent commodity flows.

Shipments

The commodity flow between two locations can be transported in different amounts, called lot sizes. The optimal lot size can be determined based on the minimization of lot size dependent costs like storage or transport costs. Since transport costs decrease for larger lot sizes, commodity flows are often bundled for transport. A shipment is defined by the chosen lot size, the good, and the locations of shipper and recipient.

Transport services and links

A transport service is defined by parameters describing the result and the quality of the transport of a shipment. This includes time of departure and arrival, costs and parameters that express how the good is handled. It is the outcome of the underlying logistic system. The transport service does not determine how this system functions.

It may be the outcome of a direct trip of a vehicle (truck, train or ship) on the transport infrastructure (roads, railways or waterways) or it may be the outcome of a round trip of this vehicle that also provides other transport services. It might even be a transport service that is provided by a complex logistic system including the reloading of this good and different vehicle trips.

The transport link includes all possible transport services between two locations. The existence of a transport link between two locations means that there is at least one transport service available.

A transport service is provided by logistic systems. This logistic system may be part of another company providing logistic services.

The roles on markets for transport services (see Liedtke (2006) and Friedrich (2003)) can serve to classify the actors involved:

- A shipper is the company sending the good
- A recipient is the company receiving the good
- Hauliers or carriers are companies that provide the physical transport service
- Forwarding companies negotiate between shippers and carriers and organize the transport

It may however happen that companies include several roles, for example a shipper that organizes and also carries out the transport. Therefore logistic systems can be part of all companies. Logistic service providers however are only those companies that operate logistic systems to provide services to others.

Logistic systems

A logistic system aims at providing services for the supply of goods. This includes transport, storing and commissioning. The components of a logistic system are warehouses, reloading points, transport links and all sorts of vehicles.

The transport services for the link can either be provided by another logistic system or by vehicles. The transport infrastructure used by the vehicles, usually is shared with different logistic systems.

Logistic systems are part of companies. This can be shipping companies that for example have logistic systems for the distribution of goods, trading or logistic companies. Logistic companies do not work on the provision of goods owned by the company but provide logistic services to other companies. Therefore they will be called "logistic service providers" (LSP) in this study.

Looking at commodity flows, logistic systems are responsible for assuring the provision of the corresponding goods. Through the exchange of services between logistic systems, a commodity flow or parts of the commodity flow can be assured by different logistic systems.

Conclusions bottom-up and top-down analysis

As shown in the analysis, demand for freight transport emerges from the interaction of economic activity system and transportation system. Logistic systems are the part of companies (systems) within the economic activity system, that provide goods. Transport services either provided by the system itself or other logistic systems are produced by vehicle tours on the transport infrastructure. These are the transport flows that emerge from the interaction of economic activity system and transportation system.

The logistic systems can be seen as the entities that translate commodity flows, constituting the demand for freight transport in the economic activity system, into the vehicle flows, constituting the freight transport demand on the transport infrastructure. To clarify this process of translation, the concept of mesostructures will be introduced in the next paragraph.

3.1.3 Mesostructures

How, where and when goods of a commodity flow are finally transported, stored, and bundled, depends on the logistic systems involved. One can assume that the companies (actors) that run these systems, try to optimize them. This optimization may happen for the overall system or for parts of the system. It may happen isolated or in partnership with other logistic systems. The core of the supply chain management idea, for example, is a collaboration along the supply chain potentially including several logistic systems. Logistics literature would assign such an optimization to the field of meso logistics (Pfohl, 2004). Therefore, we want to refer to the structures resulting from such an optimization as logistic mesostructures:

> A **logistic mesostructure** is an emergent operational structure, that handles several commodity flows. It can be described by how, where and when the goods of the commodity flows are transported, reloaded and stored. A mesostructure is the result of an optimization of one or several actors under specific circumstances. These circumstances include the state of the actors and the state of their environment.

The first sentence of the definition emphasizes that mesostructures are a phenomenon which can be observed in reality (emergent operational structure). The core of the second sentence of the definition are the words "how, where and when": "how" should include the bundling of goods and the resulting lot size, the mode of transport and the logistic service provider used. "Where" describes the supply paths including reloading or storing locations used and "when" refers to the point in time the different activities take place. The last part of the definition emphasizes that the structures are the result of an optimization under specific circumstances. Hence, it is assumed that the actors involved act rationally. The circumstances refer to all factors influencing the optimization. They either result from the situation of the actor himself, for example the characteristics of his overall logistic system, or they are coming from the environment of this actor, for instance, transport services that are offered by other logistic systems. The notion of rational behavior under circumstances corresponds to the concept of bounded rationality (see Simon (1996)) To further clarify the concept of mesostructures, examples for mesostrucures are given and the relation to the concept of networks will be described.

Examples of mesostructures and related concepts

Figure 3.4 gives examples for the formation of logistic mesostructures. The scope or the set of flows included, depend on the perspective of the actor or group of actors. Depending on this perspective, different sets of flows are included in the optimization. The first example takes the perspective of a logistic service provider, who includes flows from different actors. In contrast to the first one, the second example shows all outbound flows of only one shipper, which is the view of a producer thinking about his distribution structure.

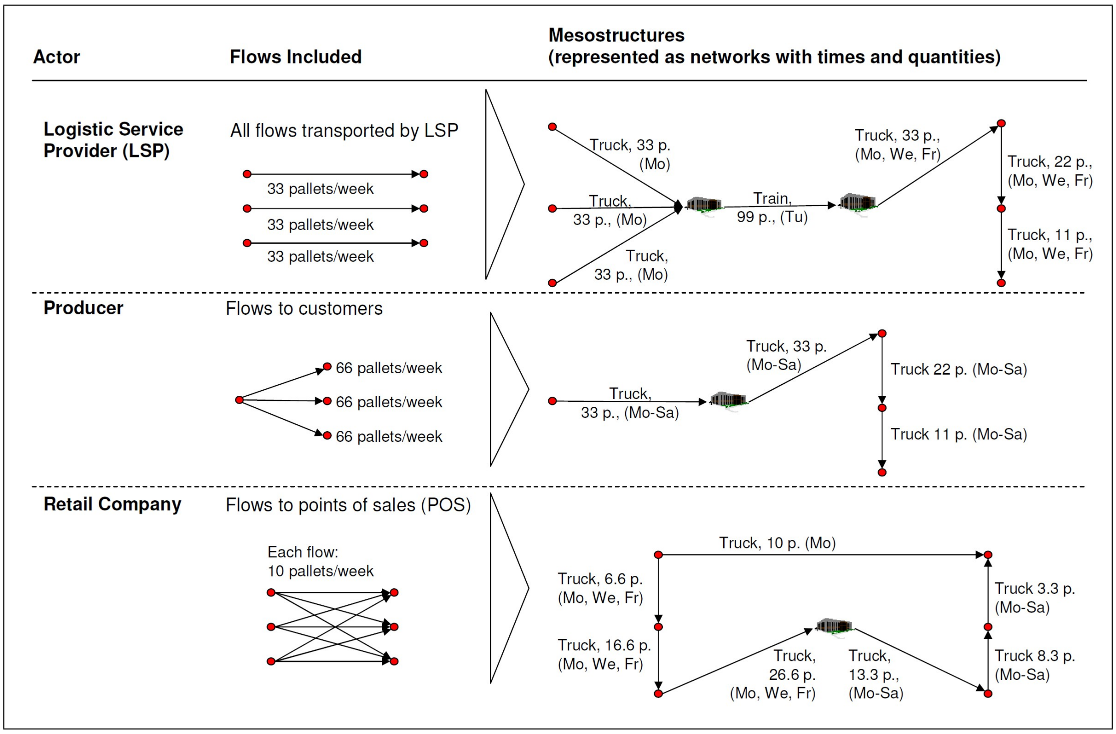

Figure 3.4: Examples of logistic mesostructures by actor perspective

The last example shows another perspective, the one of a retail company which includes all flows that lead to the points of sales of the company.

The perspective determines which parameters are fixed or variable during the optimization procedure. For any actor on the transport supply side (carrier or forwarder) the lot sizes and the timing of each microscopic flow are given. On the other hand, a "pure" demand actor depends in his decisions on the transport services offered. At the same time, both sides interact with each other over time and sometimes the optimization might even lead to an adaptation of the parameters of both sides (see for example Holguin-Véras et al. (2009)).

The mesostructures shown, include information about lot sizes and timing of the transport. Still it is a simplified view of the structure, since geographic data and information about the warehouses and reloading points used are left out.

Patterns or typical mesostructures

Since actors are in similar situations (distribution of goods to a set of stores for example), the resulting mesostructures look alike and therefore can be recognized as patterns (meaning structures that reoccur at different occasions).

Figure 3.5 shows such typical mesostructures in a conceptual way. Distribution and procurement structures are established by producing companies, often also by using LSPs for parts of the distribution (in practice - see interviews in appendix C.2 - usually specific distribution regions are allocated to LSPs). LSPs themselves do have their own view and form their mesostructure including all commodity flows that they handle. This already shows, that structures overlap, as also shown in the figure of interrelated networks in the

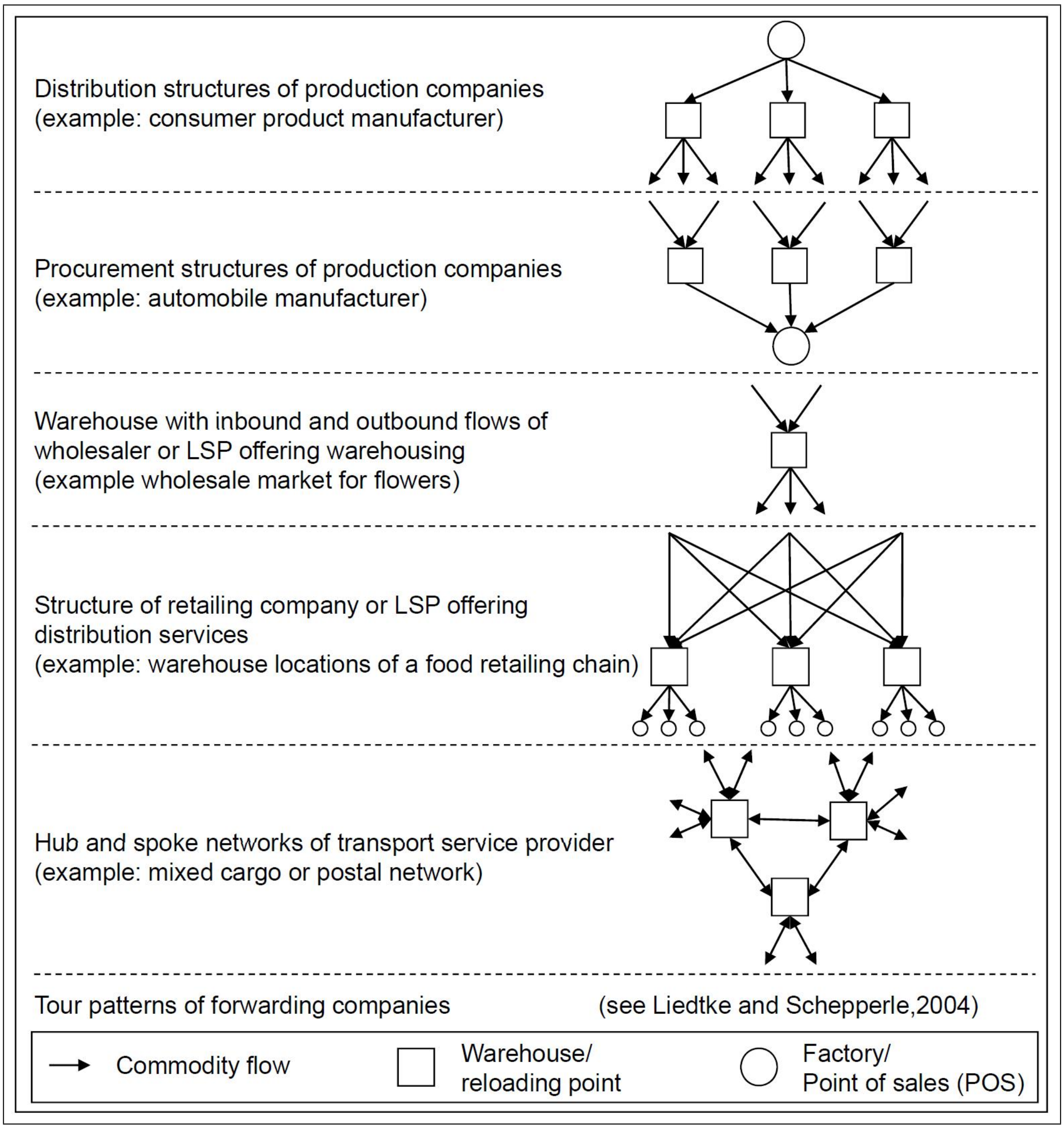

Figure 3.5: Typical Mesostructures (patterns)

next paragraph. Hub and spoke networks are also a reoccurring mesostrcture, for example postal networks or mixed cargo networks.

Figure 3.6 shows tour types identified out of empirical data by Liedtke and Schepperle (2004). In this context, they represent concrete empirical examples for very simple logistic mesostructures. Simple, because they do not include reloading points or warehouses and only represent the limited perspective of single vehicles. In these cases the optimization would be limited to the tour optimization of single vehicles. These structures probably are part of larger structures that take a broader perspective for optimization. In chapter 6 empirical examples for more complicated mesostructures in food retailing are given. Since these structures include thousands of flows, visualization becomes difficult and graphs only contain single aspects of the structure, like number and location of warehouses or locations of suppliers.

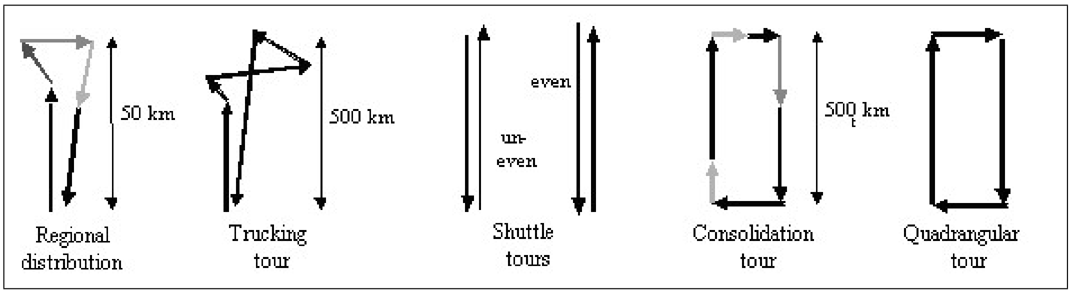

Figure 3.6: Tour types (Liedtke and Schepperle, 2004)

Depending on the perspective of the actor, different attributes would be used for further classifications. For distribution structures number and levels (regional or central) of warehouses or frequency of delivery are of interest. For a network of a LSP number of vehicles used and structure of the transport chain (e.g. Hub and spoke) are of interest.

Relationship to the concept of "Networks"

As sketched in the preceding paragraph, mesostructures can be represented as networks. A basic definition of a network from graph theory is a set of vertices and a set of edges connecting the vertices. In this sense one could describe a mesostructure as a network with the vertices representing locations of the economic actors and the edges representing transport connections between the locations. Additionally, the information on timing, mode, and lot size for the transport has to be represented.

The focus of the concept of mesostructures is on the emergence and the dynamic development of this network. A mesostructure consists of commodity flows that can, in the network sense, be represented as paths on the network including several vertices and edges. A network is either the result of a mesostructure (e.g. distribution structures) or a mesostructure uses other networks (e.g. transport networks of logistic service providers). Network effects, e.g. economies of scale through bundling the transport, are drivers that form mesostructures.

Network theory (Newman, 2006) can provide methods and ideas for modeling the emergence of mesostructures. Only recent research in network theory emphasizes the aspects of networks as evolving structures and dynamic structures, which includes the aspect of interaction (Newman, 2006). This fits very well with the presented concept of mesostructures explaining the emergence of logistic networks.

Interrelated mesostructures

Mesostructures are interrelated: actors include commodity flows into their considerations that are also included in other actors optimization. This is because different actors are involved in handling the same commodity flow. By definition the commodity flow already connects two locations with potentially two actors. By using services of LSPs, this number increases. Ohnell (2003) designs a picture to represent inter modal connections between networks (figure 3.7), which fits well to our understanding of interrelated or entangled logistics mesostructures.

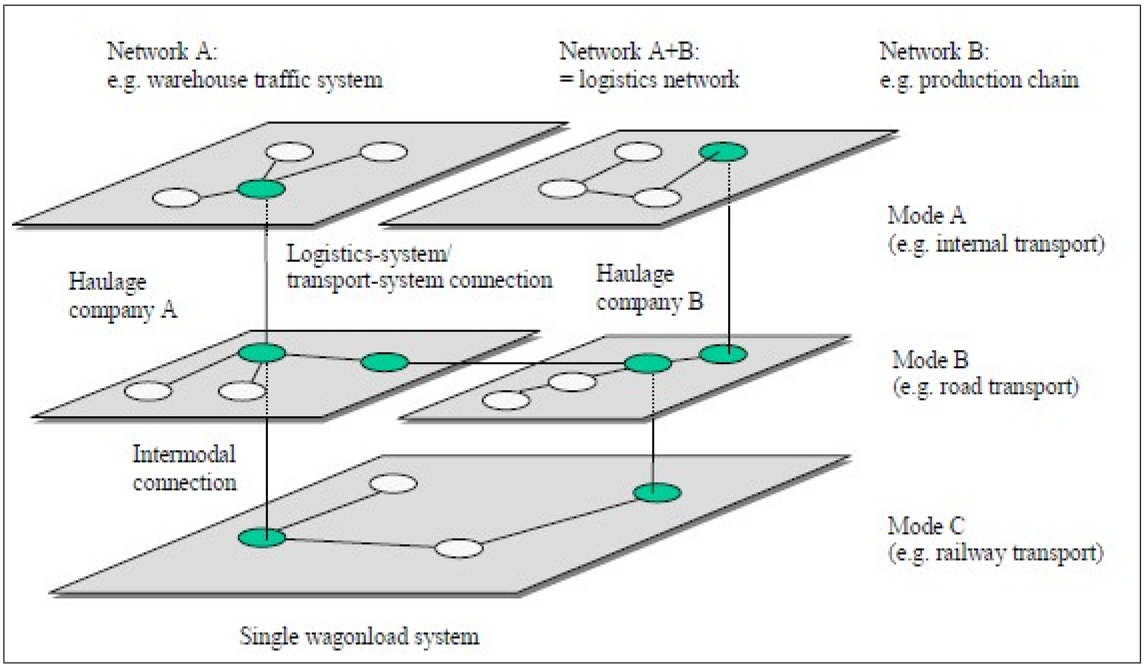

Figure 3.7: Interrelated networks (Ohnell, 2003)

Micro-Macro gap in freight transportation

Looking at commodity flows resulting from economic activities of actors on the one hand (micro perspective on transport demand) and at traffic loads of the transportation system (a macro perspective) on the other hand , there seems to be an explanation gap between the micro demand of transport and the macro picture of transport. This gap is visualized in figure 3.8.

One can distinguish between the micro, meso and macro levels: The macro-level on the top corresponds to the perspective of transportation planners and policy markers. This level deals with aggregate truck flows on infrastructure networks, market shares by segment or container throughput in ports.

The micro-level corresponds to the perspective of individual decision makers. The arrows in space symbolize commodity flows. These flows are combined in groups to form logistic mesostructures, that represent the meso-level.

From this meso-level the link to the macro level can be established by aggregating the vehicle tours. To arrive at mesostructures in form of vehicle tours, several steps of actors and group of actors may have taken place. For example a producer of consumer goods may have commodity flows from his factory to different retailing stores. He might at first combine these flows to a distribution structure and than give some combined flows to a forwarder who might again combine these flows together with others to vehicle tours. To model these steps methods of optimization and simulation can be used.

Since commodity flows are very different to vehicle trips, there seldom is a direct link from micro to macro, but one has mostly to understand the meso level to be able to explain phenomena of freight transport on the macro level. This gap between micro and macro level and the importance of a meso level was already shown by Sjoestedt (2004). He differs between micro and meso by number of actors involved (not by using the concept

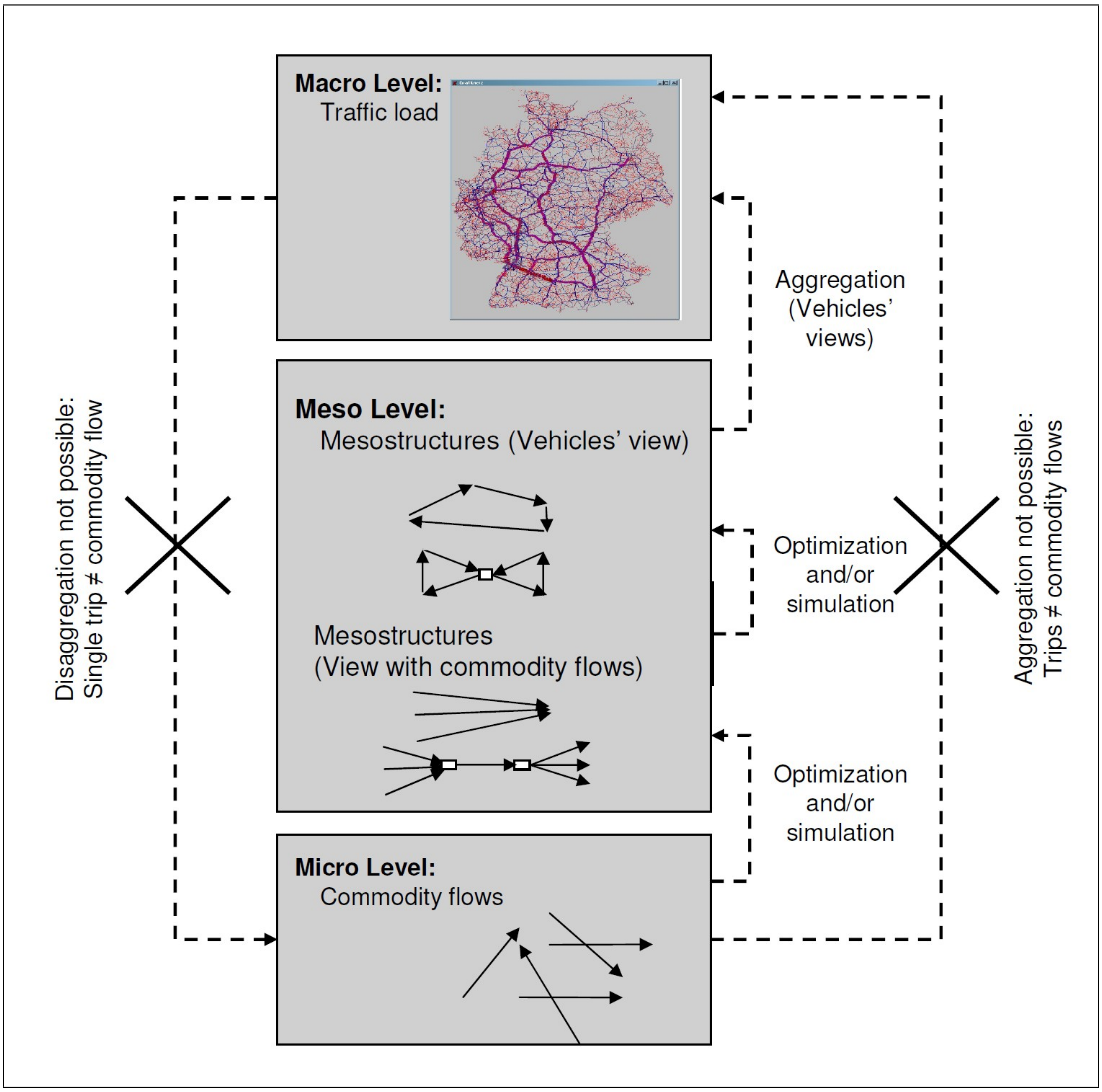

Figure 3.8: Micro-Macro gap in freight transportation

of commodity flows), but concludes as well that there is a gap and that there "is still poor understanding of methods and data needs to handle the meso level".

3.1.4 Decisions leading to freight transport demand

As described before, mesostructures emerge out of an optimization, which means that there are rational decisions leading to mesostructures. This paragraph will discuss these decisions in more detail. It will be orientated at the ideas of Eisenführ and Weber (2003) that discuss rational decision making. This general approach is chosen since it includes all kinds of decisions not just discrete choices, as it is often assumed in transportation system analysis.

Following Weber (Eisenführ and Weber, 2003) components of a decision problem are alternatives, influences of the environment, consequences, objectives and preferences of the deciding party. Alternatives can be discrete alternatives or more generally a solution space of alternative solutions. The environment describes the factors that influence the decisions and are perceived as external factors for the deciding party, hence cannot be changed by it. The consequences are the states of the system and its subsystems that will occur if an alternative is chosen. Finally, the objectives and preferences of the deciding party determine the criteria and the objectives based on which the optimization takes place.

These components and their application on logistic decisions will be discussed in more detail, but before existing logistic decisions will be described in form of a choice hierarchy.

Hierarchy of decisions leading to freight transport demand

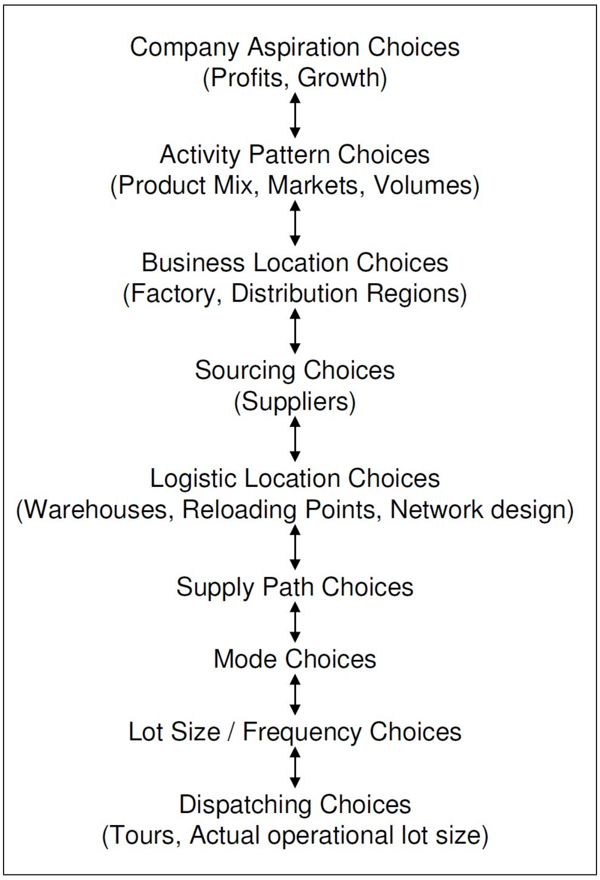

Figure 3.9: Levels of choice for a firm (Top three levels based on Manheim (1979))

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 study (see figure 3.9).

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.

The bottom five levels represent pure logistic choices. For this study, 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. The choice of a logistic location for example depends highly on the business locations as well as on the future supply paths chosen in case the alternative is implemented. Thus, a decision on warehouse location might also include the decision on supply paths. The planning of a logistic system (Gudehus (2004), p. 571) integrates many levels (logistic location, supply paths, frequencies and modes).

The example of a dispatcher in a food retailer warehouse shows how fluent the borders between the levels are: The dispatcher decides on the order size based on the actual demand, the factors he knows of that will change the demand in the near future (for example promotions, sport events) and tendencies of demand that he knows from his experience (seasonal fluctuations). If he realizes that order sizes get very small (or very large) due to a mid-term/long-term change in demand, he will initiate a change in frequency of delivery, which would already be part of the next level of choice in our framework. This shows the degree of level integration in reality. Not only the levels are determined top-down by the logistic choices taken for higher levels but also bottom-up by feedbacks that can lead to a rethinking of the higher level.

The model developed in this study, will focus on the logistic choices starting with the logistic locations and will leave out the short-term level.

In the following paragraphs, the components of these decisions and the specifics and challenges in the logistic context will be discussed in more detail.

Alternatives

Two important questions arise for the identification of alternatives in logistic decisions: dependency between the levels and existence of discrete alternatives.

As discussed in the last paragraph, the levels are interdependent. Usually, decisions on a higher level will also include the choice options on the next levels (top-down), thinking about a new warehouse would, for example, for sure include considerations to change the current supply paths of commodity flows. And, as described, choices on lower levels initiate potentially rethinking of choices on higher levels (bottom-up). In this context also the dependency on the economic activity is important. In some areas this limits the potential solution space. An example is the choice of food retailers to what extend perishable goods are part of the assortment, which clearly limits the time available for logistics.

The second question focuses on the solution space: can a limited number of alternatives be isolated? Some decisions in logistics like location choices are combinatorial problems that have a huge amount of potential solutions. Other decisions like the one on lot sizes have continuous parameters. This indicates that the assumption of discrete alternatives is questionable. One might argue that a limited number of representative solutions could be isolated, but since each company taking these decisions, has different circumstances (distribution of economic activity, transport services offered, transport infrastructure), these alternatives would be different. This is part of what makes the heterogeneity in freight transportation. As a consequence, it is difficult to apply stochastic discrete choice models in freight transportation. So the statement of Manheim that "most transport choices are among discrete items" (Manheim (1979), p.86) cannot be applied to logistic choices.

Influences of environment and consequences

The determination of consequences and influences is not easy for logistic decisions. The right parameters describing the consequences and the right scope concerning both time and adjacent systems have to be chosen.

The first difficulty is to choose the right parameters describing the consequences that together with the preferences determine the outcome of the decision. Gudehus (2004) speaks of planning a logistic system by developing a system that meets the performance requirements with minimum costs. This leaves the cost parameter (to be minimized) as only decision parameter and puts all other parameters into the prerequisites to be formulated, for example in form of service levels. Besides hard requirements like capacity and throughput time, there are softer quality parameter as listed by Beuthe et al. (2004) like reliability, safety or flexibility.

The second challenge is to determine the right scope. For the scope of logistic systems it has to be clear that decisions in one logistic system have consequences on the adjacent systems. A new warehouse structure in a logistic system of a retailer for example changes the throughput costs and therefore adjacent logistic systems of suppliers might change their supply paths. To what extend does the retailing company already include the changes of the adjacent systems into its considerations?

Also concerning the time horizons the question of scope can be rethought. Although the inclusion of future aspects in the decision seems clear and as Weber states (Eisenführ and Weber (2003), p.7) the future orientation is rational (backward looking would be irrational), there is still the question how far into the future the consequences shall be considered. Since predictions of the future become more fuzzy the longer the time horizons considered get, it only does make sense to a certain limit. Of course this depends also on the level of choice. The explicit recognition of future consequences is emphasized in the term of a forward looking decision.

Deciding parties

Determining the scope of the decision problem also means to define the deciding party, including its objectives and preferences. Often, there may be several actors (forming a party) involved and actors may have different and even conflicting objectives. Ortùzar and Willumsen (Ortùzar and Willumsen (1990), p.432) mention this as a factor which makes freight transportation modeling especially complicated compared to passenger transportation modeling. There may be for example a discussion between a supplier and his customer: the supplier wants to deliver large lot sizes (since he has to pay for transport, handling etc.) the customer does want small lot sizes (since he will have to pay for the capital and storage cost at his location). To explain the outcome of such a decision situation, certain forms of relations and interactions between firms have to be assumed: if they cooperate - this means to agree on a shared objective, which could be minimization of total logistic cost in the example - or how they negotiate the result, including their influence and power in this situation (see game theory Varian (1995)) - the customer might for example insist in having small lot sizes if he has a strong position.

Conclusion

The analysis of logistic decisions shows that a hierarchy of choice levels exists and that there are certain dependencies between decisions. Furthermore, because of these dependencies the solution space in logistic decisions cannot be reduced to a typical set of discrete alternatives, the application of discrete choice theory is therefore difficult. There are also many open questions that depend to a large extend on the sector of the company and the context of the logistic system under consideration:

- To what extend does the economic activity limit the alternatives?
- What parameters are considered to describe the consequences?
- What is the scope of consequences to be considered (time and adjacent logistic systems)?
- Who are the deciding parties and what are their preferences?

3.1.5 System states and equilibria

In this paragraph, system states of individual logistic systems as well as the overall system, including the market for logistic services and the transportation system will be discussed. The state of a logistic system is defined by the logistic choices made. A logistic mesostructure, describing a temporarily stable state and where, when and how all commodity flows are handled, describes to a certain extend the state of a logistic system, especially, if all commodity flows handled by the logistic system are included into the optimization of the mesostructure. The state of the overall system is defined by the state of all logistic systems and, in terms of transportation, by the vehicle flows on the transport infrastructure.

In transportation system analysis, two states of the overall system are differentiated: the overall system optimum and the user equilibrium (see for example Ortùzar and Willumsen (1990)). The idea of a traffic equilibrium was already expressed by Knight in 1924 (Knight, 1924). Wardrop formulated the first and second Wardrop principle describing the conditions for these states (Wardrop, 1952), they refer to the route choice between two points:

- Wardrop's first principle: "The journey times in all routes actually used are equal and less than those which would be experienced by a single vehicle on any unused route." This refers to a user equilibrium since there is no motivation for a single actor to change to another route.
- Wardrop's second principle: "At equilibrium the average journey time is minimum." This refers to a state where the system is optimal since the average journey time is minimum.

A rigorous framework to express these principles was formulated mathematically by Beckman et al. (1956). With this, it can be shown that a general condition for a unique solution (user optimum) is that the cost-flow functions are convex. This means especially that "the cost-flow curve should not have sections where costs decrease when flows increase" (Ortùzar and Willumsen (1990), p.358). At this point there is an important difference looking at the allocation of commodity flows to logistic systems (like within the supply path decision): average costs will increase if more flows are assigned to transport infrastructure, but average costs often decrease if more commodity flows are assigned to a logistic system.

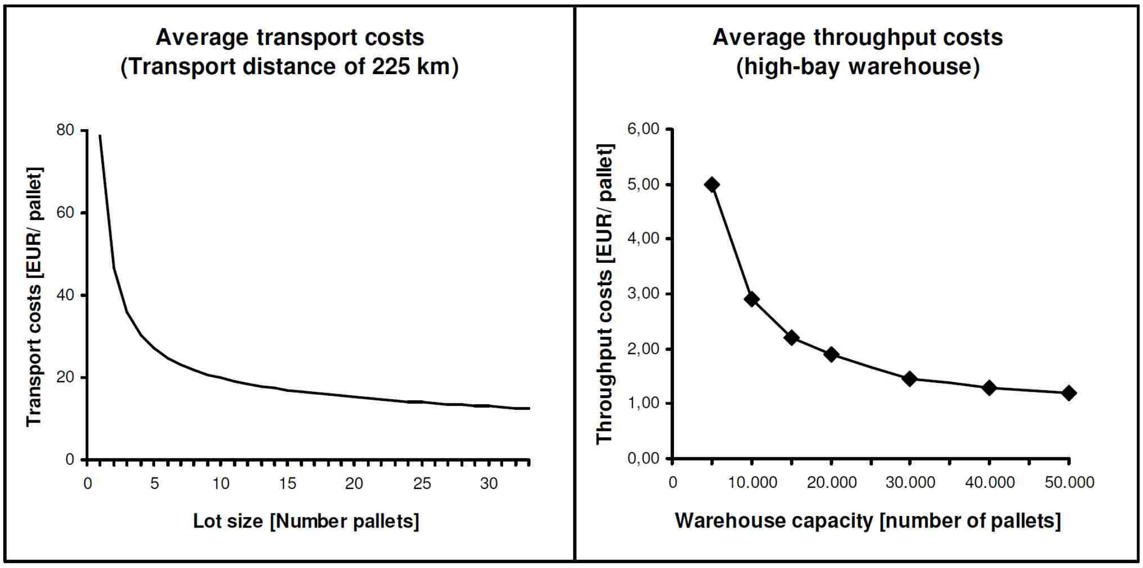

Figure 3.10: Examples of decreasing average costs in logistic systems (Source: observed transport cost matrix and warehouse costs in Gudehus (2004), p.664)

This results from economies of scale in logistic systems. Two examples of cost components within logistic systems demonstrate this. On the left side of figure 3.10 average transport costs per pallet are shown that are taken from a transport cost matrix of a logistic service provider. The higher the number of pallets the less money is asked per pallet. On the right side warehouse throughput costs per pallet for different warehouse sizes are displayed. Again, there is the effect that larger warehouses lead to lower throughput costs per pallet.

The overall system of freight transportation incorporates all logistic systems. Following the argumentation above, there can be different stable equilibria (user optima) for the overall system since cost functions (cumulated costs for transport or warehouse throughput in the examples) are not convex. Depending on the situation and the dynamic, or depending on initial settings and simulation procedures in a simulation model, the system can end up in different states. This accounts especially for the supply path decision, which represents the allocation of commodity flows to different logistic systems. To circumvent this problem and to identify stable characteristics of logistic systems, the modeler has to refer to higher decision levels with convex underlying cost functions. In food retailing the forward looking decision on the overall warehouse structure with a defined set of commodity flows fulfills this requirement. The resulting convex function of total logistic costs will be discussed within the model definition (see chapter 5 and figure 5.13).

But, another problem can occur for logistic systems: there can be system states that are close in terms of costs but very different in terms of shape and implications for transport. An example are different warehouse structures shown in chapter 6. Especially in cases where the determination of costs is difficult in practice or changes in costs occur, this is very relevant. Reasons of a difficult cost determinations can be:

- The dynamic of the activity system, circumstances change continuously and so does the optimal logistic solution.
- The complexity of optimization problems that have to be solved by approximative heuristics.
- Limited information.

For the discussion of model results and empirical observations both aspects have to be considered: the overall system can have multiple stable states, at least on certain decision levels, and states of logistic systems can be close in terms of costs but very different in terms of shape or implication for transport.

3.1.6 Conclusions from system analysis

The system analysis in this section discussed systems and elements involved in freight transport demand, decisions that lead to freight transport demand, and system states of the overall and individual logistic systems.

The main system elements identified are:

- Commodity flows, since they are the microscopic freight transport demand coming from economic activity.
- Companies and their establishments, since companies are the deciding entities and establishments are the entities located in space.
- Logistic systems and their components, since within these systems freight transport demand from economic activity is translated into freight transport demand in the transportation systems.

- Mesostructures as results of the activity of logistic systems, since they can be explained by an optimization logic and are the objects needed to bridge the micro-macro gap.

The analysis of decisions showed that a hierarchy of decisions leading from economic activity to freight transport demand can be established. But, sectoral specificities of the retailing sector have to be analyzed to determine which decisions are taken, which scope they include, and how far decision levels are treated integrated.

Finally, it was discussed that the state of the overall freight transportation system is not unique and that logistic systems can differ significantly in shape while being close in terms of costs. Empirical observations and model results have to be discussed accordingly.

The next section will first discuss data sources, then the food retailing sector in Germany will be described in detail. This is done to be able to define the right simulation procedures and optimization problems later in the study.

3.2 Research methods and data sources

In this section, the data sources are discussed. Data is needed to reason the design of the model and for model input. The discussion will be focused on the methodologies and type of sources used, the description of the findings and the data itself will be done in the next section in form of an analysis of the food retailing sector and its logistic systems.

Methods and their application in different phases of model development will be subject of the first paragraph. Then, sources and studies available will be described shortly, empty spots will be identified, and the approach of expert interviews, used for basic knowledge generation in this study, will be outlined.

3.2.1 Research methods

Figure 3.11 gives an overview on research methods[2] . The first dimension expresses the dependency on the researcher (rational-existential), the second dimension describes the kind of information used, from direct observation to artificial reconstruction of reality (natural-artificial).

In this framework, SYNTRADE would be classified into the upper right corner as explanatory model or at least into the area of simulation. But to make this research relevant, the "artificial reconstruction of reality" should be as close as possible to the real world. Therefore it has to be based on knowledge and data resulting form the left side or the middle of the framework like surveys and statistics. Depending on the phase of development of the model, the scope of information need is different. In the beginning, when the design of the model has to be determined, it has to be decided what cause and effects and what drivers should be included. Research in the lower part of the framework is needed for those questions, since the focus is more open, whereas in surveys the questions and data points are sharply defined and the scope of the model that can be built on surveys is already narrowed.

This reflects also the experience of research in other areas. Bonoma (Bonoma (1985), p.207) concludes in a paper on case research that methods that have "high currency"

[2] It originates from a study on how knowledge is generated in logistics research (adapted from Vafidis (2007), p.43) the author cites this framework on research methods originally developed for the area of operations management (Meredith et al., 1989) and describes the application of this framework in the area of logistics.

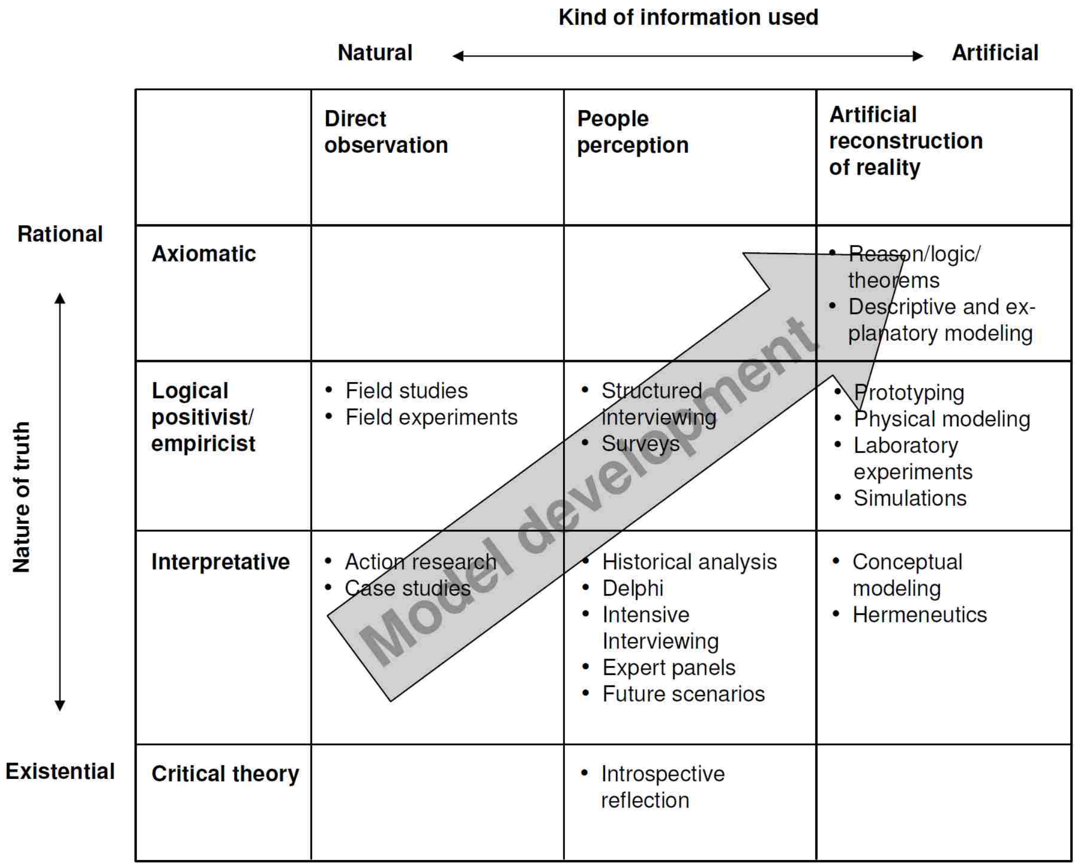

Figure 3.11: Research methods framework (adapted from Vafidis (2007), p. 43)

like case research and interviews, are particularly useful "when a phenomenon is broad and complex, where the existing body of knowledge is insufficient to permit the posing of causal questions, and when a phenomenon cannot be studied outside the context in which it naturally occurs". This can be referred to logistic system embedded in a system environment of economic activities and adjacent logistic systems. In a first phase, the drivers that determine the system have to be understood to shape the model design and scope.

In a later phase, as usually in macroscopic research like transportation system analysis, representative data of whole sectors or economic areas is needed to model the overall system. This data often origins from statistically representative surveys or statistics. Kyösti (1999) connects this different needs with the level of the research problem. He assumes that qualitative and dynamic research methods mainly are associated with the micro level whereas static and quantitative methods are more connected to the macro level.

For this study, several methods are important: qualitative case research and interviewing has to be done to design and scope the model and to base it in reality. Data from surveys and studies of more precise and quantitative nature on the other hand have to be used as input and calibration parameters for the model.

3.2.2 Data and studies used

This paragraph serves as an overview on data sources used for this study. In terms of sectors, this is general economic data, including all sectors with links to food retailing and more detailed data on the food retailing sector including logistic activities in and around the food retailing sector. In terms of geography, the main focus is on Germany, since the food retailing sector of Germany is the application example.

Data from official statistics and scientific research was used as well as data from commercial data providers, business reports and raw data from business activity.

Classifications are closely related to data and mostly determined by the objective of the source. Linking the classifications is a key challenge, especially if multiple data sources are used. Therefore, classifications and links between classifications will be described as well as the sources

General economic data

The environment of the retailing sector comprises almost all economic activity, including most sectors and all regions. The classification for economic sectors in Germany is the WZ classification (Statistisches Bundesamt, 2008b), which is orientated at the European classification NACE (EU, 2002), which is based on the ISIC classification (UN, 2009) of the UN. Regions are classified according to the "Nomenclature of Territorial Units for Statistics" (NUTS) (EU, 2001) published by the European Union. The following general data, mainly from statistics, is used to catch general economic activity:

- The statistic for employees subject to social insurance contribution published by the national labor agency in Germany (Bundesagentur für Arbeit, 2008): Since this is a census, reports on a detailed regional and sectoral level are possible. But since data of individual establishments must not be disclosed (by law), data on detailed levels gets left out especially when reports on a detailed regional and sectoral levels are produced. For this study, a report on the NUTS-3 and 3-digit WZ level was produced, the gaps caused by non-disclosure requirement where filled by a procedure presented in chapter 5.

- Statistics on business establishments in form of distributions of employees per establishment (Statistisches Bundesamt, 2006b): This statistic exists on a detailed sectoral level (4-digit WZ). To generate a synthetic economic landscape, this statistic was combined with the employee statistic.

- Input-output tables from national accounting (Statistisches Bundesamt, 2008d): These tables contain information on the linkages between economic sectors, consumers and the state in monetary flows. Figures on imports, exports and investments for each sector are included as well. The monetary flows represent goods produced by one and consumed by another sector. Estimates on transport volumes have to be based on estimates on value densities of products. Estimates on transport volumes in trade sectors cannot be based on input-output tables since products are neither produced nor consumed in these sectors. In the model, this statistic is used to estimate the total of flows, consumed in regions by consumers or sectors that need similar products as input. Together with estimates on flows from sectors into food retailing, the resulting delta can be calculated, representing those flows to regions that are not distributed via the food retailing sector. Also estimates on import proportions are based on this statistic.

- Production statistics (Statistisches Bundesamt, 2006c): Production is published down to a very detailed level (9 digits) in the GP classification (Statistisches Bundesamt, 2001) which corresponds to the NACE sectors and builds on the European CPA classification. On this level, amounts produced in weight, volume or pieces are given. The problem is the aggregation to higher levels (e.g. 3-digits) since on higher levels only monetary values are published. To get an estimation, a very time consuming procedure has to be applied, involving estimation of average value densities, as done by Friedrich (2003). In the model, data from production statistic is used together with sector specific data (see next paragraph) to estimate value densities on weight and volume.
- Foreign trade statistics (Statistisches Bundesamt, 2006a): They include monetary values as well as weights for import and export flows. Reports can be created in GP classification on a 4 digit level. This can be used in the model to detail the data on import and export flows and also to improve estimates on value densities - it has to be considered that monetary values in foreign trade correspond to wholesaler prices.
- Data on distances between regions: They where calculated, based on the shortest distances in road infrastructure networks (using the Dijkstra algorithm (Dijkstra, 1959)).

Data on the food retailing sector

The more specific data needs are, the more sources from private institutions like associations, commercial data providers or even individual companies have to be used. Following sources have been used for this study:

- Trade statistic and general description of retailing sectors (Statistisches Bundesamt (2009) and Statistisches Bundesamt (2003)): The trade statistic publishes turnover of trading activity according to WZ classification (4 digit level) and to trading activities. The classification of trading activities in this statistic is not related to other classifications of goods or sectors. For this study, based on this statistic, the turnover of the food retailing sector and the proportions of non food versus food for the overall sector was estimated. Furthermore, the statistical office publishes a description of the structure of retailing in Germany that contains definitions used in this study.
- The "EHI Retail Institute" (EHI Retail Institute, 2007): This institute publishes all sorts of statistics and data related to trade. For this study data on article assortments was used: For different retail formats, the break down of article numbers to assortments are given, for the retail format "Supermarkt", even a breakdown of turnover to assortments is given. The data originates from studies of the EHI. Based on this, turnovers and number of articles for different assortments and different retail formats were estimated (see chapter 5). The classification used for the assortments is the GS1 goods classification. This classification is maintained and sold by the GS1 institution (GS1, 2009). This classification is widely used for cross company article

identification in logistics and the retailing sector (worldwide). The EAN code (bar codes on consumer products), for example, incorporates this classification. It is based on the old official classification of traded goods in Germany that is not maintained by the statistical office any more (since the 1970's). To determine suppliers for the retail companies in the model of this study, a link between the assortments (that are based on the G1 classification) and the classification of economic sectors had to be established (the linking table is shown in appendix B.2).

- LZ report published by a German food journal "Lebensmittelzeitung" (Lebensmittel Zeitung, 2007): In this report a lot of statistics and data concerning the retailing sector are published. Sources of this data are statistical offices, ministries, associations, research institutes (EHI, IRI), commercial data providers (GFK, Nielsen, Trade Dimensions) and the journal itself. For the model of this study estimations for value densities for weight and volume (see appendix B.1) and break downs of article numbers and turnovers (see chapter 5) to assortments were based on data from these sources. Also articles in the journals on actors and developments in this sectors allow to generate insights on the behavior of actors in and around the retailing sector (see section 3.3).

- Data on companies in the retailing sector published by commercial data providers like AC Nielsen or Trade Dimensions: For this study, data on turnover, number of articles, locations and number of stores as well as locations and number of warehouses were used to calibrate and test the model.

- Scientific studies on the retailing sector and logistics in the retailing sector (Magnus (2007), Grosspietsch (2003), Thoneman (2003), Toporowski (1996), Van der Vlist (2007)): These studies have provided examples and insights in logistic behavior of actors (see section 3.3).

- Publicly available data on individual companies (internet sites and financial reports): This data has been used to verify aggregated data form research institutions and commercial data providers.

Data on transportation and logistics

An overview on sources for continuous freight data in Germany and other European countries was produced by the BESTUFS project (Binnenbruck, 2006). For the US, an overview exists within the "Quick Response Freight Manual", published by the Federal Highway Administration (Beagan et al., 2007).

Although a lot of data on traffic and transportation is available, it often does not correspond to the data needs in freight transport demand modeling. The main reason for this is that modeling freight transport demand is concentrated on the interaction between economic activity system and transportation system which mainly happens within logistic systems (see chapter 3.1). Statistics in the area of transportation however are more concentrated on traffic and entities from the transportation system (vehicles) or transport infrastructure and less on logistic systems. Before describing the data used, this is shown by listing some sources that could not be used:

- Traffic data (see for example traffic count data (BAST, 2006) or traffic statistics (DIW, 2008)): Since this data mostly is published in an aggregated form, it would require a model that covers the totality of the aggregate to compare it to model results. Thus, an exact calibration of the model with this data is not yet possible, but could become possible for future disaggregated models that cover the totality of traffic generated or parts of traffic generated (for example all food transports).
- The commodity flow survey of the KBA (Kraftfahrt-Bundesamt, 2007): This survey tracks vehicle movements of trucks (over 3.5 t). Since the statistic focuses on the activity of single vehicles, it is not possible to generate typical sets of commodity flows of economic actors out of this data. Also goods are classified in the old NSTR classification (Statistisches Bundesamt, 1996) which does not match with the CPA classification of goods produced (this will change when the new NST-2007 (Statistisches Bundesamt, 2008c) classification will be applied). The data could therefore not be used for this study. Nevertheless, Liedtke and Schepperle (2004) managed to isolate typical tour types out of this data that can be used as empirical examples for simple mesostructures.
- Data on vehicle inventory and company structure of transport logistic service providers (DIW (2008), Bundesamt für Güterverkehr (BAG) (2008), Kraftfahrt-Bundesamt (2008)): Since vehicles and tour dispatching are not described in the model and logistic service providers are represented in a simplified way, this data was not applied.
- Data on land use (Bundesamt für Bauwesen und Raumordnung BBR, 2007): This data was not used since the sectoral detail is too rough. Therefore, an artificial industry structure was reproduced, based on employee data and data on distributions of number employees per establishment.

Nevertheless, there were also some sources that could be used for this study:

- The study on logistic markets of Klaus (2008): It provides an overview on partial markets and actors. This was used for considerations on the separations of markets for logistic services in the model.
- Logistic cost data was taken from different sources: In the study of Hannemann (2007) price matrices for truck transport in Germany are simulated and Gudehus (2004) contains detailed data on warehouse cost calculation. Also statistical data on cost (DIW, 2008) could be used to determine the price development of transport services. Direct cost data from operations was used, when available, like the transport price matrix of a logistic service provider which was used as a basis to calibrate the batch size model.
- Data from operations: In general such data is difficult to get, moreover it mostly provides case examples and not representative data. An example is data from Internet platforms where logistic service contracts are traded (like Cargoclix in Germany). Partially, the information published is very rich (including for example names of shippers, destinations, sending structure), but the data only represents part of the activity of single actors. Nevertheless, this data can serve as exemplary input to determine typical behavior of actors and thus to design the model.

- Other logistic studies provide case examples, general ideas on logistics (books on logistics like Pfohl (2004), Arndt (2004), Gudehus (2004)) or categorization of actors (Clausen et al., 2007). They can be taken as input to determine logistic behavior and design the model.

3.2.3 Open data spots

The formulation of open data spots in this paragraph is held general and thus can be seen for freight transport demand modeling in general. At the end of this paragraph, some short remarks will be given on how these gaps were filled for the study at hand.

Requests of scientists and transportation planners for additional data are usually biased by the author's objective and specific data need of a certain model to be satisfied. In the last section the phenomenon of logistic mesostructures was introduced rather by empirical observation than by a formal model. Thus, it may serve as a more neutral starting point to determine open data spots for freight transport demand modeling. Three needs of data can be identified: data on the system borders or scope of mesostructures and the attached optimizing actor(s), data on the internal structure and characteristics of mesostructures, and data allowing the deduction of behavioral rules for logistic decisions and the corresponding optimization that can explain the form and dynamic development of mesostructures.

Scope and system borders of logistics mesostructures

To decompose the whole transportation system into a set of loosely coupled mesostructures the scope and the system-borders of mesostructures have to be defined. This means to collect information on the commodity flows passing through a mesostructure, as well as on the actor(s) that optimize the structure. On a micro level such data, at least in Germany, is not available in form of a representative survey. But there are some attempts and discussions to close this open data spot:

- Starting from macro statistic one can think of models, artificially reproducing inter sectoral flows in a more detailed sectoral and regional resolution. The MRIO model of Cascetta (Cascetta (2001), p.232) is an example of generating an inter-sectoral and inter-regional commodity flow matrix. The approach from Liedtke and Babani tries to determine the most likely relationship between inter-sectoral flows and transport-flows using an entropy maximization method (Babani (2005), Babani and Liedtke (2007)). Micro-level models can use such data to simulate the microscopic commodity flows between companies (see Liedtke (2006) or chapter 5).

- Shipper and carrier surveys should also raise information which is suited to position the mesostructure within the economic activity system, logistic systems, and the transportation system. Many surveys, however, do not do this, examples are the lorry survey of the Kraftfahrt-Bundesamt (federal office for road freight transport) in Germany (Kraftfahrt-Bundesamt, 2007) which does not raise the information on the sectoral origin or destination or the shipper survey of the DLR (Menge et al., 2006) that does not include information on sector of the recipients. Two positive exceptions in this context should be mentioned: The French ECHO survey (Guilbailt and Soppé, 2007) that traces shipments from their source to their destination along multi-stage transport chains. Each time another agent is commissioned with the transport process, the study also investigates this actor and his detailed operations. But as a result, this survey is extremely costly. The Canadian national Commercial Vehicle Survey (MTO, 2009) distinguishes between manufacturers, wholesalers, distribution centers, intermodal transshipment terminals as points or origin or destination of transport cases.

- It is necessary to identify new types of homogeneous groups. In this context, homogeneity refers to the kind and number of microscopic commodity flows and could be extended to behavioral aspects. Friedrich (Friedrich et al., 2007) shows that the so-called sector relations (information on source and destination sector) are a simple and important concept for this purpose. But especially, if behavioral aspects are considered too, more characteristics are needed to describe homogeneous groups as this study or a study in chemicals (Schoenhaar, 2008) show. The formulation of a topology of homogeneous logistic groups covering all economic actors, including the structure of microscopic commodity flows and logistic behavior, is a research work not yet accomplished to our knowledge.

Structural data on mesostructures

For the design, calibration and validation of models simulating the formation of mesostructures, it is important to have representative data points. A representative collection of data especially on large mesostructures including many actors and often their complete activity patterns would be very difficult. In addition, confidentiality issues arise on the side of companies. Therefore such surveys have to be limited to some key parameters that characterize the resulting mesostructures. Data on logistic locations (warehouses and reloading points) would surely provide such parameters. This kind of data was already requested from different sides like the BESTUFS report (Binnenbruck, 2006) that gives an overview on current urban freight data collection and identifies open spots.

Behavioral data

There is plenty of knowledge on normative models from logistics describing optimal behavior for specific situations. However, normative models do not cover all situations of economic actors, and normative (optimal) behavior may differ from real world behavior because of specific circumstances. Research on descriptive models (surveys and modeling) in the area of transportation system focuses mainly on the mode choice decision. Research is missing for all other decision levels and for integrated decisions. Especially for more complex combinatorial decision problems (like warehouse structure), the real world "optimization" procedures would be of interest. Statements of practitioners and researchers in logistics show that models described in theory often do not correspond to real world situations (Gudehus (2004), p. 45).

Modeling real world behavior can either mean higher complexity but also simplification. For instance: retail stores in food retailing usually have daily deliveries because of the fresh products. In such a case, the theoretic frequency decision between warehouse and stores is not necessary in a freight transportation model (see section 3.3).

To determine such behavior, research methods that are open to the unexpected (like case studies and expert interviews) have to be used. The influences and therefore the parameters of the decision under consideration may differ between sectors and even within sectors and, thus, may not be known beforehand. Only, if a model is already developed that describes this behavior, empirical surveys covering a large number of interviewees will become significant.

Closure of data spots for this study

For this study, logistic systems and commodity flows are mostly generated out of existing data or simulated (see next section for details). To verify the model results, data on warehouses in the retailing sector published by commercial data providers are used. These commercial sources are specific to the sector and to warehouse structures. Therefore, open data spots for structural data on mesostructures are likely to exist for most other sectors and also for other kinds of mesostructures. The open data spot that is most difficult to be filled, is the area of logistic behavior. Therefore expert interviews were carried out that will be described in the next paragraph.

3.2.4 Expert interviews

In this paragraph, the motivation to choose the empirical method of expert interviews, measures to assure accuracy, and details on the process will be outlined.

Motivation

As shown in section 3.2.1 expert interviews are a scientific method that is advisable in the context of complex systems where influences and relations have to be determined without the predetermining character of a questionnaire. "In an expert interview, experts are given questions that they can answer in a free speech and in their specific terminology. The interview guideline serves to start a topic focused conversation but not to predetermine more or less fixed answer categories as this is the case in structured questionnaires." (translated from (Mieg and Näf, 2009), p.4).

The main goal of the interviews in the context of this study was to determine logistic behavior which means the scope and time horizon of the decision problems and the solution procedures in place. This also includes the embedding in surrounding systems. The researcher therefore has to be open-minded to unforeseen factors. Because of the complexity of logistic systems and their interactions as well as the open scope of the decision problems, expert interviews are the method of choice in this context.

Also theory building (or in this context "model design") needs practical examples that cover more than just pure hard facts. Mintzberg (1979) states: "For while systematic data create the foundation for our theories, it is anecdotal data that enable us to do the building. Theory building seems to require rich description, the richness that comes from anecdote. We uncover all kinds of relationships in our hard data, but it is only through the use of this soft data that we are able to explain them."

Measures to assure accuracy

In the context of this study, practical experience is particularly important. Experts were chosen that have long-time experience in logistics in food retailing. As an approximation, ten years of experience is seen to be sufficient to be called an expert (Mieg and Näf (2009), p.7), this criteria was met by most experts interviewed as shown in table 3.1.

Company	Current position and work experience in the area of logistics in food retailing	Focus interview
Discounter 1	Leading management position in logistics, 8 years of working experience	Warehouse structure, inbound and outbound logistics (retailing company), stocks, promotions and demand fluctuations
Discounter 2	Head of cross docking and logistic systems Europe, 10 yeatrs of working experience	Procurement and stocks, warehouse structure, outbound logistics (retailing company), transport modes
Full sortiment retailer 1	Head of warehouse, 40 years of working experience	Warehouse structure, inbound and outbound logistic (retailing company), stocks, supply paths
Full sortiment retailer 2	Head of POS, 15 years of working experience	Inpound logistics (POS), supply paths, stocks in a POS
Full sortiment retailer 3	Leading management positions in logistics, 4 and 10 years of working experience	Supply path, warehouse structure, inbound and outbound logistics
Coffee company	CEO, 10 years of working experience	Demand fluctuations and promotions, distribution structure and outbound logistics
Milk product company	Head of logistics and employee responsible for transport organization, 23 years and 6 years of working eperience	Distribution structure and outbound logistics
Brewery company	Responsible SCM, 7 years of working experience in logistics and several years as beer brewer	Demand fluctuations, distribution structure and outbound logistics, supply paths and role of wholesalers for beverages

Table 3.1: Overview of expert interviews

Also special attention was paid to circumvent known trap-falls of the methodology of expert interviews:

- To avoid subjectivity and personal interest (see Mieg and Näf (2009), p.5), the interviewee was told the purpose of the interview, which is not to benchmark but to determine typical behavior, the interview was anonymous not giving away name of interviewee or company. Moreover, experts with different perspectives (retailers and producers) were interviewed.
- There was no fixed scope of the interview, to meet the experts' knowledge. The interview guideline represented only possible subjects to discuss. Only those were discussed in detail on which the interviewee had in-depth knowledge. The interviews therefore differed in focus (see table 3.1).
- To avoid misunderstanding and to assure the correctness of data and facts collected, most interviews were taped (in two cases interviewees preferred not to have a recorder the interview taped because of confidentiality reasons, therefore only notes were taken) and the results were documented and reviewed in follow up calls.

Interviewing process

The process of interviewing was oriented at the guidelines given by Mieg (Mieg and Näf (2009), p.11). Experts in the area of logistics in food retailing were identified based on the "ten years rule". The experts were informed before the interview by sending them an e-mail and an attached presentation giving an overview on the research objective, the interview objective and the upcoming interview process. Information including data on the company of the expert was collected beforehand.

The interviews were scheduled for two hours at the workplace of the experts (but mostly took up to four hours). An interview guideline was used to lead through the interview (shown in appendix C.1). Nevertheless, it was only taken as orientation to allow detailed discourses on topics the experts had in-depth knowledge about and also to leave out topics where they had no knowledge. This was especially important since experts of different business areas (including discounters, full assortment retailers and producing companies) were interviewed. Before the interview, the expert was informed on the research and interview objective and the process of the interview by presenting him the information slides already sent by e-mail. At the beginning of the interview, the background of the expert and the activity of the company was clarified. Afterwards, the corresponding logistic decision were discussed. As mentioned before, the interviews were taped in most cases and additionally notes were taken.

The results of the interviews were documented in form of power point slides containing key words and data points. This format was used to give a synthesizing overview on the interview content that can be reviewed in a short period of time, which is crucial to the willingness of the expert to review the results in a short (10 min) telephone conference. All interviews were held anonymous since this was demanded by some interviewees out of confidentiality reasons.

The documentations of the interviews can be found in appendix C.2, the results will serve as input for the description of the food retailing sector in the next section.

In the context of this study, several additional visits in operations and interviews with practitioners have been accomplished: two warehouse visits and observations of the dispatching process (documented in Fuchsenberger (2009)), five interviews with practitioners (in the context of a study on distribution structures in food retailing, thereof three retailing companies, one logistic service provider and one wholesaler, documented in Okutan (2007) and one case study on supply path decisions of a chain of building supplies stores (Jacobi, 2008).

3.3 Food retailing in Germany

In this section, the food retailing sector and logistic systems in and around this sector will be analyzed in detail, based on the sources described in the last section. The objective of this section is to generate more insights on structure, influences and behavior to design the model and to identify the data for input, calibration and validation. Therefore, not only the existing decision situations but also drivers from business activities, adjacent actors and logistic systems are determined. To link this analysis to the goal of this study, all paragraphs will contain short explanations how data or insights were used within SYNTRADE.

At first, a definition of the food retailing sector and the borderlines to adjacent economic activities will be given. The food retailing sector will be further described by the market structure and assortment structures. This will be supplemented by highlighting some characteristics of goods in food retailing like perishability and demand fluctuations that have significant impact on logistics. Then the linkages to other economic activities and the integration with adjacent logistic systems will be illuminated and finally logistic decision situations will be described.

3.3.1 Definition of food retailing in Germany

The statistical office in Germany defines trade as follows: "The notion trade comprises the procurement of goods and the sales to third parties without further processing of these goods. Trade therefore acts as an intermediary between producer and consumer. In general, it can be distinguished between wholesaling and retailing" (Statistisches Bundesamt

(2003), p.821). The customers of wholesalers are commercial institutions, whereas the customers of retailing are in general private households. The value added of actors in trading can be

- to realize economies of scale (buying larger quantities)
- to bridge a time gap (buy, store and sell later)
- to bridge distances (buy, transport and sell at another location)

In the NACE classification the corresponding sector G is subdivided into

- sale, maintenance and repair of motor vehicles and motorcycles; retail sale of automotive fuel
- wholesale trade and commission trade, except of motor vehicles and motorcycles
- retail trade, except of motor vehicles and motorcycles; repair of personal and household goods

Precise definitions of these sub sectors can be found in Statistisches Bundesamt (2003).

A further detailing of retail trade without repair of personal and household goods is given in figure 3.12. The food retailing sector is represented by sector 52.1., this is the

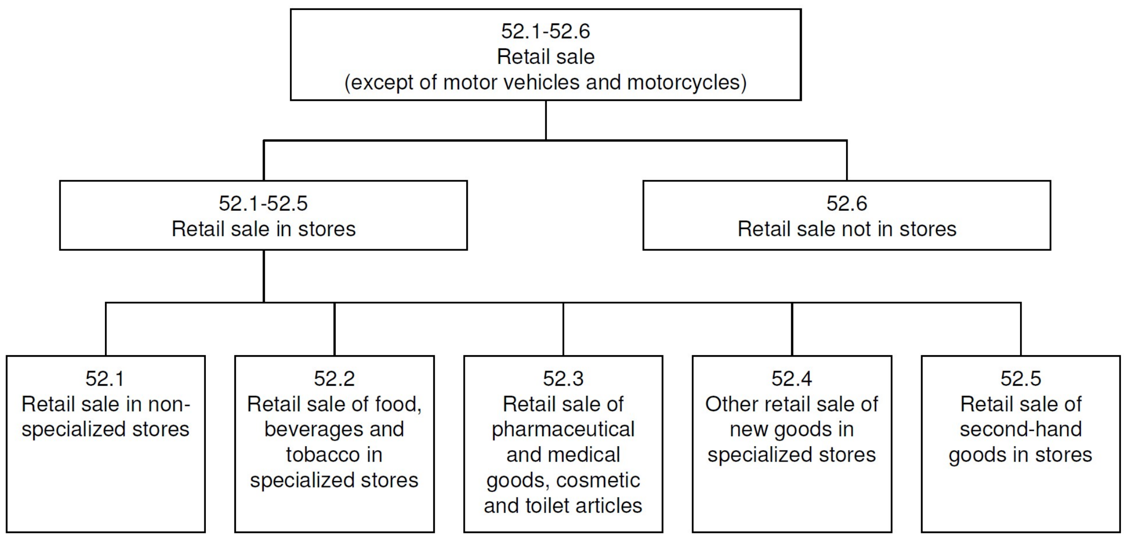

Figure 3.12: Structure of retailing in statistics (translated from Statistisches Bundesamt (2003), p.821)

sector the study refers to. It contains points of sales that have a wide range of articles and also non food articles in their assortments. Nevertheless, the main focus is on food as will be shown later in this section.

The other retail sectors will not be modeled directly in this study although food articles are sold in these sectors as well. Sector 52.2 for example contains specialized food stores like bakeries, sector 52.3. contains drug stores that often have dry food products in their assortments. Also, stores in fuel stations and wholesale cash and carry markets are not modeled directly. However, all these activities will be considered indirectly since all consumption of private household and of sectors consuming the same kind of products will be covered in a simplified way.

A problem arises from the fact that in some cases companies cannot clearly be classified into only one sector (statistics allocate mixed companies to the sector of their main activity). It is assumed that focusing on the sector 52.1 is reasonable because logistic systems of the companies in this sector do not or only to a limited extent serve other sector activities. The only significant overlap can be seen in wholesaling activity of Cash and Carry markets (this is the case for Metro, Rewe and EDEKA that also run Cash and Carry markets). But as statements from expert interviews show(see Appendix C.2), those stores are mainly delivered directly and not via the warehouses and therefore can be neglected. Also wholesaling activity of delivering to independent entrepreneurs running stores (like it is done by REWE and EDEKA) was simplified in the sense that these independent stores are seen as part of the retail companies delivering to them.

Stores in food retailing (sector 52.1) can be classified by number of articles in the assortment and sales floor. A common classification of stores formats is given in table 3.2. This classification and naming of store formats is used throughout this study. Estimates

Format	**Sales floor** (m²)	**Magnitude of number of articles**	**Examples for chain brands**
SB-Warenhaus	> 5.000	30.000 - 60.000	Real
Verbrauchermarkt	1.500 - 5.000	20.000 - 40.000	Famila
Supermarkt	400 – 1.500	5.000 - 20.000	E-neukauf
SB-Geschäft	<400	< 5.000	Nah & Gut
Discounter	Not characterized based on sales floor but based on low price and limited assortment	1.000 - 3.000	Lidl

Table 3.2: Store formats (following classifications of Metro Group (2008) and Trade Dimensions (2009))

on average turnover and occurrence of formats in Germany will be given in table 3.3. In the model also more detailed data (turnover and articles per store) for specific store brands was used if available.

A statistical publication (Statistisches Bundesamt, 2008a) shows the approximate relation between NACE sectors and store formats. This was used as a point of orientation to further precise the scope of food retailing in this study. The sector 52.11, representing the formats mentioned, is completely included in the model, additionally the food part of sector 52.122 representing food departments in department stores is covered. Based on this precisely defined focus, the turnover of food retailing in Germany can be determined in the next paragraph.

3.3.2 Market structure

Table 3.3 shows numbers for the total sector as well as the breakdown to formats. Since the definitions vary and the data bases differ between the sources numbers change slightly. For total turnover estimation numbers from official statistic (Statistisches Bundesamt (2009) are taken, including sector 51.11 and turnover with food in sector 52.122). The breakdown to formats are based on the estimates of IRI (Information Resources GmbH (IRI), 2008), AC Nielsen (A.C. Nielsen GmbH, 2007) and EHI (EHI Retail Institute, 2007). The estimated number of stores is based on figures from Trade Dimensions (Trade Dimensions, 2009) since the detailed input data on distribution of stores in space is also taken from this source. Nevertheless, it has to be completed by an estimation on the number of "SB-Geschäfte" since this source does not capture all stores as can clearly be seen by comparing the numbers to other sources.

	"SB Warenhaus"	"Verbraucher-markt"	"Food departments"	"Supermarkt"	"SB-Geschäft"	"Discounter"	Total
Number stores							
This study	**703**	**2.945**	**993**	**8.644**	**26.000**	**15.374**	**54.659**
Trade Dimensions (2006, excl. independent stores)	2.333		421	3.874		15.374	22.002
Trade Dimensions (2006, incl. Independant stores)	703	2.945	993	8.644	9.373	15.374	38.032
EHI (2006)	2.995			8.430	32.740	14.745	58.910
AC Nielsen (2006)	705	2.438		8.388	30.859	14.785	57.175
IRI (2006, without Aldi)	710	2.635		8.555	20.040	10.960	42.900
Stat. Bundesamt 2006 (number establishments in 52.11 and 52.122)	No breakdown						56.060
Turnover (in Mio EUR)							
This study	**16.876**	**20.742**	**1.984**	**29.781**	**10.892**	**55.792**	**136.067**
Trade Dimensions (2006, excl. independent stores)	40.676		15.792			58.393	114.861
EHI (2006)	33.400			28.900	12.300	53.900	128.500
AC Nielsen (2006)	16.880	19.475		27.775	10.920	49.700	124.750
IRI (2006), Aldi added with Nielsen data)	14.750	19.400		27.050	7.400	53.250	121.850
Stat. Bundesamt 2006 (Turnover in 52.11 + Food turnover in 52.122)	No breakdown		1.984	No breakdown			136.067
Turnover per POS (in Mio EUR)							
This study	**24,0**	**7,0**	**2,0**	**3,4**	**0,4**	**3,6**	**2,5**

Table 3.3: Estimations on market structure 2006 (based on A.C. Nielsen GmbH (2007), Information Resources GmbH (IRI) (2008), EHI Retail Institute (2007), Statistisches Bundesamt (2009) and Trade Dimensions (2009))

Based on these estimations also average turnover by format can be calculated. For model input in some cases more detailed data on individual companies and the characteristics of their specific formats is taken into account (this data is available at a charge from data providers like Trade Dimensions or AC Nielsen).

Breakdown to logistic systems

The breakdown of market turnover to actors (see figure 3.13) has to be done according to logistic systems. This means turnover is allocated to the logistic system that distributes the goods. The turnover numbers are based on published company data or data from commercial data providers. Also, data is available that allows the allocation of turnover

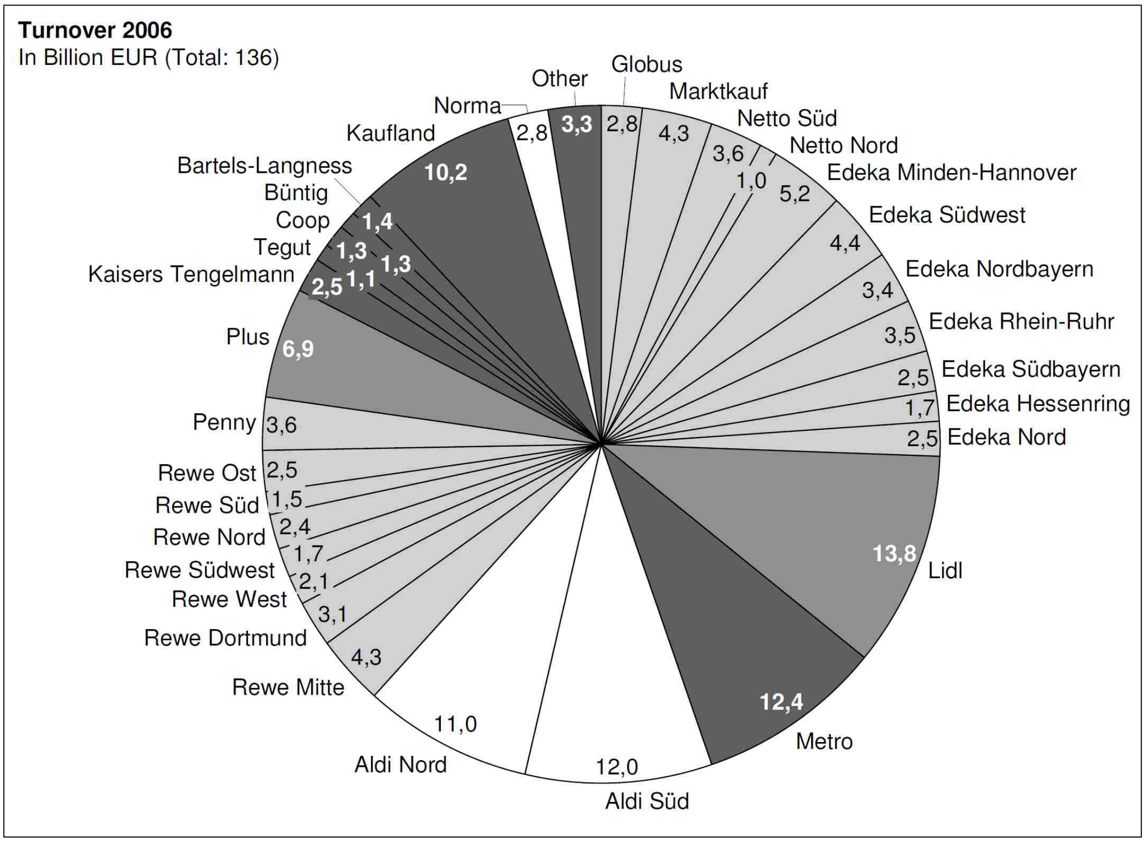

Figure 3.13: Breakdown of food retailing turnover to logistic systems (based on company data)

to warehouses of the logistic systems. The turnover of the individual logistic system does not always represent the retailing activity of the brands as following examples show:

- Especially within the logistic systems of EDEKA and REWE, a lot of independent retailers are incorporated that get their goods via these systems. EDEKA or REWE formally act as wholesaler in these cases.
- Some chains are supplied by different logistic systems, Penny stores for example are to a large extend supplied by the general logistic systems of REWE (for example REWE Ost), the corresponding part of the turnover is therefore allocated there.

These logistic systems are the bases of SYNTRADE, all stores belonging to a system are treated as if they belong to the same actor. Out of a logistic perspective, this is the correct allocation since the logistic decisions will be based on the scope of the logistic systems. But for modeling economic activity a different allocation would have to be chosen. Regarding the results, it has to be considered that the logistic systems named after the main brands do not always correspond to the company. For example Tengelmann is represented as two separate logistic systems, also the Kaisers Tengelman warehouses supply some independent retailers. The turnover that cannot be allocated to logistic systems (3,3 billion EUR) is the part of the market that either is not covered by the data available or does not get delivered via logistic systems of food retailing. In most cases, these retailers probably are supplied via wholesalers or via direct deliveries. In the model, this part of the market will be covered indirectly by commodity flows from suppliers to regions.

Distribution in space

The retailing activities are distributed in space. Especially for a model that aims to represent freight transport demand, data on the distribution of points of sales is crucial. For the purpose of national freight transportation modeling, the spacial resolution of NUTS-3 (Kreise in Germany) seems sufficient.

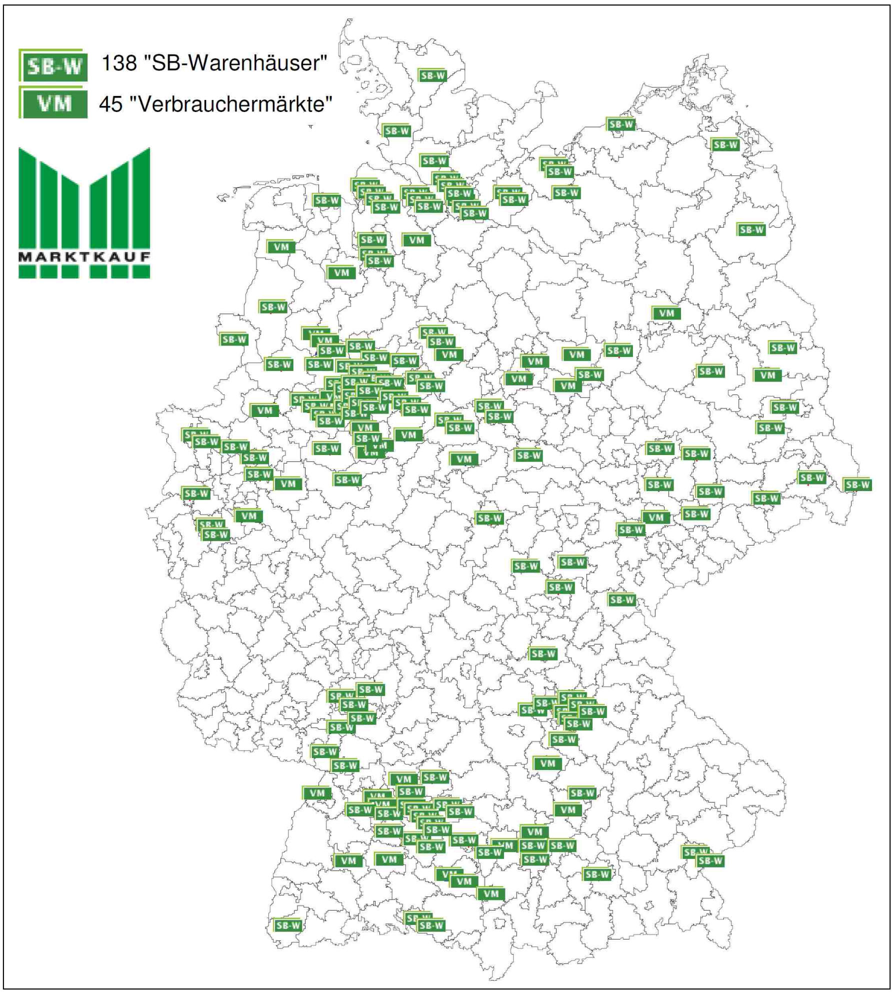

Figure 3.14: Exemplary spatial distribution of Marktkauf stores (based on data from company homepage - accessed 25.1.2009)

This kind of data is available directly from companies (for example the stores structure of Marktkauf as shown in figure 3.14) or from commercial data providers. Also, locations of stores are published as points of interest in public geographic information systems. Commercial navigation systems in cars (or in the Internet) for example already often provide locations of certain retail stores as well. Nevertheless, these data sources are mostly incomplete. For the preparation of this study, an econometric model was developed to synthetically reproduce the spatial structure of stores in food retailing in Germany (for details see Pirk (2008)). It was found out that the best results could be achieved by using indicators that contain in some form the number of residents. It could be shown that especially the distribution of discounters, large companies and companies with few historical background can be reproduced quite accurately. For SYNTRADE such estimations are used to reproduce the structure of some regions where no data was available. It is extremely time consuming to reconstruct industry structure on this detailed level (12.000 data points have to be checked - about 30 logistic systems multiplied by 400 regions). Nevertheless, this is a deciding factor for the model, since the reproduction of individual logistic structures needs this information. Since in this study the functioning of the model is proved by comparison to real world logistic structures, this is crucial. For the purpose of transportation modeling in general and the later use of the model, input data with the same structural characteristics is sufficient.

Dynamics in market structure

Year	1980	1990	2000	2006	2010
Proportion of Top 5 companies in the food retailing market	26,3%	44,7%	62,6%	69,2%	72,2%

Table 3.4: Development of market concentration (Metro Group (2008),p. 19)

The market for food retailing in Germany has been subject to change for the last decades (see for example Zentes (2006) or Müller-Hagedorn (1998) for details). In the beginning of the 70's independent merchants affiliated to cooperations like EDEKA or REWE. In the 60's and 70's Verbrauchermärkte and SB-Warenhäuser emerged and replaced more and more neighborhood stores. In the 80's the saturation of the market was reached and the concentration process has started.

This concentration process and the spread of discounters are the most obvious changes in the market structure during the last years. Table 3.4 shows the market share of the biggest ten players in the market. A significant trend which, according to the numbers of Metro (Metro Group, 2008), will continue in the next years.

Also, the development of the market shares of the formats show significant changes. Discounters have won up to more than 40 percent whereas SB-Geschäfte lost half of their market shares since the mid 90's (see figure 3.15).

Both trends have consequences for the corresponding logistic systems and for freight transport demand. A higher concentration could for example lead to larger and less warehouses with warehouse structures on a national scale whereas more discounters lead to warehouses with lower reach. The analysis behind these effects can be done with SYNTRADE and will be presented in chapter 6.

Another interesting fact as described by Vahrenkamp (2005) (p. 87) and also repeatedly mentioned in the expert interviews, is the dominance of the food retailing companies compared to the producers. This leads to the replacement of logistic systems of suppliers by logistic systems of food retailing companies (as described by Prümper (1979)). This

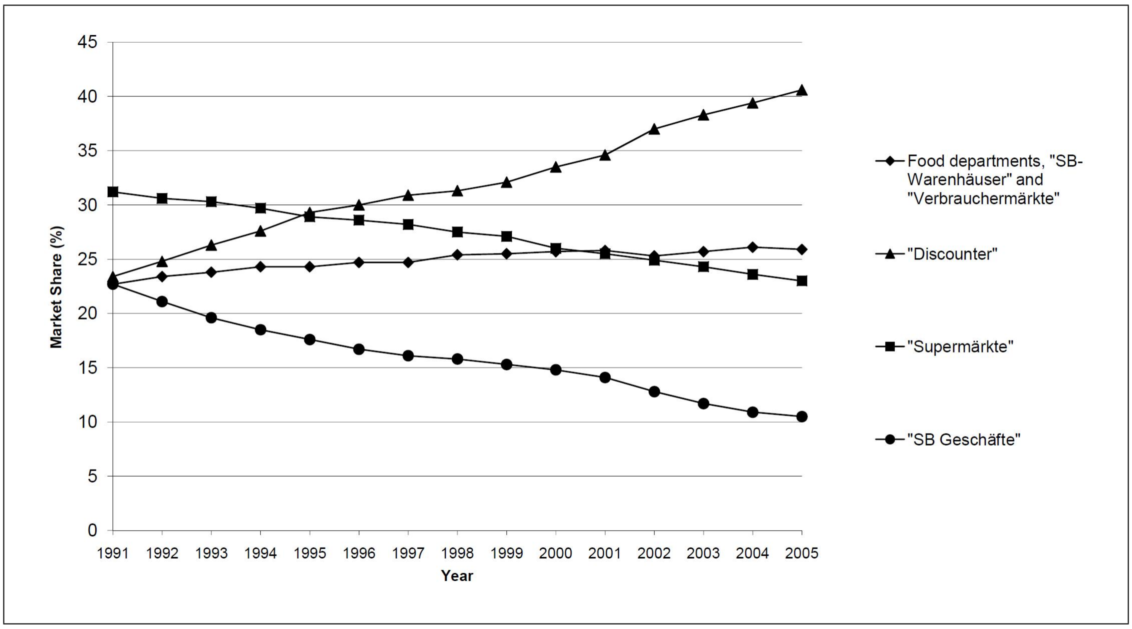

Figure 3.15: Development of market shares of store formats (based on data from Lebensmittel Zeitung (2007))

observation shows that the overall system can have multiple (at least two) stable states: either the dominating food retailing systems that offer low logistic costs through inbound bundling or dominating distribution structures that offer low logistic costs by bundling outbound flows.

3.3.3 Assortments

The articles sold in stores form the assortment of a food retailing company. High level categories of articles in assortments are fresh food, frozen food, dry food and non food I and II. These categories are based on the GS1 goods classification (GS1, 2009) and are commonly used in data publications (like EHI Retail Institute (2007)) as well as by practitioners as in the interviews. In figure 3.16 the breakdown by numbers of articles and by turnover to these categories is shown for the different store formats. It can be seen that for "Discounters" and "Supermärkte" (D and SM), only a small part of the activity (turnover and number of articles) comes from non food articles. This is different for "Verbrauchermärkte" and "SB Warenhäuser", especially for the latter the number of articles in non food is very high. Nevertheless, looking at the turnover, the major focus for these two formats still is on food (about 60% for "SB Warenhäuser"). Another interesting fact is the difference in the proportion of fresh food looking at numbers of articles or turnover for all formats. This shows that there is a higher turnover per article in average for fresh food than for articles in the other categories.

The data for the breakdown by number of articles in figure 3.16 is published by the EHI (EHI Retail Institute (2007), p. 360ff). The breakdown for turnover is only available for "Supermärkte". Therefore, other statistics and sources have to be used as well: with the trade statistic (Statistisches Bundesamt, 2009) a breakdown for the overall sector to the five categories can be estimated and with other statistics (Lebensmittel Zeitung, 2007) the turnover proportions of formats in different categories are given. Also, the total turnover

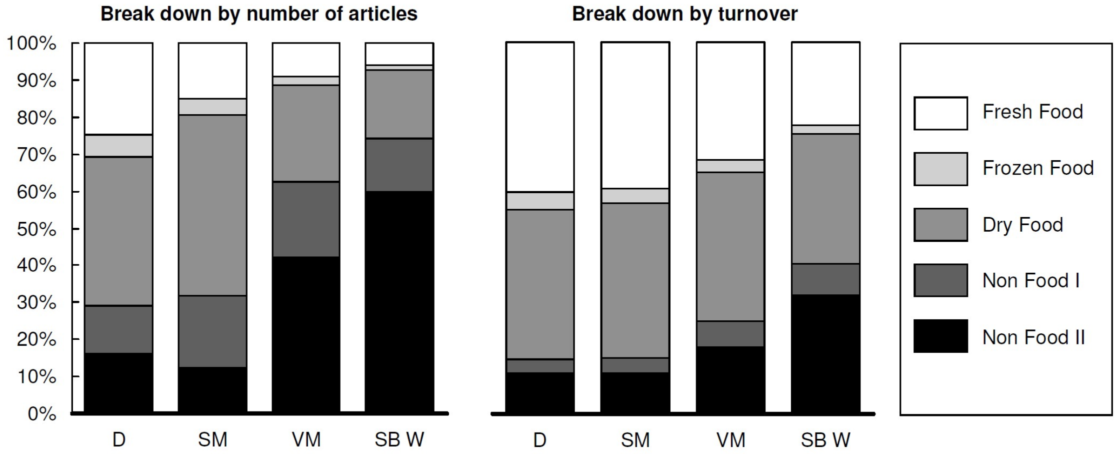

Figure 3.16: Breakdown of assortments (EHI Retail Institute (2007) and own calculations)

proportions of the formats as shown before are set. Thus, with the "Furness method" (see section 4.2.4), the matrix (dimensions: formats and categories) and the data shown in figure 3.16 can be generated.

The assortments can be broken down in more detailed categories following the GS1 goods classification. The more detailed the categories are, the more specific characteristics of articles in the single categories can be identified. Important characteristics in the context of logistics are, besides the number of articles in the category, value density (value per kg or cubic meters), perishability and characteristics that determine the logistic handling. For this study, a breakdown to 41 categories was chosen, since only down to this resolution data on number of articles in different store formats (from EHI Retail Institute (2007)) is available. The list of these categories with estimates of value densities and assumed period of perishability is shown in appendix B.1. This study assumes within these categories the same characteristics for the articles. In reality, even within these categories, the articles still differ, but due to data availability, this simplification had to be made. The estimates of value densities were based on data from production statistics (see Statistisches Bundesamt (2001) for data and Friedrich (2003) for the approach), sectoral statistics (Lebensmittel Zeitung, 2007) and original data from operations (Jacobi, 2008). The differences between the categories show that there is a need to be as detailed as possible. The estimates of value per kg reach from 0,48 EUR for articles of the category non-alcoholic drinks up to 120 EUR for articles in the category of tobacco products.

The quantities sold per article (volumes, weights or values) within the categories are not equally distributed. For logistic decisions, the quantities per supplier are important (which may incorporate many articles). A Pareto distribution of quantities was assumed to account for this effect. The cumulated Pareto distribution function can be described as:

$$F(x) = 1 - (x_{min}/x)^k, x > x_{min} \qquad (3.1)$$

For some parameter values, the cumulated distribution function (normalized to $F(x_{max}) = 100\%$) is represented graphically in figure 3.17. This representation of cumulated distribution function is also known as Lorenz curve or Pareto classification (see Gudehus (2004), p. 134 ff. for details). Also ABC analysis that classifies articles by

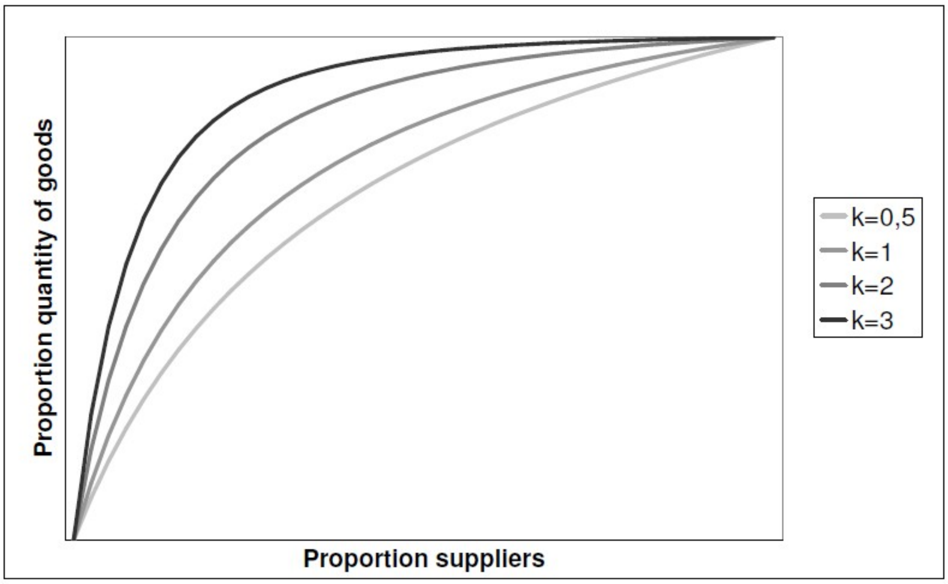

Figure 3.17: Cumulative Pareto distribution function

the distribution of a characteristic (for example amount sold) refers to these proportions - mostly 80% and 95% are taken as class borders.

The distribution represents the effect observed in food retailing that there are some articles with very high amounts sold and many articles with low amounts. For discounters a rather small k has to be chosen, since articles are only taken into the assortment if certain amounts can be sold, whereas for "SB Warenhäuser" high k values have to be chosen, since the assortments in this formats cover a large number of articles.

The detailed knowledge on the assortment described in this paragraph can also serve another purpose: through linking the classification of articles (in this case the GS1 goods classification) to sectors in which these goods are produced (in this case WZ classification), the relations to other sectors can be determined including volumes, weight and values. For this study, such a link between the classifications is estimated (see appendix B.2). Based on this link, turnover data and data on assortments in food retailing can be used to estimate the proportions of sector productions used to supply the food retailing sector. This will be part of the overview on the adjacent economic activity in paragraph 3.3.5.

3.3.4 Special characteristics of goods in food retailing

Looking at groups of articles or individual articles, special characteristics of these goods become more evident. Two of them, perishability and fluctuations in demand, will be discussed in more detail since they have direct impact on logistics.

Perishability

Perishability of goods and the corresponding expiration periods of articles or article groups are an important characteristic to classify goods throughout all expert interviews with food retailers. This is because it has significant impact on logistics. The time available for logistics is limited for perishable products. A graph of Pastors (2005) (figure

3.18) shows that only a part of the expiry period of a good is available for logistics since the retailer wants to sell the good at the time when it looks best, in interviews it was repeatedly mentioned that only a third of the time should be used by the retailer including time for logistics and sales. The used perishability periods in the model for article types are shown in appendix B.1.

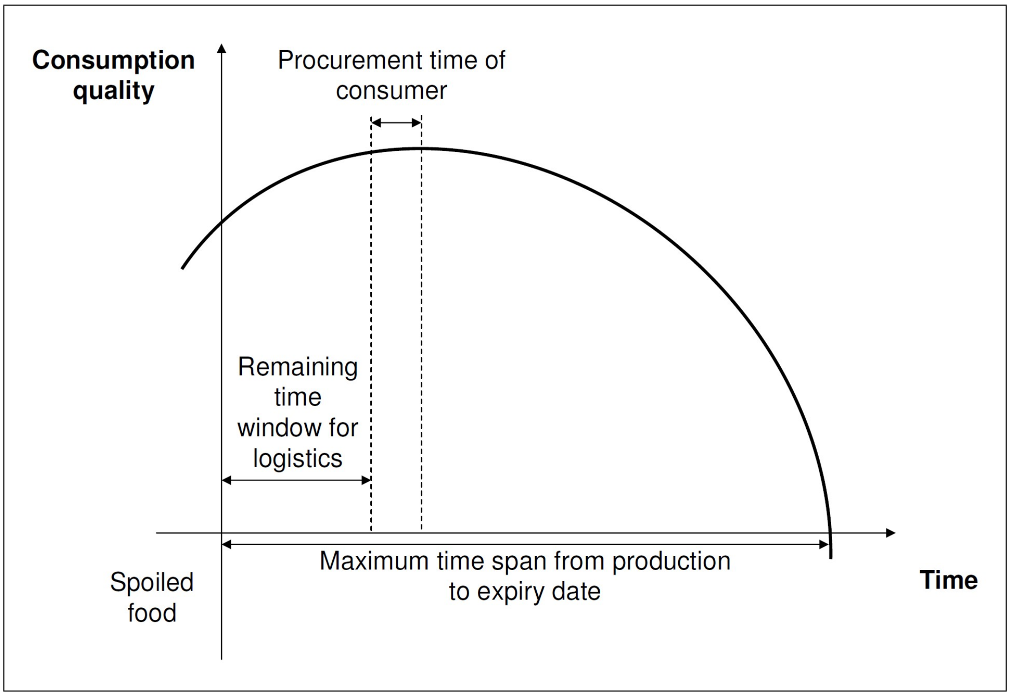

Figure 3.18: Logistic window of perishable consumer goods (translated from Pastors (2005))

Having only limited time for logistics leads to the fact that less time can be used to buffer products, and thus, smaller batch sizes have to be transported. In the extreme case (for example products like fresh bread or convenience food) there is not enough time left to ship the goods via the warehouses of the retailing company to the stores. Thus, the expiry period has direct impact on the lot size decision and the supply path decision and through the system load also on the warehouse structure. Therefore, it is reflected as a parameter in SYNTRADE.

Closely related to the perishability topic are temperature requirements for goods. The detailed temperature requirements for food products in Germany are published in a standard by the German institute for standards - DIN (DIN, 2008). In SYNTRADE, these requirements are represented in the classification of suppliers, in the classification of interregional and local adjacent logistic systems and the differentiation of warehouse types within the food retailing sector.

Fluctuation of demand

Another important topic in the day-to-day work of practitioners in food retailing are fluctuations in demand (see interviews). The fluctuation of transport time and the danger of late arrivals in transport on the contrary is less important (probably with the exception of cross-docking systems). Late arrivals caused by transport are in the order of hours and this can easily be balanced out by safety stocks and flexibility in warehouses and stores. Demand fluctuation however shapes the day-to-day work of logisticians (see visit documentation of dispatchers in Fuchsenberger (2009)) in the warehouses.

Demand fluctuations can be distinguished by the time horizon considered: short-term versus mid-term versus long-term fluctuations. A graph from Gudehus (Gudehus, 2004) originally describing fluctuation in car selling, clarifies this distinction (see figure 3.19). On the day-to-day basis huge differences in sales can be identified. The prognosis data shows the seasonal course of demand (mid term) and considering an even longer time period the long term trend can be seen which in this example shows increasing sales.

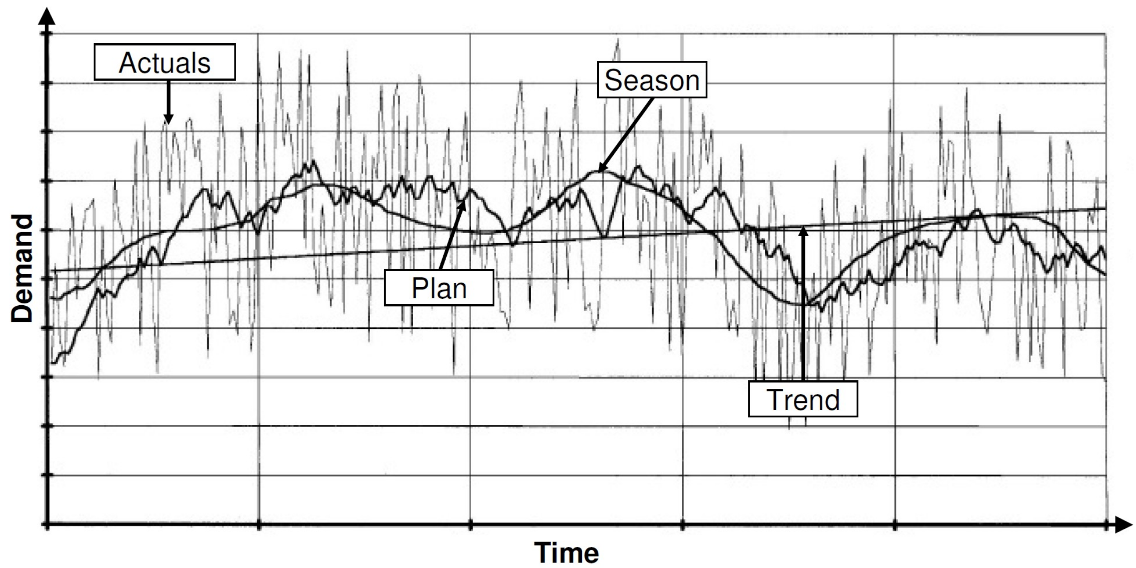

Figure 3.19: Demand fluctuations (based on Gudehus (2004))

For logistics the important question is, if the reason behind the demand fluctuation can be identified and to what extend the fluctuation can be foreseen. Depending on this, the design of the logistic system differs: if the fluctuation can be planned, the inbound flows can be adapted mid-term, if the fluctuations cannot be foreseen and a short-term adaptation of inbound flows is not feasible (because of long lead time or inability of the supplier to deliver), buffers in form of safety stocks have to be established. Reasons behind demand fluctuations can be different:

- Promotions of articles often connected with price reduction lead to high fluctuation. As documented in the interviews, especially discounters use promotions in order to attract customers. For some goods, sales are even mainly determined by promotions (see interview with coffee producer). The increased demand through promotion is at least partially foreseeable, even though the exact demand depends on many factors.

- Seasonal variations of demand can be another reason, examples are public holidays like Christmas or Eastern when general demand for food increases, seasons of specific goods that are only available during a specific period like some sorts of fruits or demand for goods that occurs during specific periods like gelling sugar (see interviews for examples). Also, these fluctuations can be predicted to a certain extent based on historic data.

- Identifiable external influences like good weather or sport events also increase demand as the example of the beer producer shows clearly. Whereas sports events can be foreseen, the forecast of weather is only available short-term.
- Finally, there are non identifiable external influences or just random fluctuations that cannot be foreseen. For this kind of fluctuation the rule of large numbers applies: the higher the number of observations, the weaker the pure random element.

Besides the difficulty of estimating effects of the factors shown, forecasting of demand is complicated since the factors mentioned overlap and the effects can be enforced or softened through the parallel occurrence of events.

The influence of demand fluctuations on logistic decisions are most obvious for the short-term decisions on the operational (dispatching) level. Here, especially the day-to-day determination of order sizes of incoming flows (to the warehouse) has to be mentioned. For the bundled transport to the stores, fluctuations of individual goods equalize another, only fluctuation of general demand like increased demand at Christmas causes extra tours for the logistic system of the food retailing company. This might be different for direct delivery, for example distribution tours of a beverage wholesaler during football championship in summer. On the higher decision levels the influence declines. Regular transport frequencies only change if the average demand changes, this can be the case for seasonal products. A high influence can also be observed, if no regular frequencies exist, for example if sales are completely determined by promotions like in the coffee case. Nevertheless, it can be assumed that for most goods the influence of demand fluctuations on mid-term decisions (mainly transport frequencies) is minor. For decisions on the warehouse structure influence can be seen on the dimensioning of the warehouses and the safety stocks hold. The dimensioning has to be oriented to the peak demand that in food retailing usually is reached around the Christmas holidays. The safety stock is driven by fluctuations that cannot be foreseen and planned. If fluctuation is purely random and therefore independent in different stores, it can be shown that centralization of warehouses leads to less safety demand (see Toporowski (1996), p. 86), this results from the fact that the fluctuations equalize another as already described before.

In SYNTRADE, short-term decisions on the level of dispatching are not included. For mid-term and long-term it was assumed that fluctuations have less influence, also data on fluctuations was only available for some examples. Therefore fluctuations were not considered.

3.3.5 Adjacent economic activity, actors and logistic systems

The food retailing sector covers only a part of the provision of goods to consumers. Starting at the location of suppliers, goods can reach the consumer through different paths, only some paths lead through the food retailing sector.

An overview on alternative channels of food provision to consumers is published by the Metro Group (Metro Group (2004), p.115) and shown in figure 3.20. It also comprises the proportion of the channels in total institutionalized provision of food. The application case for this study is focused on stationary food retailing in not specialized stores. But

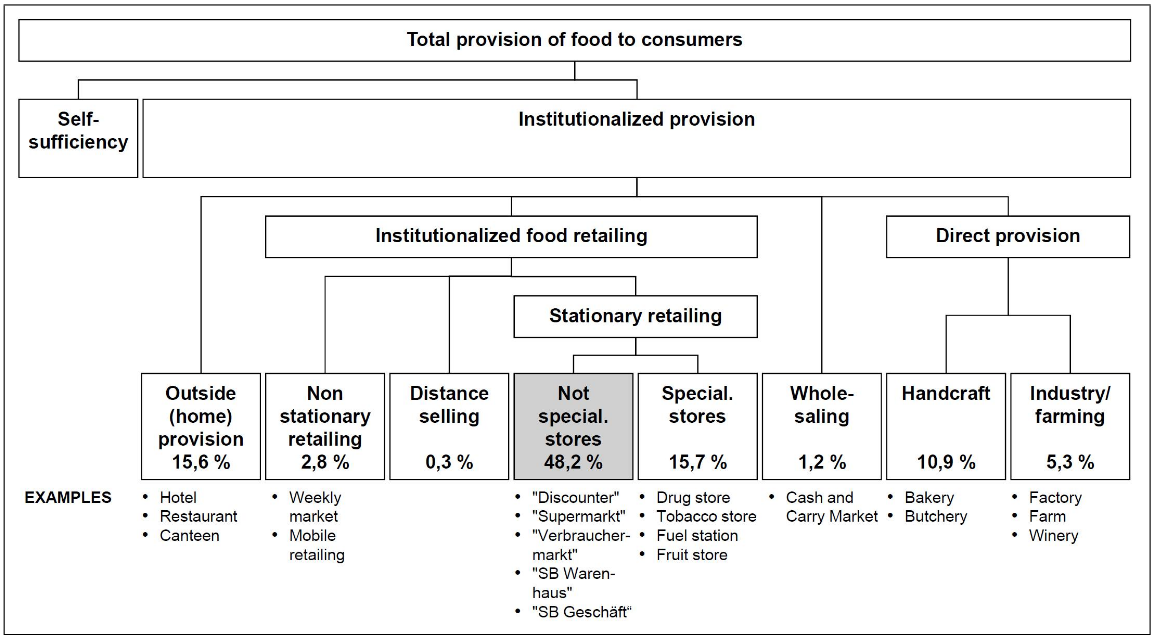

Figure 3.20: Food provision to consumers (data published in Metro Group (2004), original sources: Dr. Lehmann and Partner, M+M EURODATA)

it cannot be seen isolated to the other channels, since goods from different channels are partly handled together in logistic systems. These are systems of suppliers, wholesalers or logistic service providers. Beverages, for example, are often delivered to retail stores via wholesalers that also deliver to specialized stores, restaurants or canteens (see expert interviews). With the same reasoning consumer goods consumed by companies have to be considered as well. In addition to that, also non food consumer goods have to be taken into account, since non food articles represent a significant part of turnover in food retailing.

In the next paragraphs, the total demand of these goods in regions, the suppliers of these goods and the logistic systems used, will be discussed in more detail.

Total demand of consumer goods in regions

Based on the input-output table from national accounting, consumption of goods by consumers and sectors on an aggregated level can be calculated in monetary values. Using data on residents and employees in regions, this data can be broken down to the regional level, assuming that the demand is distributed equally among employees and residents.

This total demand of goods is only partially satisfied by the food retailing sector. By linking the GS1 classification to the NACE classification the amount of goods provided by the food retailing sector can be estimated (building on the knowledge of assortments and market structure shown before). This can be broken down to regions by store data. Thus, the resulting delta can be used as estimate on a regional level for demand that is not satisfied by the food retailing sector. Figure 3.21 shows the estimations on proportions of consumer goods provided by the retailing sector for some exemplary good classes (CPA classification). Only goods are included that are destined to consumers or to sectors that demand the same kind of goods.

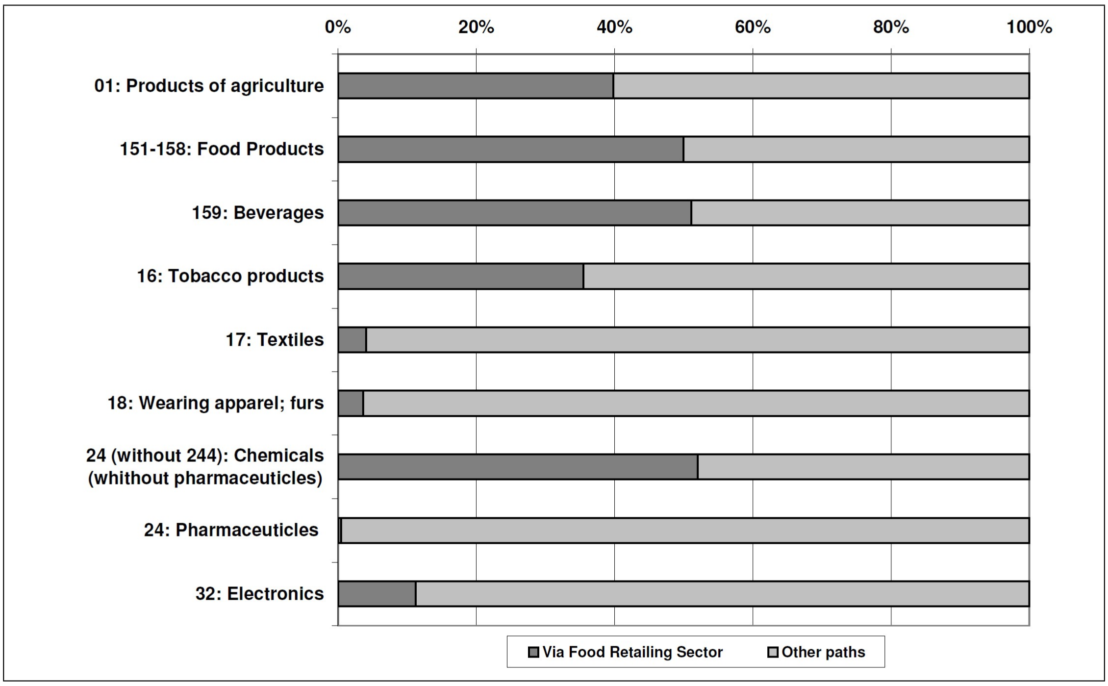

Figure 3.21: Proportions of selected consumer goods provided by food retailing sector (Source: authors calculation - model results - based on data from national accounting and sectoral data)

For the first three classes representing food products, the proportion is quite high. The numbers correspond to the estimation published by the Metro group shown in the last paragraph. For non food goods the proportion of the food retailing sector is rather low. Exceptions are tobacco products and chemicals (without pharmaceuticals). The number calculated for tobacco products can be verified by another publication: Philipp Morris estimates that 31 percent are provided by the food retailing sector (see EHI Retail Institute (2007), p. 383).

In SYNTRADE, these proportions can be generated for more detailed sectoral and regional resolutions, this can be done based on an artificial industry structure, the simulation of sourcing decisions of retailing companies and a gravity model for regions. By mapping this demand to classes of regional distribution systems, the load for these alternative logistic systems is estimated.

Suppliers

The most important suppliers of consumer goods are production companies and agriculture. Goods can be of national origin or imported.

Imports play a significant role for the food retailing sector, because companies source internationally (as the interview with discounter 2 shows). About 20 percent of food products consumed in Germany are imports. For non food the proportion can even be higher, for example about 60 percent for clothing [3].

[3] Numbers are calculated based on the input-output table, assuming that imported goods and goods produced nationally are consumed in the same way

In the model, imports are represented in form of suppliers for the complete imports of a country. By sourcing from these artificial suppliers, the model assumes implicitly that imports get bundled in the country of origin. Geographically it is assumed that logistic hubs are placed within Germany. For the distance from the hub to the regions an average distance between German regions is assumed for European imports. For non European imports the distances to the region of Hamburg are taken.

Farmers in Germany are often organized in regional production cooperations (Genossenschaften) that coordinate sales. As interviews during preparation of this study show, this often results in supply paths that pass the regional warehouse of the cooperation in case of less than truck load transports. Therefore, in the model a simplified representation of the agricultural sector is chosen: one artificial supplier of agricultural goods per region subsumes the total agricultural output of each region.

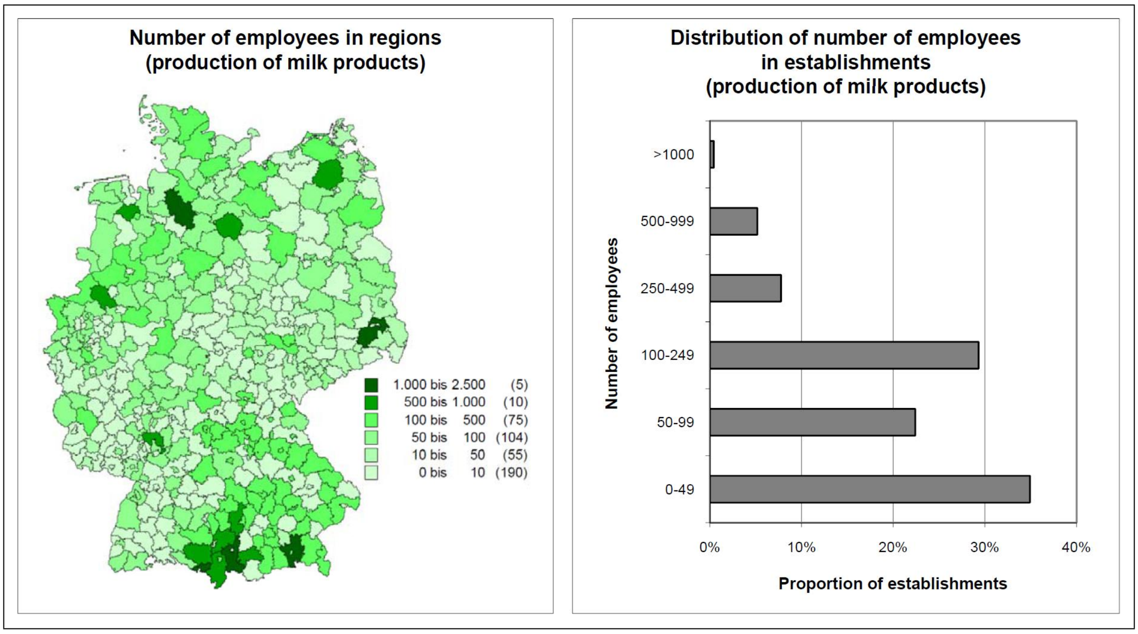

Figure 3.22: Distribution of employees in milk production (Source: Bundesagentur für Arbeit (2008) for employees in regions and Statistisches Bundesamt (2006b) for distribution of establishment size)

For sectors of producing companies, more detailed information is used: numbers of employees in regions (down to NUTS 3 regions and 3 digit sectors in NACE classification) from Bundesagentur für Arbeit (2008) and distribution of number of employees per establishment (down to 4 digit sectors in NACE classification) from Statistisches Bundesamt (2006b). Exemplary data for sector 155 (production of milk products) is shown in figure 3.22.

Based on this data, an artificial industry structure is generated for the model. For the goal of this study, not the complete sectors have to be considered: production of "non" consumer goods or production of export can be left out. By leaving out the respective proportion in the model, it is indirectly assumed that logistics for exports and for non consumer goods is separated from national distribution of consumer goods.

There is few official data on sector relationships other than the input-output table from national accounting, which does only represent good flows to sectors in which the goods are consumed. This is not the case for trade and logistics, where goods are handled but not consumed. Representative data on the level of individual companies is also not available to the author's knowledge. Therefore, for the model the relationship between the sectors and the food retailing sector are reproduced based on assortment data and the respective link between GS1 and NACE classification (see appendix B.2). Links between individual retailing companies and suppliers are generated with a sourcing module. For the remaining goods (not distributed via the retailing sector) a gravity model coupled with the Furness method is applied to distribute goods to regions according to the remaining demand (see section 4.2.4 for details).

Adjacent logistic systems

The logistic systems under consideration provide consumer goods from suppliers to points of sales or consumption points. An overview is given in figure 3.23. Logic systems can

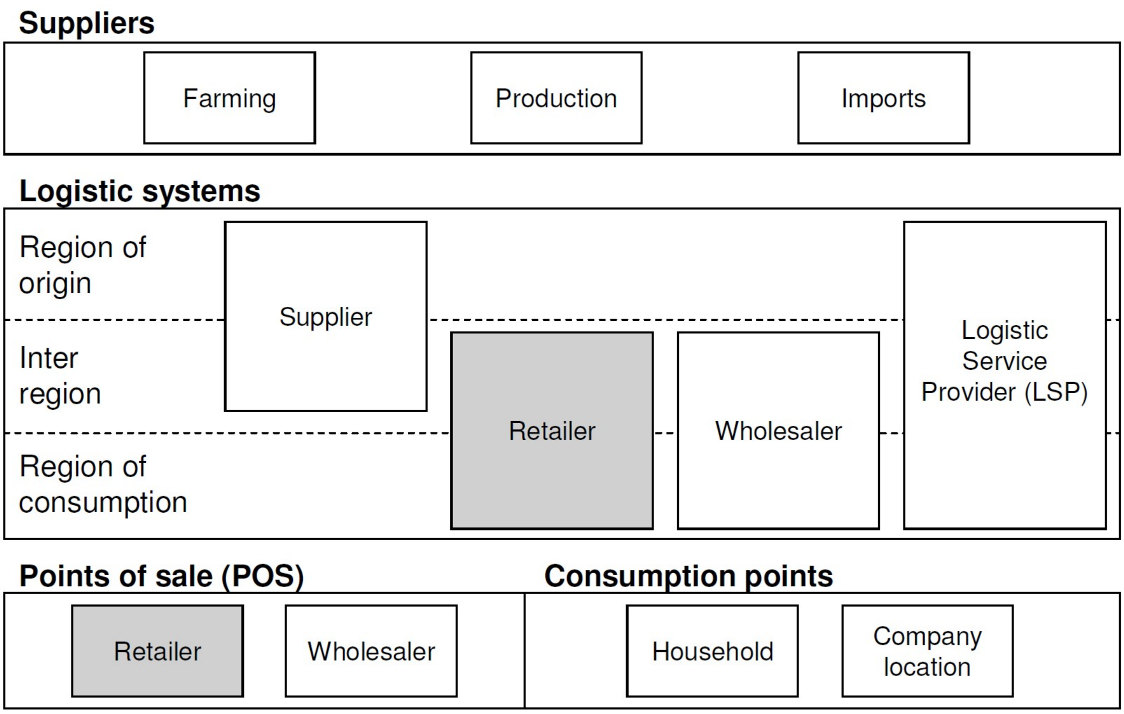

Figure 3.23: Overview of possible locations of consumer goods

be further classified into logistic systems of suppliers, retailers, wholesalers and logistic service providers (LSPs):

- Suppliers: The industry structure described in the last paragraph consists of establishments (production sites). However, logistic systems usually are managed by companies or even cooperations of companies that can include several establishments. So, for an exact modeling of these structures, it is necessary to collect company data as it was done for the food retailing sector in this study.

The expert interviews show that for large amounts, transports start directly from the production site. Only for small transport amounts (in the expert interviews a typical bound of five pallets was mentioned twice) separate outbound warehouses are used. These warehouses were located close to the production sites: the coffee producer uses for small transports the logistic system of the mother company in the same region, the dairy producer uses either own warehouses at production sites or warehouses of LSPs nearby, the brewery only shipped full loads. It is therefore assumed, that the first logistic bundling rather happens close to production.

The more it comes to the destination region, the more attractive a bundling with goods from other origins gets for distribution. But this is rather done by logistic systems of retailers, wholesalers or LSPs. In the interviews, only the coffee company still upholds distribution in the destination regions mainly for maintenance of coffee dispensers. Most products, however, are distributed via logistic systems of retailing companies.

- Retailers: Besides retailers from the food retailing sector a lot of other retailing companies exist in provision of consumer goods. Examples are fuel stations (e.g. Lekkerland), drug stores (e.g. Schlecker) or fashion stores (e.g. C& A). The focus of logistic systems of retailers is on the distribution of goods to the points of sales. But, as the interviews show, some retailers today also include the inbound transport into their considerations through establishing cross docking or offering transport services to their suppliers. Also, a second level in the warehouse structure (central warehouses in addition to regional warehouses) takes over parts of the outbound logistics from suppliers.

  Outbound transport (warehouse to points of sales) is much more expensive than inbound transport (supplier to retailers warehouse), therefore regional warehouses of logistic systems of retailers are oriented towards the destination region.

- Wholesalers: The focus of wholesalers is on the distribution of goods as well. The local distribution of goods often is part of their business (for example wholesalers for beverages, see expert interview with brewery). A classification of wholesalers is difficult to find, a point of orientation can be trade statistics (Statistisches Bundesamt, 2009).

- Logistic Service Providers (LSP): The logistic systems of LSPs can be manifold. They may only concentrate on transport or include warehousing or even additional services like commissioning. A classification of logistic markets of LSPs is given by Klaus (Klaus, 2008). For food retailing, mainly the markets of general cargo load and distribution of consumer goods covering especially food products are of interest.

Consumer goods can pass through different logistic systems, resulting in different supply paths. Examples for such supply paths are:

- Milk products (see interview with producer of milk products): production site - (warehouse of logistic service provider) - food retailing company warehouse - stores of retailing company

- Beer (see interview with brewery): production site - warehouse producer - warehouse wholesaler - stores of retailing company

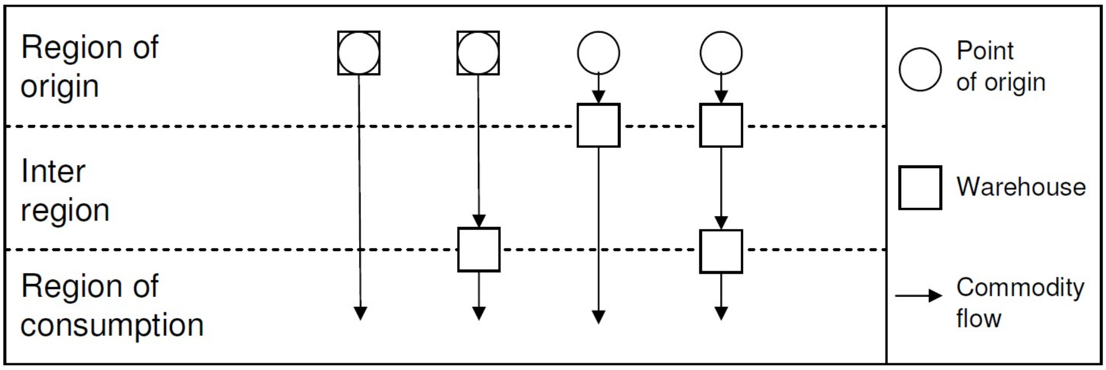

Figure 3.24: Warehouses in supply paths of consumer products

Looking closely at the existing supply paths and the points where warehouses are used (not just as reloading point but as storage location), four categories of paths can be distinguished, as shown in figure 3.24:

- The first category describes cases of direct delivery from supplier to the consumption point or point of sales. The only warehouse used, is the one at the point of origin. An example from expert interviews is the delivery of milk to large points of sales.

- In the second category, goods are stored at the point of origin and at a distribution center, which is oriented towards the destination region. This case describes the usual distribution via warehouses of retailing or wholesaling.

- The last two categories describe the usage of another warehouse, separated from the supplier location. This can be the warehouse of the company, the company cooperation or a logistic service provider where products from different points of origin are gathered for outbound transport. Examples from expert interviews are the central warehouse of the producer of milk products or the logistic service providers, used by the producer of milk products or the coffee producer in case of small transport cases. Like in the first two cases, either the direct transport or the transport via another distribution warehouse is possible.

It can be concluded that in many cases the used warehouse locations are situated in the origin and/or destination region. This is used to simplify the modeling of the adjacent logistic systems.

In SYNTRADE, the detailed logistic systems and especially the warehouse structure decision is only modeled for the food retailing sector. The adjacent logistic systems are modeled in a simplified way:

- Two sorts of logistic systems are modeled: interregional logistic systems and local logistic systems for distribution. Both consist of one warehouse and inbound and outbound flows. The classification of the interregional logistic systems is oriented at logistic markets (non food, food, and cooled products). The classification of local logistic systems is oriented at the classification of wholesalers in trade statistics.

- The costs for transport on the links depend on usage and are based on a transport price matrix of a transport logistic service provider. Therefore, they include indirectly potential bundling for transport through third party logistic system.
- The locations of warehouses are fix, there is no decision on warehouse structures and locations outside the food retailing sector.
- Supply path decision for commodity flows is modeled, assuming cooperation of actors concerned. It includes decisions on frequencies and average batch sizes (lower levels in decision hierarchy). Four supply paths can be chosen: Either through the logistic system of the retailer or directly into the region. In both cases, the interregional logistic systems of the supplier region can be used. For distribution in the destination region, all flows not using the logistic systems of the food retailers run through the regional logistic systems in the destination region.

Even so the adjacent logistic systems in SYNTRADE are highly simplified, the model represents the potential for loads on the local distribution systems and the potential for bundling of transports from the origin region to retailer warehouses or destination regions. This is important in order to model differences between goods in the usage of alternative supply paths. Beverages, for example, are often supplied via wholesalers, whereas milk products usually pass the logistic systems of retailers. Looking at the model output, it has to be emphasized that only the flows through the logistic systems of retailing are modeled in a realistic way. The flows around it only correspond to reality in the sense of what flows do or do not run through the logistic system of food retailing companies. But they can be false in the sense that they take the direct route from origin to destination region. In reality, this can be different, for example if warehouses of other retailers are used that are not located in the destination region.

3.3.6 Logistic decisions in the food retailing sector

The aim of this paragraph is to present empirical insight from expert interviews and other sources on logistic decisions. Based on these insights, parts of the model design are reasoned.

The goal of this study is to model warehouse structures in the food retailing sector. In terms of logistic decisions, the main focus is on the warehouse structure decision, but as decisions on lower levels influence it or decisions even are integrated, also the supply path decision and the frequency decision are analyzed. As expert interviews show, only trucks are used for transport in almost all cases in food retailing, new warehouses mostly do not even have rail siding any more. Only for inter European transport some cases of inter modal transport were reported. Therefore, modal choice is not considered within the model.

In the following, the decisions on warehouse structure, supply path and frequency will be analyzed in more detail. This is done by outlining at first the observations from expert interviews and other sources, and then explaining the usage of these insights within the model.

Warehouse structure decision

For the warehouse structure decision, the following observations were made:

- Historic growth: Warehouse structures in practice grow over time. The actual structure, therefore, often has to be explained by historic development. This accounts especially for full-line distributors that seldom change or add new warehouse locations. On the other side, discounters add or change warehouse locations more often probably because of their high growth rates in recent years. An expert working for a discounter stated that they added a warehouse every two years in Germany during the last years. If a new warehouse location is planned, this is done including the overall warehouse structure or at least the surrounding warehouses.
- Size of warehouses and warehouse levels: Often, the size of regional warehouses of a company for discounters is standardized. This was stated in both interviews with discounters. For retail companies with many regional warehouses, often a second (central) warehouse level for parts of the assortment exists. In these cases, the distribution to the stores often takes place via the regional warehouses, at least for the small and medium stores. In the regional warehouses cross docking is used to bundle the outbound flows.
- Allocation of stores to warehouses and warehouse locations: The determination of locations and the assignment of stores to warehouses is often done based on turnover data of the stores which was confirmed by two experts. This shows that for these two components of the warehouse structure decision, the outbound transport is the major driver. This can be confirmed by estimations that outbound transports are much more expensive than inbound transports - factors of three (Toporowski (1996), p. 69) to ten (Geoffrion (1979), p. 106) can be found. It also shows that mainly the aggregated view on the flows transported to the stores is of interest. Thus, the bundle of outbound flows are considered as a whole and not as single commodity flows on article level.
- Costs considered: Looking at the cost components, expert interviews show that a broad view is taken. Transport cost, logistic discounts of suppliers, storage cost, capital cost for stock, costs for damages and cost of running out of stock are considered. Logistic discounts of suppliers are a way to give incentives to the food retailing company that large orders are given (truck loads or several pallets), so that transport costs that are paid by the supplier are kept low. The inclusion in the warehouse structure decision shows that the future frequencies of inbound transports are taken into consideration. Another important observation is that capital cost of stock is taken into account.

Many of these observations are directly reflected in the heuristics for the warehouse structure decision applied in SYNTRADE:

- Same size for all regional warehouses of a company
- Possibility of second (central) warehouse level (cross docking for distribution)
- Aggregated view on outbound flows

- Inclusion of a forward looking frequency decision for inbound transports
- Capital cost for stocks

The observation on historic growth of warehouse structures, however, cannot be translated into the model due to complexity and data availability reasons. Instead a greenfield approach is used in the heuristic.

Supply path decision

The supply path incorporates the possible usage of warehouses and transport links. Therefore, decisions are based on warehouse structures and frequencies on links.

Two main observations were made, the first one on alternatives, the second one on the level of cooperation and costs considered:

Two main alternatives were distinguished in the expert interviews: direct delivery versus delivery via the warehouse of the food retailing company. Looking at further details, several sub alternatives can be formulated by potentially using additional warehouses or reloading points of logistic service providers, wholesalers, the supplier, or the retailer.

Which supply path is taken, finally depends on several actors, at least supplier and food retailing company; in some cases also logistic service providers and wholesalers. Logistic questions are part of negotiations between the actors that also include many non logistic topics like prices, sold quantities and payment conditions. If these negotiations result in an optimal logistic decision (minimum of total logistic cost) is difficult to say. Measures like logistic discounts or minimum order sizes, that were mentioned before, show that incentives are set by suppliers that the retailers include all logistic costs into their consideration. In one expert interview with a retailer the explicit consideration of cost of the overall supply path was reported as current practice.

During interviews examples of lacking cooperation were reported especially by suppliers. The reason for a potentially negative perception of a practice that tries to optimize the overall cost of the supply path by some actors is the following: the basis for the comparison of different supply paths are the average costs resulting from the actual state of the logistic system. But, if based on the isolated consideration of single commodity flows, many commodity flows are rerouted to other paths, the bundling possibilities for the remaining commodity flows become worse and the total costs for the actor increase. This circle can be changed by either the inclusion of negative effects on the system into the calculation, which is very complex and therefore hardly feasible or by referring to higher level logistic decisions that include all commodity flows of the actor.

As a result of this decision, experts reported that mainly commodity flows of small quantities are delivered directly. This fits well with the observation that there is rarely direct delivery for discounters. As already mentioned perishability is another reason for direct delivery, an example for this is fresh bread that is delivered directly. Another driver for direct transport is the existence of good alternative regional distribution systems like wholesalers of beverages. Finally, direct deliveries also occur without a logistic reasoning, for example, if the supplier pushes for a direct contact to stores.

For SYNTRADE four possible paths are modeled. The decision is based on an optimization of total logistic cost for the supply paths of individual commodity flows, taking average cost of the actual logistic systems.

Frequency decision

For food retailing companies two main sorts of frequencies can be distinguished: firstly, the frequency of distribution to stores or end consumer and secondly, the frequency between production locations and warehouses.

For the distribution, the decision is taken integrated with tour planning. According to the expert interviews, the delivery frequencies to stores are rather fix. The storage facilities within the stores are usually limited and stock is almost exclusively limited to the goods in shelfs in the selling area. This shows that the systems are based on a high delivery frequency.

The frequency for inbound transports to warehouses of the retailing company is determined within the negotiations on the supply path and through adaptations within day-to-day operations. If the dispatcher in the warehouse realizes that the order sizes get too small or too large, he changes the inbound frequency. For the transport between supplier and warehouse, in most cases full loads were reported, for small lot sizes suppliers from the expert interviews used LSPs, that bundled the goods. Concerning the costs, the expert interviews show that transport and storage cost as well as capital cost caused by stock are considered. However, this is not done within an integrated calculation but through negotiation between supplier and food retailing company or even between logistic and purchasing department within the food retailing company.

In SYNTRADE, a daily delivery to the stores for all products is assumed for the food retailing companies not distinguishing what product categories are delivered at each specific day. But for direct delivery and for transport within a two layer warehouse structure, the lower frequencies (once or twice a week) are taken into account for different article groups. An explicit modeling of the distribution frequency decision for outbound transports is not done since it is assumed that the system state of high frequencies in retailing distribution is stable in German retailing.

Frequency decisions for other transport links between suppliers, warehouses of interregional and local logistic service providers and retailing warehouses are modeled. The decisions are always modeled considering the total loads on links. Warehouses at start and destination point are assumed to provide possibilities for buffering and perishability is considered for each commodity flow.

3.4 Conclusions

In this chapter, an analysis of freight transport demand in general and of logistics in and around the food retailing sector was carried out.

In the general system analysis, mesostructures were identified representing the result of optimization in logistic systems. Logistic systems are the elements that translate freight transport demand from economic activity into demand of the transportation system. Logistic decisions determine the scope and the conditions of this optimizations. These decisions can be listed and ordered into hierarchical levels. However, interdependency between levels and the occurrence of decisions in practice is specific to the economic activity under consideration.

Therefore, a more specific analysis was carried out for the food retailing sector, based on a wide range of empirical data. Open knowledge spots in the area of the actors' behavior were filled by expert interviews. Based on the analysis, covering the food retailing sector and adjacent economic activity, following logistic decisions were identified:

- Warehouse structure decisions for retailing companies, including forward looking decisions for lower decision levels,
- Supply path decisions, based on average cost of included logistic systems,
- Frequency decisions on bundled flows between suppliers and warehouses of retailing companies, wholesalers, and LSPs.

Special attention has to be paid to the impact of perishability of goods.

With this detailed analysis, this chapter described the basis for the design of the SYNTRADE model defined in chapter 5.

4 Existing models in literature

In this chapter existing modeling approaches in literature will be discussed. This has two objectives: The first one is to clarify the innovative elements of SYNTRADE compared to existing models. Therefore a review of existing freight transportation models will be conducted. To keep the discussion on individual models precise, there is an short introduction to general modeling methodologies at the beginning of this chapter. The second objective of this chapter is to introduce methodologies from literature used within SYNTRADE. This relates especially to approaches from logistic optimization used to model logistic decisions within SYNTRADE, a separate section will be devoted to this area.

The chapter will start with a general definition of models, in order to structure the following discussion. Then general modeling methodologies will be introduced shortly, a separate section will describe approaches from logistic optimization. Afterwards the review of existing freight transportation models will be conducted and at the end of this chapter, conclusions for the SYNTRADE model will be drawn.

4.1 Models

A model is a simplified representation of reality. There are physical models and abstract models. In the context of transportation system analysis, abstract formalized models are used. They are defined by formalized descriptions in form of specifications and computer programs. The specifications consist mainly of mathematical formulas or conceptual diagrams (see Ortùzar and Willumsen (1990), p.2 for details). Models can be characterized by their purpose, their scope and the methodology used.

Depending on the purpose, a model can either describe system behavior or explain system functioning, which is visualized in figure 4.1. Models that focus on the description

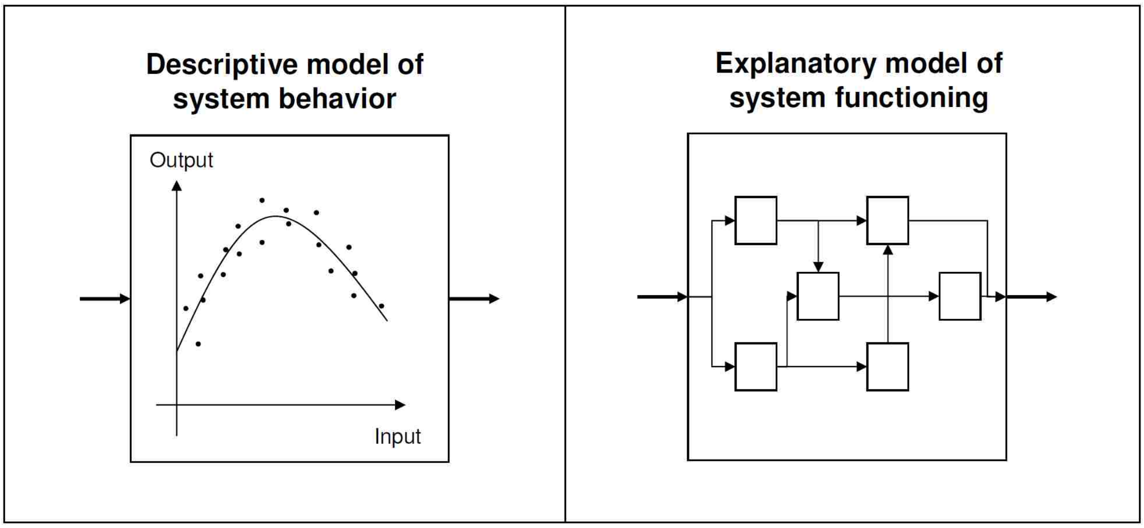

Figure 4.1: Descriptive versus explanatory models (oriented at Bossel (1994), p. 54/55)

of the system behavior (descriptive models), consider the system as a black box and try to imitate its behavior based on observed data sets. Thus, the output generated by these models can only represent trends or dependencies that were observed within the data, changes in behavior cannot be covered. Models imitating the functioning of the system on the contrary, try to explain the most important components of the system and their interdependencies that determine the behavior of the system, they are called explanatory models. The purpose of these models can either be to explain what should be done (normative) or what is done (positive). A detailed discussion can be found in Bossel (1994) (p. 52 ff).

The purpose of transportation models is to analyze the behavior of the transportation system (Ben-Akiva et al. (2008), p. 2). If explanatory models are used they are rather positive (not normative) since their objective usually is to understand the transportation system and not to optimize it. The models are, however, applied to test or assess different scenarios and policy measures.

The part of reality covered by the model represents the scope. It can differ, regarding objects (systems/subsystems), activities, choices, time horizon and space horizon:

- Scope of objects: The scope of objects describes which objects are included in a model, but also in what detail they are modeled. A model can refer to very aggregate or disaggregate objects or indicators. In economic models macroeconomic entities like nations, markets or individual economic actors like companies or households may be modeled. Also, it can be differentiated between the overall object of interest whose behavior shall be analyzed by the model (like the overall system) and the objects represented within the model (like components of the system analyzed). A model can, for example, analyze the behavior of a macroeconomic entity, by describing its disaggregate components as in this study.

- Activity scope: A model can focus on different activities of the objects modeled. Depending on the model scope, some activities will be described in detail, some only superficially and some will be left out completely. For modeling transport demand, economic activity and especially logistic activity is of interest.

- Decision scope: If a model describes economic actors like companies or households, the scope may also be defined by the decisions modeled. In a transportation model it often occurs that the modal choice decision is modeled explicitly.

- Scope of time: Another dimension, describing the scope of models can be seen in the consideration of time. This can refer to whether and how (for example to what detail) a model accounts for time. Or it can refer to what time span is included in the model scope. A model that accounts for time is called a dynamic model, whereas a model that does not account for time is called static.

- Scope of space: Finally, also the representation of space can be seen under two points of view: firstly, to what detail space is represented (spatial resolution), and secondly, what the total space included within the model is.

The scope of a model is limited due to processing capacity and data availability. Therefore, as will be shown for the example of freight transportation models, a focus has to be chosen depending on the purpose.

4.2 Modeling methods

Besides purpose and scope, models can also be characterized by the modeling methods used. In this section, modeling methods used in freight transportation models, will be listed. This list serves as preparation to describe existing models later in this chapter, it does not claim to be exhaustive or free of overlaps.

4.2.1 Optimization

Operations research is the research area in applied mathematics that focuses on optimization. It can be characterized as the search for the optimal decision under consideration of constrains in form of optimization problems (Neumann and Morlock (1993), p. 5). Most descriptions of optimization problems in this study are based on literature from this area.

In general, optimization problems can be formulated by a real-valued objective function $f(x), f : V \longrightarrow \mathbb{R}$ and constraints $x \in M$, with $M \subset V, M = \{x \in V : g(x) \leq 0\}, g : V \longrightarrow \mathbb{R}^n$ (Neumann and Morlock (1993), p.40). The objective function has to be minimized or maximized, depending on the formulation of the problem. Depending on the form of V, X, f and g, the type of problem can be defined. A very common type are linear optimization problems. This type can be described in a standardized form:

$$
\begin{aligned}
Min.f(x) &= \sum_{j=1}^{n} c_j x_j \\
s.t. \sum_{j=1}^{n} a_{ij} x_j &\leq b_i, (i = 1, ..., m) \\
x_j &\geq 0, (j = 1, ..., n) \\
c_j, x_j, a_{ij}, b_i &\in \mathbb{R}, \forall i, j
\end{aligned}
$$

It can be solved efficiently using the simplex algorithm. However, many problems have a non linear objective function. Or variables are not real numbers but integer numbers. For these problems the solving process can become very complex.

As described in the last chapter, a convex form of the objective function ($f''(x_i) > 0, \forall i$) leads to a unique solution. This is often not the case for problems in logistics. Also for the above described linear problems the objective function is not strictly convex ($f''(x_i) = 0$), and multiple solutions are possible.

Within economic models, optimization can be applied in various forms:

- It can be the objective of the model to find the optimal design or state of a system. The model can thus be specified in form of an optimization problem. This can refer to the level of economic actors, like for example the optimization of logistic systems of companies, as well as to macroeconomic systems like welfare maximization within a market.
- It can describe the behavior of actors in a model. Assuming rational economic behavior often includes optimization, for example it is mostly assumed for companies to maximize their profits or minimize their costs.
- It can be bases or part of a procedure. For traffic assignment, shortest path search is used. Another example is entropy maximization that can be seen as the basis for the Furness algorithm and the gravity model, described later in this section.

Since the main focus of this study is on logistic decisions, a separate section will describe logistic optimization problems and solution approaches in detail (section 4.3).

4.2.2 Simulation

In general, simulation can be described as the imitation of a real thing, the original (scientific) meaning, however, refers mainly to the dynamic, thus in the original sense, a simulation imitates a real system over time or differently phrased, a simulation imitates one process by another process. The term process at this place refers solely to some object or system whose state changes in time (Hartmann, 1996).

The goal of a simulation is the imitation of a process, not its optimization. It can nevertheless include optimization in sub-models. Simulation can be useful for explaining the behavior or functioning of systems, it can even be useful in case of poorly understood systems (Simon, 1996). In the case of understood systems the mechanisms are known and therefore the simulation can be used to describe implications that can be derived. The reasoning to use simulation for not understood systems lies in the fact that a simulation may concentrate on the essential that causes the phenomenon to simulate and can abstract from the detail (Simon (1996), p.16). Often phenomena in the real world can be simulated just from the knowledge, won from a top down analysis without knowing the systems in detail. Simon, for example, refers to physics or chemistry where behavior of matter was explained before knowing the atomic theory.

It can be differentiated between deterministic and stochastic simulation. In a deterministic simulation, all mechanisms are fix and therefore the development paths of the system stay the same if the input does not change. A stochastic simulation on the other hand incorporates random elements like transition possibilities to a next system state, therefore the outcome can change even if input is stable.

Extension of the simulation concept

Contrary to the narrow definition that connects simulation to dynamic, simulation is often also referred to as the imitation of possible system states (Neumann and Morlock (1993), p. 697).

Thus simulation can be used as heuristic to search for the best system state for a certain objective, which is the interface to optimization. If simulation is used for optimization it is however recommendable to enhance pure simulation by search procedures that change the system states (by varying the models parameters) in a systematic way (Biethahn et al., 2004). Computer simulations can be used to search for good solutions of mathematic models where analytical methods are unavailable (Humophreys, 1990).

Another application is the statistical simulation of a population with certain characteristics. The "Monte Carlo" method (Metropolis and Ulam, 1949) simulates characteristic values, oriented at a stochastic distribution. This can be used to generate artificial populations (of micro objects) with characteristic values that, if aggregated, correspond to the given stochastic distribution. As input, a one or multidimensional distribution of the characteristic values is needed. Based on this, a cumulative distribution function $F(x)$ can be generated and afterwards, by drawing a uniformly distributed random number $z \in [0,1]$, the characteristic value $y = F^{-1}(z)$ can be generated. By repeating this procedure, a population can be generated, whose distribution of characteristic values corresponds to the initial distribution function $F(x)$.

The generation of establishments, described in figure 4.2, can serve as an example for the application of the "Monte Carlo" method within SYNTRADE. Out of the distribution of employees per establishment, a cumulative distribution function is formed. By drawing random numbers, an artificial population of establishments is generated.

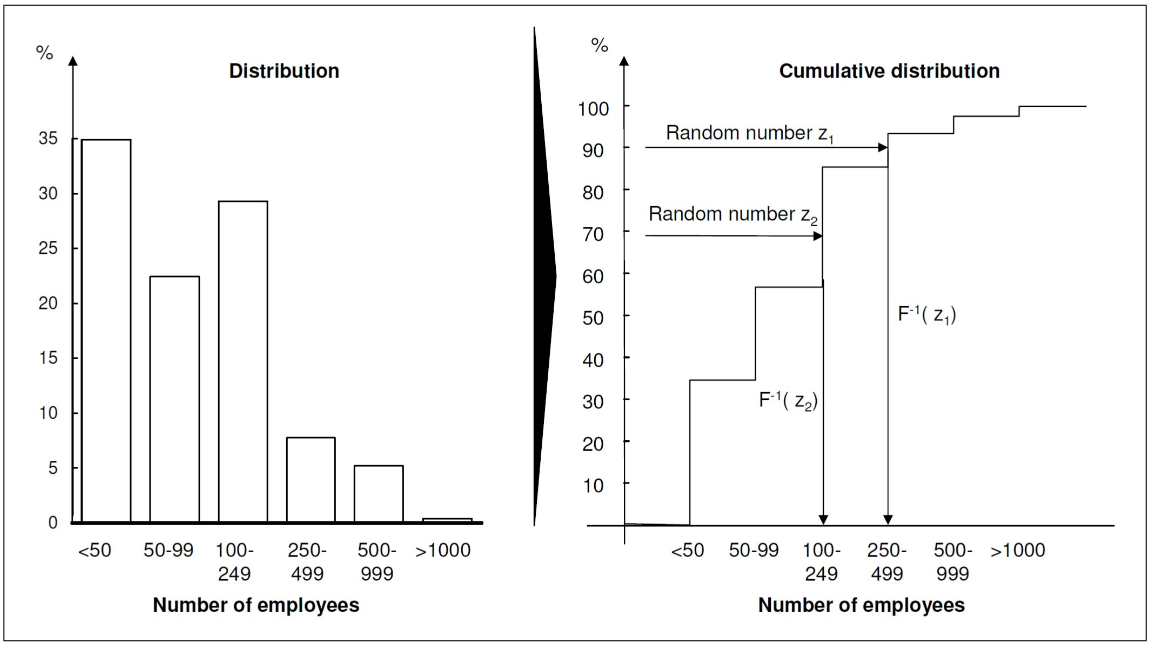

Figure 4.2: Example for an application of the "Monte Carlo" method: artificial generation of establishments in sector 155 (production of milk products)

In micro simulation of passenger transport, the "Monte Carlo" method has already been used for a long time to generate typical households and activity patterns (see for example Zumkeller (2000), p.5-1).

Examples in logistic and transportation modeling

In logistics, simulation, in the (narrow) sense of imitating a process, is widely used. Some examples are:

- In a research project on modeling large networks in logistics, supply chain processes are simulated with consideration of changing organization structures (Bause and Buchholz, 2006).
- The VeloS model simulates material and information flows including road transport within and between logistic establishments for logistic hubs (Goerke et al., 2006).
- Arena is an example of commercial software in enterprises that is used to simulate processes in companies. Simulation of logistic transport processes is one possible area of application. (see for example Stec (2006))

These examples show that simulation in logistics is usually used to model business processes. Mostly, this is done on a very detailed operational level. This kind of detailed simulation cannot be transfered directly to model freight transport demand of whole regions or sectors, therefore another level of abstraction has to be chosen.

In transportation analysis, simulation is often used in models that describe traffic flows on a real time (operational) basis. In this area, commercial software like VISSIM is widespread. An overview on real time traffic simulation is given in Brannolte (2006).

For transportation models that reproduce traffic flows for whole time periods (years, days or hours) the usage of simulation (in the narrow sense) is however rare. For freight transportation, an example on the disaggregate level is the INTERLOG model of Liedtke (2006). It simulates the formation of truck tours and the market interaction between shippers and transport companies. On an aggregate level, the method of system dynamics is an example for simulation, which will be introduced in the next paragraph.

Simulation in a larger sense (imitation of system states), on the other hand, is used by many transportation models. An example within modeling of passenger transportation is the model of Zumkeller (2000) (p. 5-1), which is called a "simulation" model while time is not modeled explicitly - here simulation in the larger sense is meant.

4.2.3 System dynamics

System dynamics is a methodology to explain the dynamic behavior of systems from the combined actions of its components. Since time is modeled explicitly, it can be seen as a form of simulation. The central elements are the dependencies of the components over time modeled as feedback loops: "A feedback loop is identified when a sequence of relations of which the first relation commenced at the system component X reaches the component X again. Usually the sequence of relations leading from X via other system components back to X again incorporates a time structure i.e. commencing at X and feeding back to X would not happen at the same point of time." (Schade (2005), p.7). All dynamics arise from the interaction of these loops with one another (Sterman (2000), p.13 and Schade (2005), p.7).

The methodology was developed by Forrester (1961) who wanted to analyze counter-intuitive behavior of social systems. He assumed that the reason for such behavior are information feedbacks of higher order incorporating non-linearities and the human way of thinking that is focused on first order negative feedbacks (Schade (2005), p.9).

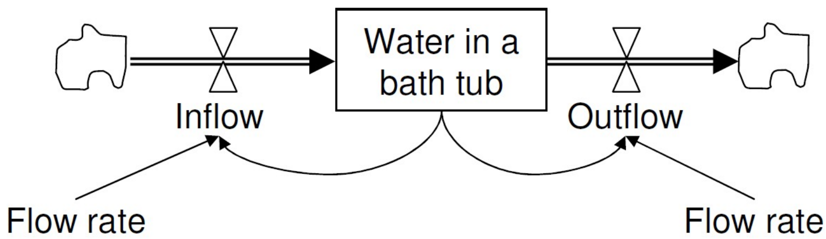

Figure 4.3: Example of a small System Dynamics model: water level in bath tub

The most important elements of a system dynamic model are level variables and flow variables. Their usage can be shown by a very simple model, describing the water level of a bath tub (see figure 4.3): It represents how the water level changes over time depending on the in- and outflow of water. The water in the bath tub is a level variable whose value is defined for specific points in time. Inflow and outflow are flow variables that are defined as a change over a certain time period.

In economics, system dynamic models are often used to describe macroeconomic phenomena. An example of a system dynamics model that focuses on the description of transport within the overall economic activity is ASTRA. It will be described in more detail at the end of this chapter.

4.2.4 Structured estimations and approximations

In many cases, models do not use real data but are based on estimations or approximations. Reasons for this can be limited data availability, data inconsistency or model simplifications.

Model simplifications have to be done due to limitations in computation power and limitations in the ability to handle complexity. Simplifying reality and concentrating on the important aspects is the nature of modeling (see definition at the beginning of this chapter). Quantitative estimates have a long scientific tradition (as researchers like Enrico Fermi show). Nevertheless, the usage of estimations or approximations within a model has to be done in a prudent way ensuring that the model results are valid.

Approaches for estimations are:

- The use of comparable data (or situations)
- Trend extrapolation over time
- Estimation based on a sample of data points
- Expert estimation
- Aggregation of data
- Disaggregation of data

These approaches can often be supported by statistical methods like regression analysis, calculation of frequency distribution parameters or parameter estimations.

In the following two approaches in transportation modeling and logistics are described in more detail: the estimation of value distribution in matrices (a disaggregation approach) and the estimation of distances in idealized space (the use of a comparable situation).

Value distribution in matrices, Furness method and gravity models

The problem of distributing values in matrices can be formulated like this (the following descriptions are based on Ortùzar and Willumsen (1990) p. 151 ff):

Given is a Matrix T with the matrix values T_{ij}, the column total $O_i$and row total D_j are given so that

$$\sum_j T_{ij} = O_i$$

$$\sum_i T_{ij} = D_j$$

The problem is to find a distribution of values T_{ij} that satisfies the constraints and resembles the distribution in reality.

This problem occurs at different occasions in transportation modeling. Very common is the distribution of trips which is also reflected in the chosen naming of the variables (T like trips, O like origins, D like destinations). But also in other areas like the estimation of trade matrices, this problem occurs. In this study, the problem can be found within the distribution of total turnover in food retailing to assortments and store types, as well as within the distribution of turnover between production companies on the one hand, and consuming regions or retail stores on the other hand.

The following approaches are described below: the "Furness" method and the gravity model.

In the "Furness" method, two factors a_i and b_j determine T_{ij} based on given matrix values t_{ij}:

$$T_{ij} = t_{ij} * a_i * b_j$$

These given values can contain existing information on the matrix structure, for example they originate from historic data. Now, factors have to be chosen in a way to fulfill the constraints, given by the row and column totals:

$$\begin{aligned} \sum_j t_{ij} * a_i * b_j &= O_i \\ a_i &= \frac{O_i}{\sum_j t_{ij} * b_j} \end{aligned}$$

and

$$\begin{aligned} \sum_i t_{ij} * a_i * b_j &= D_j \\ b_j &= \frac{D_j}{\sum_j t_{ij} * a_i} \end{aligned}$$

This can be done by following an iterative process:

1. Set all b_j=1.0 and solve for a_i.
2. With the latest a_i solve for b_j.
3. Keep the b_j's fixed, solve for a_i and repeat steps (2) and (3) until all changes can be neglected.

The two main advantages of this method are the generation of converging solutions after a small number of repetitions and the minimum correction to the origin matrix structure t_{ij}.

The idea of gravity models originated from gravitational interaction is described in Isaac Newton's law of gravity. It additionally (to the Furness method) assumes a certain "deterrence" function $f(c_{ij})$. This function causes that for pairs (i,j) that have a higher c_{ij}, representing costs or distances between i and j, the matrix values T_{ij} get lower. This function $f(c_{ij})$ usually has a decreasing form. Popular functions are exponential functions ($f(c_{ij}) = exp^{(-\beta c_{ij})}$) or power functions ($f(c_{ij}) = c_{ij}^{-n}$). The matrix values can then be calculated as:

$$T_{ij} = t_{ij} * a_i * b_j * f(c_{ij})$$

The procedure to adapt the values to column and row total works similar to the "Furness" method.

The gravity model approach is often used, since the described behavior of the model (decreasing activity caused by higher distance or cost) can be observed in trade or passenger traveling.

Estimation of distances

In some cases it can be sufficient to work with approximated distances instead of using the exact values. The advantages are a simplification of complexity for calculation and a reduction in data needs. In the case of warehouse structure determination in SYNTRADE, for example, it is sufficient to determine approximated distances since the important effect on the warehouse structure is already reflected in the approximated numbers and input data only represents approximated spatial information.

In figure 4.4 the average distances from a circle center to points within the circle area with the radius R, the average distance between two points within a circle with the radius R and the length of an idealized distribution tour are shown.

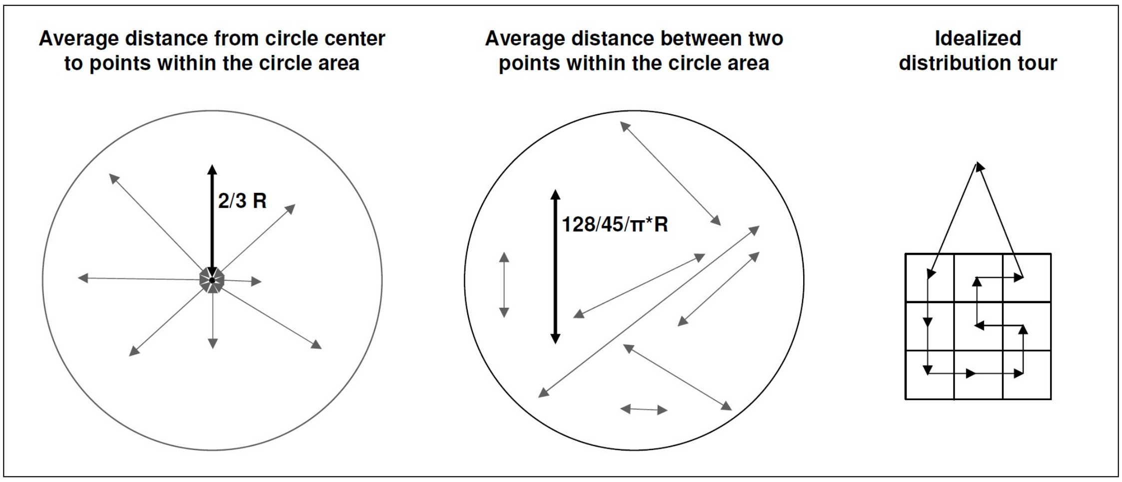

Figure 4.4: Approximations for average distances

These distances are used as approximations within SYNTRADE: The first one is used as a basis to calculate the average distance between a warehouse and a store in the service area ($dwp_{average}$). Considering a detour factor of 1,23 in Germany it can be written as:

$$dwp_{average} \cong 1,23 * 2/3 * R = 1,23 * \frac{2 * \sqrt{A}}{3 * \sqrt{\pi}} = 0,46 * \sqrt{A}$$

This formula corresponds to the one published by Gudehus (Gudehus (2006), p.234, formula 34), it can easily be derived based on geometric considerations (see appendix A.4).

The second can be taken as an approximation for the distance between two locations (dtl) within an area, again a detour factor of 1,23 is taken into account.

$$dtl_{average} =\cong 1,23 * \frac{128}{45 * \pi} * R = 1,23 * \frac{128 * \sqrt{A}}{45 * \pi * \sqrt{\pi}} = 0,63 * \sqrt{A}$$

A detailed derivation of the basic formula can be found in CZuber (CZuber (1884), p. 196, problem IX).

Finally, the length of a distribution tour can be estimated, following the assumptions that the n stores that have to be served are equally distributed in the service area, the service area has a quadratic form and it can be divided into n squares, where each one has a store in its center (see figure 4.4). Thus, the length of the distribution tour (ldt) can be estimated as:

$$ldt \cong 2 * dis + (n-1) * \sqrt{A/n}$$

where dis means the distance from a store to the warehouse.

4.2.5 Modeling of equilibria

A system equilibrium can be described as a system state where driving forces equalize another. An example was discussed in section 3.1.5, describing the equilibrium of traffic flows. Modeling can take advantage of the existence of such equilibria and use them to describe likely system states. Examples are:

- Batch size models (like Harris (1913)) with the cost optimum, describing a state where marginal ordering costs and marginal inventory holding costs are equal,
- Models of traffic assignment to transport infrastructure use the equilibrium mentioned above,
- Economic analysis of markets that are based on the equilibrium between supply and demand.

Models describing the overall economic activity, using equilibria, are widespread. In the following, General Equilibrium models and Input Output models will be introduced.

General Equilibrium models

General Equilibrium Models describe the overall economic activity of a country or region, based on market equilibria. An example of a very simple model from Ginsburgh and Keyzer (2002) and the according definition of a general competitive equilibrium can be found in appendix A.2

Prices and volumes on the markets for commodities are determined, assuming that producers maximize their profits and consumers maximize their utilities. In the equilibrium, all markets are in an equilibrium. To analyze phenomena of transport in such models, space in form of different regions has to be described explicitly. Spacial computable general equilibrium models (SCGE) do so (see Koike et al. (2009)). An example of a SCGE model is the RAEM model, developed in the Netherlands (see Osterhaven et al. (2001)). The extension of SCGE models is reflected by variations of price across different regions, caused by cost for transport and communication, delivering the product.

Input-Output analysis

The input-output analysis is a method of describing the interrelationship among the sectors of the overall economic system (see Leontief (1986), p.19). An "Input-Output" table describes the flows of goods or services between the sectors over a period of time, the corresponding input-output statistic mentioned earlier contains the monetary values of these flows for Germany. A short definition of an Input-Output model is given in appendix A.3.

Equilibria are used in the sense that flows in and out of a sector have to be equal, so the origin and the usage of commodities is explained: This equilibrium is different to the market equilibria in general equilibrium models.

To be able to include aspects of transport into this analysis, space in form of regions has to be included like Multi Regional Input Output models do (see for example Cascetta et al. (2008)). In addition to the technical coefficients, trade coefficients are introduced, indicating from which region the input originates or to which region the output of a sector is destined (see Cascetta et al. (2008)). Aspects of transport can be integrated into the estimation of these coefficients. An approach, called "random utility-based MRIO", simulates variations in trade coefficients through a discrete choice model where for example transport costs can be included (De la Barra, 1989).

Comparison of General Equilibrium models with Input-Output analysis

Both model types, general equilibrium models as well as the input-output models, describe the interdependencies of an overall economy, but they are based on different approaches; general equilibrium models on microeconomic market equilibria and IO models on flows within an economic system. For their application in modeling, Koike et al. (2009) state that a main difference is that IO models describe the distribution of total demand, whereas general equilibrium models describe the total demand itself.

For the application in the area of transportation modeling this means that effects of transport on economic activity are modeled differently. While the consequences on demand can be described in general equilibrium models, input-output models would stick to the same final demand. This is due to the way interrelations between sectors are modeled. In Input Output models they are assumed fix through the coefficient matrix, in general equilibrium models the technology set and the utility function can describe a change in sector relationships.

4.2.6 Discrete choice

Discrete choice models are often applied to describe modal choice in transportation analysis. The basis for these models is the random utility maximization (RUM) theory. An overview on the history of methodological development can be found in (McFadden, 2001). The connection of discrete choice models and entropy maximization (and therefore for example gravity models) can be found in Anas (1983). The basic model forms (MNL and nested logit models) and a list of methodological extensions and their main advantage are introduced in appendix A.1 oriented at Ben-Akiva and Bierlaire (2003).

The main challenges for the application of discrete choice models in freight transportation are the heterogeneity of actors (decision parties) and the diversity of alternatives in freight transportation. In the formulation of the multinomial logit, this is reflected in a large number of alternatives and in attributes that are specific to certain individuals. Causes for heterogeneity and diversity in freight transportation are:

- Differences of alternatives (between individuals): Individual companies have different logistic structures and different possibilities of bundling commodity flows.

Also, supply of logistic services for specific regions or transport markets differ. Therefore, the alternatives of logistic services can be very different depending on the individual (company).

- Diversity of possible alternatives: The alternatives in logistic decisions are often of continuous and not of discrete character (for example for batch sizes). Or numerous discrete alternatives exist like for combinatorial problems, for example the warehouse location problem.
- Differences in preferences resulting from economic activity: As an example one can easily imagine that capital cost and therefore the discount rates differ between sectors.

To handle this heterogeneity in discrete choice models for modal choice, often segmentations by sectors or by lot sizes are undertaken and advanced discrete choice models are defined. A recent study (Park, 1995) uses a mixed logit model combined with latent variables to construct a decision support system for a railway company. In this study, the approach of minimizing total logistic cost and a mixed logit model with latent variable are combined. Logistic cost components are taken as explanatory variables and qualitative influences like flexibility and quality are modeled in form of latent variables. Unfortunately, since the empirical data on lot sizes was not available, storage costs, which are a very important logistic cost component, could not be considered. Probably, this explains to a large extent the high weight, given to the latent variables.

As this example shows, there are attempts within discrete choice modeling to solve the problem of heterogeneity at least for the modal choice decision. However, these models get very complex and have high data needs, because of the heterogeneity of actors and alternatives specified before. Such data was not available for this study. The author also believes that the solution to the problem of heterogeneity lies in the detailed description of logistic optimization, that includes combinatorial problems, non linearity and a continuous solution space instead of discrete alternatives. This way, available data sources can be used that are not considered by existing models.

4.3 Logistic optimization models

In this section existing models of logistic optimization problems will be discussed with regards to an application in SYNTRADE. Since cost minimization usually is the objective function of these problems, logistic cost components will be defined first, then models of specific logistic decision problems will be discussed. Referring to the framework of choice levels in the last chapter (figure 3.9), the main focus will be on the level of average lot size/frequencies and of warehouse structure choice. The discussion on lot size models will partially include the neighboring levels of supply path and mode choice as well as the operative level of dispatching choices. The usability of the presented approaches within SYNTRADE is discussed out of two perspectives: does it represent reality in food retailing and is the modeled matter worth the computational effort to be invested.

4.3.1 Logistic costs

Objective functions in logistics are primarily of monetary nature like operating and investment cost, service cost or return on invested capital (Gudehus (2004), p. 114). Non monetary objectives like improvement of performance, services and quality, mostly are modeled as constraints or in a monetarized form like risk cost for the case of late delivery.

This study focuses on cost minimization. Costs as well can be described in different ways, for example by activity (transport, warehousing, etc.) or by cost positions (personal, buildings or racks, fuel etc). Most interesting for the purpose of optimization modeling is the allocation to activities. Common categories are shown in table 4.1 (for more detailed discussions see Gudehus (2004) p. 148 ff, Beuthe et al. (2004) or Park (1995), p.87/88)).

	Notation	Description
Transport Costs	TC	All costs connected with the transport activity (e.g. costs for driver, truck, etc.)
Storage Costs - Cycle stock - Safety stock - In transit stock	SC	All costs connected with the storing of goods, including the costs for warehousing (WC) and capital cost (CC). Storage costs can occur for cycle stock, safety stock or in transit stock (in this case no warehousing costs occur)
Ordering- and Handling Costs	OHC=OC+HC	All administrative costs connected to order goods (OC) and all costs connected to the handling of goods (HC), meaning preparation for transport or storing, bundling and commissioning
Risk Costs - Out of stock - Obsolescence - Spoilage - Loss and damage	RC	Costs resulting from unplanned events like demand fluctuations, accidents or delays. Safety measures (e.g. safety stock or time buffers) are taken to avoid some of these costs.

Table 4.1: Logistic costs by activity

The following differentiations are of interest as well:

- Marginal versus average costs: Marginal costs mark the change in total costs if one more unit is produced, whereas the average costs is the total costs divided by the units produced. The definition of which costs are marginal can differ, depending on the scope of decision.
- Fixed versus variable costs: Fixed costs are not dependent on the number of units produced, variable costs can be allocated directly to units.
- Investments versus operating costs: These two terms refer to expenses (cash outflow) over time. Operating costs are those expenses, that occur during operation while investments occur at certain points in time, for example initially to buy a machine.

The necessity of this discussion can be clarified with the example of the decision on lot sizes: for the optimization, a cost rate for storing the goods has to be assumed. Given are two decision situations: in the first situation, the warehouse is taken as given and its capacity is not fully used. In the second situation, the lot size decision is taken in the context of sizing the capacity of the warehouse. Economic theory recommends to take the marginal costs. In the first situation, the marginal costs are the variable part of the operating costs. In the second situation, however, they consist of the variable part of investments and operating costs, the variable part of investments is included since this money could be saved in case the capacity is not used.

4.3.2 Lot size optimization

This subsection will give an overview on existing models for lot size optimization. The goal is not to establish a complete list of models in this area[1] but to discuss possible extension to the basic EOQ model within SYNTRADE. Therefore the application within SYNTRADE will be discussed for each model category.

Basic EOQ model	Extensions	
Static	Dynamic	
Constant demand	Fluctuating demand	
	Deterministic	Stochastic
Constant lead time	Fluctuating lead time	
	Deterministic	Stochastic
Constant cost parameters	Variable cost parameters	
Constant price	Variable price	
One product	Multiple products	
One level structure	Multiple level structure	
Unlimited resources	Capacitated resources	

Table 4.2: Possible characteristics of EOQ models (some dimensions based on Toporowski (1996))

The basic EOQ model

The basic EOQ (economic order quantity) model serves as a starting point of discussion. According to Within (Within (1957)), several authors arrived at this formula during the 1920's while searching for methods of determining optimum inventory levels (see Within (1957), p. 32 for details[2]) . The costs (C) connected to the lot size are separated in two sets of cost factors: those costs that increase (that we call inventory cost C_I for simplification) and those that decrease (that we call ordering cost C_O for simplification) with increasing lot size. The economic lot size is then determined by balancing these two sets of costs. Let X be the expected flow of goods (physical units per year), Q the lot size and p the price per unit. The increasing costs are expressed by a rate on the bound capital r_S, representing

1 For a more complete lists of EOQ models refer to Fuchsenberger (2009)

2 Other sources refer to Harris (1913) as the first author describing this basic model

costs like inventory costs or capital cost, and the set of decreasing costs are represented by costs per order c_O representing costs for ordering or transport:

$$C = C_I + C_O = \frac{Q}{2} pr_S + \frac{X}{Q} c_O$$

The optimal lot size (Q*) can be calculated by setting the derivate equal to zero and solving the resulting equation:

$$Q* = \sqrt{\frac{2Xc_O}{pr_S}} \tag{4.1}$$

This model was extended in many ways, an overview of possible characteristics is given in table 4.2. In the following all characteristics will be discussed shortly.

Dynamic models on the operational level

Dynamic models include the explicit description of time. The basic EOQ model remains static. But on the operational level, questions of timing are of high importance since demand fluctuations have to be taken into account. Thus, a decision maker on the operational level[3] (choice level of dispatching) estimates expected demand in future time periods and adapts his order quantities accordingly. This is reflected in dynamic models (see Wagner and Within (1958)). In these models the demand and costs of the current and coming time periods are modeled explicitly. An example of a model formulation is given in appendix A.5.1. The dynamic reflects the requirements of the day-to-day ordering process (dispatching level in the choice hierarchy). Referring to the framework of choice levels, this reflects the lowest level (dispatching).

Since the focus of SYNTRADE is on the warehouse structure decision and the usage of dynamic models implies a high need for detailed data and processing capacity, the lot size model within SYNTRADE is static. It only describes the lot size decision (frequency decision) on a mid term basis with an average demand.

Fluctuations

Fluctuations can occur in demand as well as in lead time (time from ordering to receiving a good). Examples of identifiable reasons behind demand fluctuations in food retailing are promotions or seasonal events (e.g. Christmas). Reasons for fluctuation in lead time can be delays in transport or production.

Important for the modeling of fluctuation is the distinction between deterministic and stochastic fluctuation. In the deterministic case, the demand fluctuates in a way that can be predicted. Such deterministic demand fluctuation was already covered by dynamic models. More difficult to handle, however, is the stochastic case, representing fluctuations that only occur with certain probabilities. In the example of increased demand in food retailing at Christmas, the exact quantities cannot be predicted, special influences like cold weather may change demand for certain products. Therefore, stochastic elements can be included in lot size models. Figure 4.5 shows the effect of stochastic fluctuation on the stock level. Within this figure, different developments of the stock level depending on

[3] See interviews with dispatchers in warehouses in Fuchsenberger (2009)

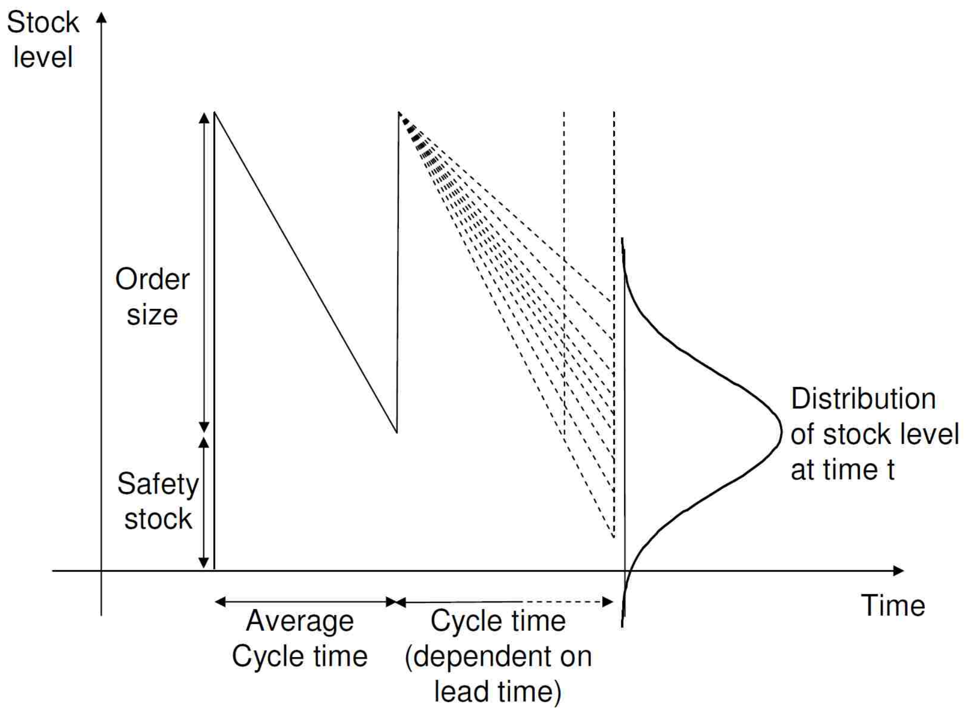

Figure 4.5: Stock level with stochastic fluctuations (adapted from Arnold (2003), p.151)

fluctuations in demand and lead time can be seen. It also becomes clear that the stock level is the result of a combination of both fluctuations. There has been a lot of discussion on the form of the distributions, especially, wether assuming a normal distribution is appropriate (see for example Tyworth and O'Neill (1997) for details). A critical discussion is especially useful when events are seldom, since the Gaussian distribution is not a good approximation in these cases.

The aspect of stochastic fluctuation can be included in static as well as dynamic models. In appendix A.5.2 the formulation within static models is given.

In SYNTRADE, an average demand is assumed and thus, fluctuations are not considered explicitly. Since the quantity of safety stock is small in comparison to the usual cycle stock the impact of this simplification on the warehouse structure decision is minor, therefore the simplification is justifiable.

Variable cost parameters

Cost components can be described in different forms and levels of detail depending on the focus of the modeling activity. In contrast to the basic model where cost parameters are modeled in a constant form (interest rate and unit cost), these costs are often variable. In this study especially the modeling of transport costs is of interest. By describing these costs in a variable form - differentiating cost levels for different distances and lot sizes - synergies from bundling can be described.

A classic model, combining lot size (inventory) considerations and transport mode choice, is the model of Baumol and Vinod (1970), who considers direct shipping costs, total in transit carrying cost, ordering cost and the recipients' inventory cost. The focus of this model, however, is mainly on the transport selection and the resulting transport demand and transport costs are differentiated by transport mode. There are many models that follow this approach, Tyworth (1991) gives an overview on the inventory approach in transport selection models.

To further explain transport costs, the activity on the transport supply side can be described. This leads to tour planning models (see Dethloff (1994) for an overview of classical routing and scheduling problems). The INTERLOG model (Liedtke, 2006) includes such an explicit description of tour building and uses the result to model the interaction between shippers and carriers. This is, however, too detailed for the focus of SYNTRADE. Therefore an approach was developped that includes the potential of bundling:

A transport cost matrix, differentiating transport costs by distance (in km) and lot size (number of pallets) transported, is taken as basis (see table 4.3).

Transportation costs in EUR

Number pallets	Km 25	125	225	325	425	525	625	725
1	69	74	79	84	89	94	99	105
5	91	113	135	158	182	206	231	256
10	117	157	199	241	285	329	374	420
15	142	198	255	314	373	434	497	560
20	167	235	305	377	450	525	601	679
25	191	269	350	432	516	602	689	779
30	214	301	390	480	573	667	764	863
33	228	319	411	506	603	702	803	906

Table 4.3: Transport cost matrix based on real data (33 pallets = full load)

The discrete values are not taken directly as model input, since solving the lot size model fast (for a large amount of cases) needs a cost description that allows an analytic solution, as in the basic lot size model. Therefore, a functional form describing transport costs for different lot sizes is chosen. The approach is shown in the following:

The unit cost per order is described in a functional form $c_O(Q)$. The functional description $c_O(Q)$ is chosen in a way that the equation still is solvable analytically with C_{full} representing the cost for a full load truck:

$$\begin{aligned}
C = C_I + C_O &= \frac{Qp}{2} r_S + \frac{X}{Q} c_O(Q) \\
&= \frac{Qp}{2} r_S + \frac{X}{Q} (\alpha Q + \beta Q^{\gamma}) C_{full} \\
\frac{\delta C}{\delta Q} &= \frac{p r_S}{2} + X C_{full} \beta (\gamma - 1) Q^{\gamma - 2} = 0 \\
Q^* &= \left(\frac{p r_S}{2 X C_{full} \beta (1 - \gamma)}\right)^{\frac{1}{\gamma - 2}}
\end{aligned}$$

where

Q	=	Lot size
p	=	Price of goods
r_S	=	Cost rate for storage costs
X	=	Volume of goods
$c_O(Q)$	=	Volume dependant ordering costs
C_{full}	=	Costs for full load transport
α, β, γ	=	Model parameters

This way the costs per unit are described in a lot size dependent manner while keeping the model analytically solvable. The model is calibrated based on the cost matrix data using the least square method. The parameters change for different distances as can be seen within the matrix data by normalizing it by the full cost rate (cost for 33 pallets). This is shown graphically in figure 4.6.

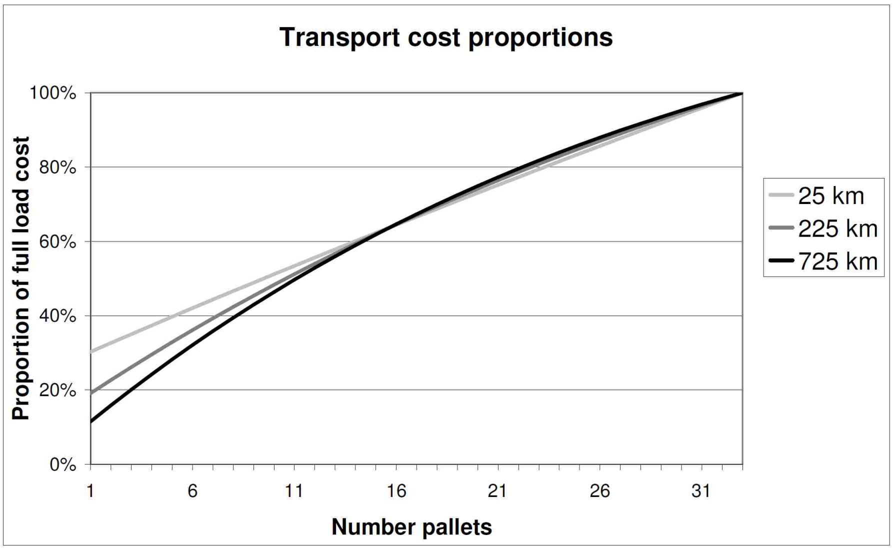

Figure 4.6: Full load transport cost proportions for different transport distances

The graph shows that with larger distances the transport cost proportion for small lot sizes gets lower. This is plausible since for larger distances possibilities for bundling increase. The curves do not start on a certain level reflecting costs that are not specific to the lot size, like costs to get to the loading point.

Variable article prices (quantity discounts)

As costs, also prices p of goods can be variable and dependent on quantity Q especially due to quantity discounts. Some lot size models like Tersine and Toelle (1985) account for these price variations. In these models, costs for purchasing the goods are included in the lot size optimization:

$$C = p(Q)X + \frac{Qp(Q)}{2}c_S + \frac{X}{Q}c_O(Q)$$

In literature, two forms of discounts influencing the price function are distinguished: unit discounts and incremental discounts. For both, there are certain quantities Q (price breaks) where the prices change. For the all unit discount case, this reduced price applies to the overall quantity, for the incremental price only to the quantity above the price break. The total cost function for the first case is represented graphically in comparison with the basic EOQ model in figure 4.7. For the solution procedures costs at price breaks Q_i have to be analyzed, considering the stepwise form of the cost curve (see Tersine and Toelle (1985) for details).

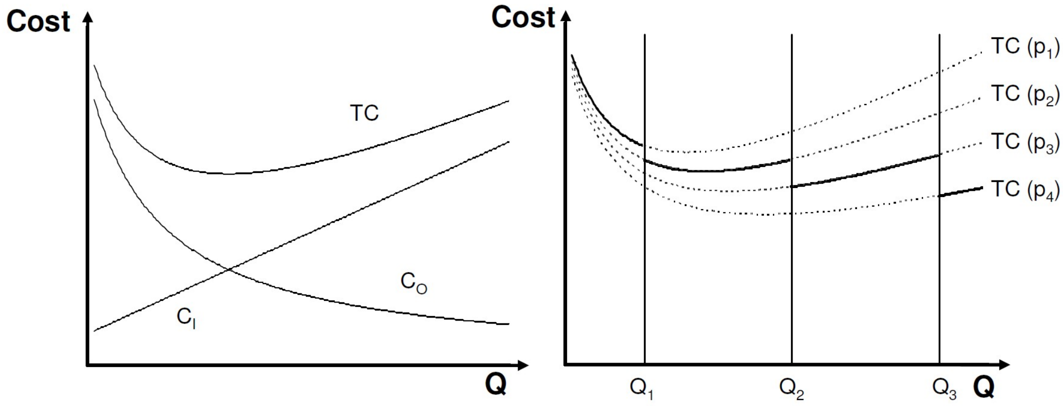

Figure 4.7: Cost course of EOQ model with quantity discounts

In food retailing prices are usually negotiated for quantities consumed in whole time periods (e.g. one year) and not for single orders. Nevertheless, in expert interviews conducted for this study, two kinds of price variations influencing lot sizes could be observed: major market price changes (coffee) and so called "logistic discounts". In the first case, the retailer put goods on stock because of a major price increase. Nevertheless, this was a unique event and did not influence the average lot size, besides that there was no delivery as long as there was stock left.

In the second case, "logistic discounts" were allowed for large lot sizes, comparable with the all unit discount case above. These discounts are given by suppliers to avoid small orders by the customer, leading to small lot sizes and high transport costs. This can be seen as a mechanism to balance out the fact that not the overall total logistic costs are optimized by the actors, but that supplier pay for transport costs and food retailing companies for storage costs. Another mechanism of this kind lies in the price negotiation, where logistic aspects can play a role. Assuming that these mechanisms work, the final lot sizes correspond to the lot sizes that results from an overall optimization of total logistic costs, as it would be done in a cooperative setting.

SYNTRADE assumes cooperation (or efficient mechanisms like "logistic discounts" or price negotiations). Therefore, lot size determination is modeled by total logistic cost optimization and "logistic discounts" have not to be considered.

Multiple products

To introduce to this problem category, the joint replenishment problem (JRP) is described, representing a typical case of a lot size model that explicitly considers multiple products. This problem represents the deterministic case with product specific ordering cost. Other models, including aspects like fluctuation (deterministic and stochastic) or resource restrictions, will not be discussed in detail (see Assfalg (1976) for a detailed discussion).

The Joint Replenishment Problem considers for each product i the demand X_i, the price p_i, the storage cost rate r_{Si} and the ordering cost c_{Oi} additionally to the general ordering cost c_O. Instead of Q the time period T of one delivery cycle is optimized, which can be easily translated by $T = Q/X$. Furthermore the individual cycle times of products can be chosen as multiple k_i of T, with k being the vector of all multipliers. The problem can be written as mixed integer problem:

$$\begin{aligned} \text{Min } C(T,k) &= \frac{c_O}{T} + \sum_i \left(\frac{c_{Oi}}{k_i T} + \frac{1}{2} r_{Si} p_i k_i X_i T\right) \\ T &> 0 \\ k_i &\geq 1, \forall i\ k_i \textit{ is an integer} \end{aligned}$$

For solving this problem not only an optimal T has to be determined but also the optimal k_i. This can not be done analytically, numerical procedures have to be used (see for example Porras and Dekker (2006)).

In food retailing, differences in costs between articles for the direct "ordering" activity do not exist. However, for all articles costs for receiving and moving goods into shelves can increase with decreasing article lot size - costs for putting six packages into a shelve are the same as putting only one package into the shelve. This would imply to model a standard $c_{Os} = c_{Oi}$ for all i.

Still, this problem has to be solved by numerical procedures (k_i are integers) which is very processing intensive. Therefore, in SYNTRADE, following simplifications are made: only lot size decisions to warehouses are modeled, where this problem is assumed less important, since the number of articles bundled is lower. Delivery frequencies to stores are assumed to be fix, individual article delivery frequencies to stores are not modeled.

For lot size decisions of flows to warehouses only general ordering costs are considered, the costs for receiving and putting into shelves are assumed to be linear to the number of pallets and thus, independent of the lot size. This is a major simplification, since, also in a warehouse, costs can increase if article lot size are bellow a pallet. For these cases, it is assumed that ways are found to avoid this, like multiple articles on a joint pallet for picking or store packages with multiple articles (e.g. different sorts of chocolate). For the overall incoming flow bundle a minimum lot size of one pallet is assumed.

Assuming only general ordering costs, $k_i = 1 \forall i$ gets optimal. This can be shown easily: imagine a cycle time of T is set, without individual ordering costs, the solution can be improved by choosing a k as low as possible. This results in a formula for optimal T which can be reformulated to the standard EOQ model that just considers the group of products as an average product with average price (assuming the storage cost rate is equal for all products):

$$T^* = \sqrt{\frac{2c_O}{\sum_i r_{Si} p_i X_i}} = \sqrt{\frac{2c_O}{X \bar{p} r_S}}$$

or

$$Q^* = \sqrt{\frac{2c_O X}{\bar{p} r_S}}$$

In SYNTRADE the one product EOQ model is applied to bundled flows, composed of many products. This results in an optimal batch size for the overall bundle (assuming individual article ordering costs are not relevant). A remaining problem within SYNTRADE is the split of logistic costs of these flow bundles to individual article flows. This problem will be discussed in section 5.2.1, in the next chapter.

Multiple level structure and cooperation

The consideration of multiple levels is closely related to the aspect of cooperation. Including two or more parties into the optimization, often means to map several levels in a model. Extending this idea further, by also including neighboring decisions like the supply path decisions (Blumfeld et al., 1985) or even warehouse location decisions, results in modeling higher choice levels.

Two examples of multiple level models are shown graphically (see figure 4.8): The

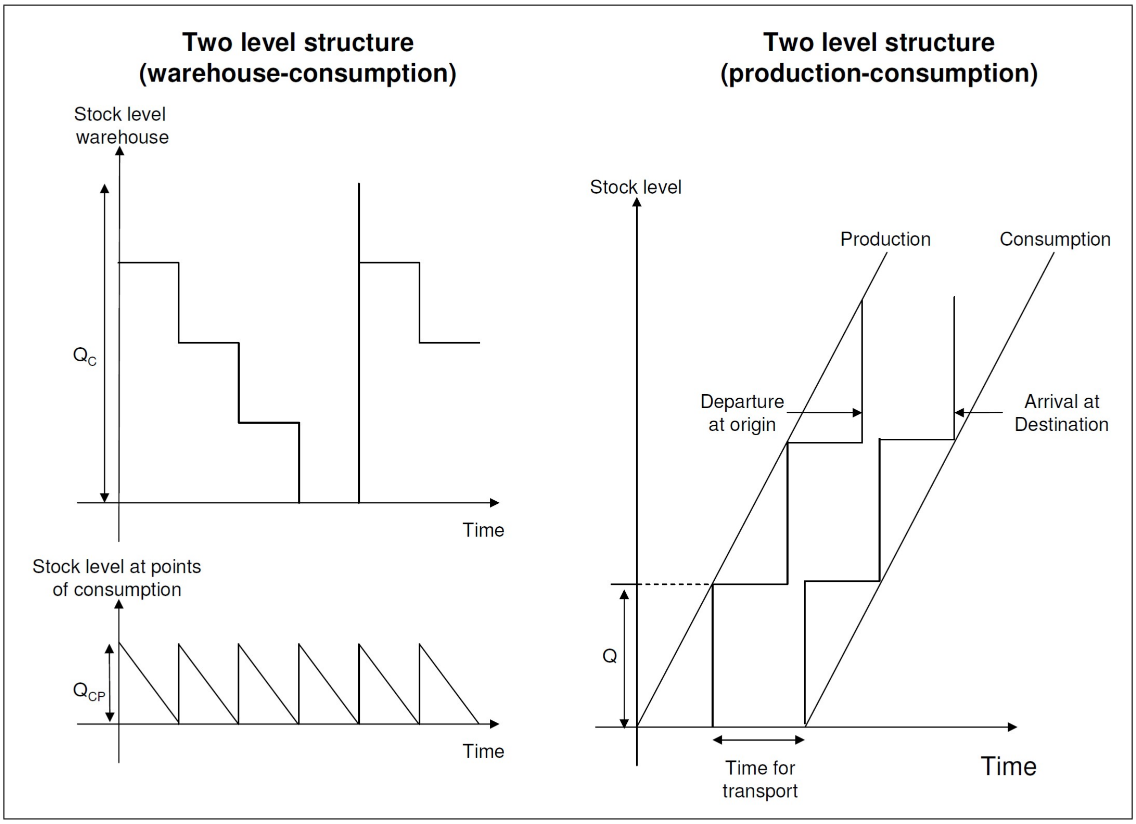

Figure 4.8: Examples for multiple level considerations (Toporowski (1996) and Blumfeld et al. (1985))

first example (left side of figure 4.8) shows the effect of coordinating orders of the warehouse and its consumption points. By coordinating the deliveries (harmonizing inbound and outbound tacts), the stock level of the warehouse can be reduced by the cumulated order quantity of all consumption points (see Toporowski (1996), p. 152 ff. for details). When the warehouse gets a delivery, part of the goods are directly reshipped to consumption points. The main saving of such a regime comes from the direct reshipping, therefore large quantities are needed. During warehouse visits, this was observed for cross docking and for promotions when large quantities are needed at the retail stores. But in general, commissioning of small quantities needs to be done and goods are first put into warehouses and then commissioned for retail stores.

The second example (right side of figure 4.8) shows the consideration of stock at origin and destination (Blumfeld et al., 1985). A higher lot size leads to increased stock levels at destination and origin. This model represents a situation where a good is exclusively produced for one consumption point. Usually, this is not the case for consumer products. Even if a good is exclusively produced for one retail chain, there are still several warehouses that have to be served.

For SYNTRADE, the question of consideration of several levels in lot size models arises for the transport relations from warehouses to stores, from central to regional warehouses and from producers (or LSP) to warehouses:

- Based on the statements of the interviews conducted for this study, it is assumed that there are only limited stocks in the retail stores that get delivered daily. Therefore there are not two level considerations between warehouse and retail store.
- In case of a two layer warehouse structure, cross-docking is assumed for the centralized goods. This describes the extreme case of the first example, the commissioning in this case is done in the central warehouse for all centralized goods.
- For the relation between supplier (producer or LSP) and retail chain, cooperation is assumed, meaning the total cost of all parties involved are optimized. Even if cases where observed in the interviews, where the cost responsibility was split (transport cost to supplier and warehouse stock cost to retailer), it is assumed that mechanisms like price negotiations are in place that lead to an overall optimum. Origin stock, however, is not considered since it is assumed that the goods are not exclusively delivered to one warehouse.

Assuming cooperative optimization on the individual commodity flows does include parameters of the surrounding logistic systems, like transport costs, provided by the logistic system. There is a certain pull from larger logistic systems that can produce higher synergies. This corresponds to the situation, observed in reality. Thus, setting the starting configuration of the model is important because it can change synergy potential, and thus the outcome of lot size, supply paths, and finally warehouse structure decisions. In Germany, retail chains have large logistic systems with regional warehouses. An absence of such structures might lead to completely different logistic structures within an optimization, this will be discussed in more detail during the description of the model result.

Capacitated resources

Finally, the resources can be capacitated, like the warehousing capacity or the maximum transport capacity. Especially in combination with multiple products or dynamic setup, combinatoric problems evolve that are often complex to solve (a detailed discussion on capacitated problems can be found in Reith-Ahlemeier (2002)).

Assuming capacitated transport capacity Q_{max} for the basic EOQ problem results in an enhanced formulation of the optimal quantity of (see Blumfeld et al. (1985)):

$$Q^* = \text{ Min } (\sqrt{\frac{2c_O X}{\bar{p} r_S}}, Q_{max})$$

This extension is quite easy to implement and is used within SYNTRADE to reflect two observations: the limited capacity in truck transport, Q_{max} is therefore set to 33 pallets, and the problem of perishability that, given a certain consumption rate, can also be translated into a Q_{max}.

Limited warehouse capacity on the other hand is not reflected in SYNTRADE. Since the model focuses on the warehouse structure setup, it reflects a long-term planning where the warehouse capacity can be assumed as flexible.

Conclusions

In this subsection, it was shown that there are many possible extensions to the basic EOQ model. As Toporowski puts it (Toporowski (1996), p. 112), to describe a real situation, almost all possible extensions have to be included. Nevertheless, for SYNTRADE only some extensions are applied, two main arguments support this simplifying approach:

Firstly, as interviews with practitioners showed, also the real world decision is taken under simplifying assumptions and limited data availability. The goal of the model is only to imitate these approximate decisions, not to find the optimal solution. Therefore, it is important to match the main drivers not to model the detail.

Secondly, the processing capacity for modeling a single decision is limited. The model developed has to be capable to repeat the lot size decision several million times.

Discussed aspects were included in the following way:

- The model is kept static because of its mid or long term character.
- Fluctuation are not considered. Since safety stock is minor compared to cycle stock, this simplification is justifiable for a model focusing on the warehouse structure decision.
- An extension was developed to be able to describe transport costs in a variable way while keeping the model analytically solvable.
- Variable prices are not considered because prices are negotiated for overall time periods, effects of major market price breaks on the average lot size are limited and because cooperation is assumed (instead of logistic discounts or other coordinating mechanisms).
- Multiple product flows are simplified by modeling a one product flow with the sum of demands of the individual products.
- Multiple levels are not considered between warehouse and store, cross-docking is assumed between central and regional warehouses and cooperation is assumed between supplier and retail chain.

- Capacitated resources are incorporated in form of a maximum lot size (Q_{max}) representing maximum truck load and perishability.

In the next chapter, a formal definition of the resulting model will be given.

4.3.3 Warehouse structure optimization

The determination of warehouse structure includes the number of warehouses, warehouse levels, warehouse locations and allocation of consumption points or customers to warehouses. Each one of these problems is highly dependent on the others (see figure 4.9). Especially, if several of these subproblems are handled together, finding optimal solution

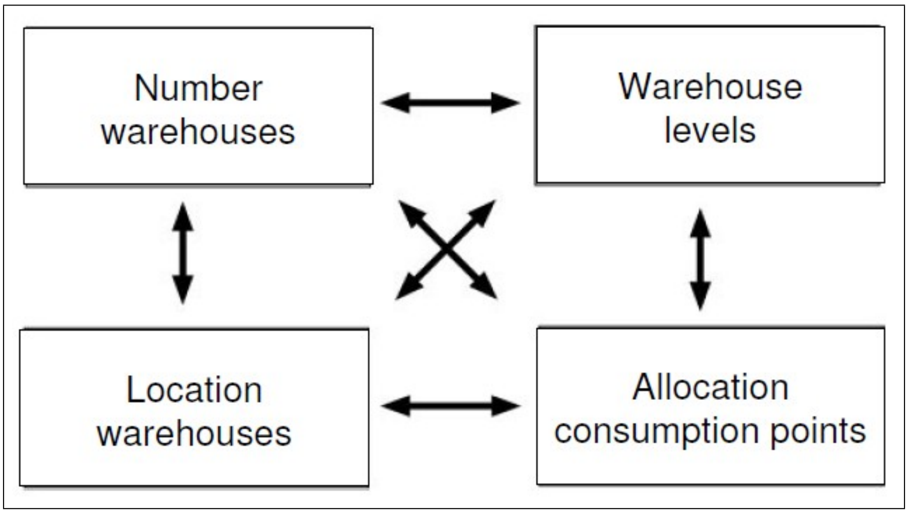

Figure 4.9: Components of warehouse structure (adapted from Pawelleck (1996))

is very complex and heuristics are used to solve the problems approximately. This subsection cannot give a complete overview on all existing problem variations and solution procedures in literature, since a lot of research has been done in this area. But common approaches can be outlined for each individual problem as well as for some combinations. These approaches will be discussed in terms of application within food retailing. At the end of this subsection the elements used within SYNTRADE will be listed.

Number of warehouses

This paragraph starts with a discussion of the model of Tempelmeier (Tempelmeier (1980), p.50-57). Afterwards some aspects will be added from the model of Geoffrion (Geoffrion, 1979).

Tempelmeier assumes a one level warehouse structure with R (r=1...R) retail stores, P (p=1...P) products and S (s=1...S) suppliers. To determine the optimal number of warehouses N (n=1...N), he includes three cost components:

Costs for inbound transport C_{IT}, costs for outbound transport C_{OT}, and warehousing costs C_W:

$$Min.\, C_{IT}(N) + C_{OT}(N) + C_W(N)$$

The transport inbound costs are calculated as:

$$C_{IT} = \sum_{s=1}^{S} \sum_{n=1}^{N} \sum_{p \in A_s} c_{1np} d_{sn} Q_{np} a_{1np}$$

where
c_{1np} = Cost rate for transport of product p from supplier to warehouse n
d_{sn} = Distance between supplier s and warehouse n
Q_{np} = Lot size of products p for the transport to warehouse n
a_{1np} = Number of deliveries of product p to warehouse n
A_s = Set of indices of articles that are supplied by supplier s

Cost rate and lot size are defined as exogenous input into this model, this can be combined with the corresponding lot size model discussed in the previous subsection. Thus, the cost rate and lot sizes could be described dependent on the number of warehouses since total quantity of a product per year and warehouse changes with the number of warehouses, and so does the lot size and therefore the transport cost rate. Also the formulation assumes that location and allocation problem are solved, a more generic formulation of distances is required if this is not the case. This can be done in form of average distances for a certain area as described in subsection 4.2.4.

The transport outbound costs are calculated as:

$$C_{OT} = \sum_{n=1}^{N} \sum_{r \in R_n} \sum_{p=1}^{P} c_{2rp} d_{nr} Q_{rp} a_{2rp}$$

where
c_{2rp} = Cost rate for transport of product p from warehouse to retail store r
d_{nr} = Distance between warehouse n and retail store r
Q_{rp} = Lot size of products p for the transport to retail store r
a_{2rp} = Number of deliveries of product p to retail store r
R_n = Set of indices of retail stores supplied by warehouse n

As for the inbound transport cost, the lot sizes and transport cost rates are expected as input. To model effects of bundling and therefore the differences between retail stores with different order volume, a more detailed modeling has to be chosen for the distribution cost calculation. It is also assumed that location and allocation problems are solved.

Finally, the warehousing costs are calculated as:

$$C_W = \sum_{n=1}^{N} \sum_{g=1}^{G} \sum_{u=1}^{U} [C_{3ru} + c_{3ru} \sum_{p=1}^{P} f_p \sum_{r \in R_n} Q_{rp} a_{2rp}] \gamma_{ngu}$$

where
C_{3ru} = Warehouse fixed costs of warehouse in geographic region g (g=1...G) and capacity class u (u=1...U)
c_{3ru} = Variable warehouse cost per handling unit (e.g. pallet) for warehouse in geographic region g and capacity class u
f_p = Conversion factor from transport quantity to handling unit
γ_{ngu} = Boolean variable indicating if warehouse n belongs to capacity class u and geographic region g

The formulation of warehouse fix and variable costs stays very general, although capacity classes are differentiated, the link to the number of warehouses is missing in the formulation. Also, variable costs are probably not only dependent on throughput. A bottom up analysis of warehouse costs (see Gudehus (2004), p. 583) shows that they are also driven by number of storing positions. Only by modeling the dependency of storing positions, stock and therefore the consequences of lot size choices on the warehouse costs can be included. This is especially important to model differences between discounters and full service retailers, where number of articles and therefore stock levels (cycle stock and safety stock) are very different.

Two main criticisms can be formulated for this model of Tempelmeier: first many external inputs are needed, including lot sizes and distances between locations. Second warehouse costs are modeled in a very simplified way.

A simplified warehouse model of Geoffrion (Geoffrion, 1979) proposes a formulation that does not need data on locations. He assumes an equally distributed demand in a plane, described by a demand density d and the considered area A. The distances to suppliers and consumption points are estimated, based on average geometric distances as presented in subsection 4.2.4. Assuming a ratio of inbound to outbound cost of 1:10 he arrives at a formula for the optimized number of warehouses:

$$n^* = 0,332F(d\frac{c_2}{C_3})^{\frac{2}{3}})$$

	F	=	Area served
	d	=	Demand density in area
where	c_2	=	Outbound transport cost rate
	C_3	=	Warehouse fixed cost

Even though this model is simplified in many ways, it makes some dependencies clear. The number of warehouses increases with the service area, with the demand density and with the outbound cost rate, it decreases with the warehouse fixed costs. The variable service costs do not occur in this final formula, since it is assumed that they do not differ by warehouse size and thus do not have an influence. Also, obviously, no differences in stock levels are considered, thus again the model could not explain the difference in the number of warehouses in case of a discounter and a full service retailer. However, a main lesson learned from this model is the decoupling of the number problem of location and allocation by using average distances.

The influence of the number of warehouses on stock levels was analyzed in detail by Toporowski (1996) (p.82 ff). Assuming the basic lot size model, he calculates cycle stock for n compared to one warehouse. He concludes that the cycle stock increases by a factor of $\sqrt{n}$ when changing from one to n warehouses.

His analysis shows how significant the influence of stock level is on the decision of the number of warehouses. In terms of costs, an increased stock level is reflected in additional costs for stock positions and capital costs. The model has to include variable warehouse cost dependent on storing positions as proposed earlier.

The discussed extensions to the model do not allow a simple analytic solution as for the model of Geoffrion. A decoupling of the model of the location and allocation problem by working with average distances, however, seems recommendable to keep the problem solvable.

Warehouse levels

This paragraph focuses on the isolated warehouse level problem. In food retailing, this problem is limited to the question if a second warehouse level (central warehouses) is established. Therefore, we refer to an approach of Bartholdi and Hackmann (Bartholdi and Hackman (2008), p.73 ff). Their approach origins from the problem of what articles should be placed in an additional forward area in a warehouse. In this forward area, picking is cheaper and therefore it is recommendable to put those articles in the forward area that promise the highest cost savings. Given is a volume V of the forward area, the volume v_a that is needed to put article a (a=1...A) into the forward area and the potential saving s_a of putting article a into the forward area. Thus, maximizing the total savings S, the optimization problem can be written as:

$$\begin{aligned} \text{Max } S &= \sum_{a=1}^{A} s_a \\ \sum_{a=1}^{A} v_a &\leq V \\ v_a &\geq 0, \forall a \in 1 \ldots A \end{aligned}$$

If this idea is transfered to the question of a second (central) warehouse level, it has to be considered which articles should be put into the central warehouse. Instead of setting a certain volume as given, it can be analyzed for which article a centralization would result in savings in variable costs. These savings have to be compared to the additional costs of a central warehouse (C_{add}). Thus, it is beneficial to introduce a central warehouse level, if:

$$\sum_{a=1}^{A} max\{s_a, 0\} - C_{add} > 0$$

The savings in variable costs result from lower stock levels and less transport inbound costs. If one assumes a cross-docking on the regional warehouse level, as it was described in expert interviews, additional costs emerge through the transport from central to regional warehouses and the handling activity for cross-docking. The distribution costs from the regional warehouse to the stores rest stable in this case.

Warehouse locations

The basic "warehouse location" (or "facility location") problem in literature includes location, allocation and number problem. It will be discussed in the last paragraph of this subsection. At this point the focus is on the location problem only. If the location can be chosen freely in the plain (no discrete alternatives), the problem is known as "Steiner-Weber" problem (Domschke and Drexl (1996), p.167ff): Given are the locations of the consumption points $i(i = 1 \ldots I)$ in form of coordinates (a_i, b_i) and each consumption point has a demand of X_i. Then the (transport) optimal location (a^*, b^*) for the warehouse is, where the total distance between the warehouse and the locations is minimized:

$$\text{Min } \sum_{i=1}^{I} X_i \sqrt{(a - a_i)^2 + (b - b_i)^2} \tag{4.2}$$

This function cannot be solved analytically, but Miehle (1958) defines an iterative procedure that follows the Steiner Weber model. The "mental model" behind this approach (also called weights and strings model) describes a physical apparatus in form of the table which represents a map. A hole is made at each consumption point with a string going through, holding a weight at the end that corresponds to the demand. All strings are fixed at a ring on the table. The position where the ring comes to an hold, is the optimal position.

As a starting solution (first iteration in the Miehle procedure), the center of gravity can be taken:

$$(a_{gr}, b_{gr}) = (\frac{\sum_{i=1}^{I} a_i X_i}{\sum_{i=1}^{I} X_i}, \frac{\sum_{i=1}^{I} b_i X_i}{\sum_{i=1}^{I} X_i})$$

This location often is already close to the above described minimum. For the following iterations the new coordinates (a,b) are determined by differentiating 4.2 with respect to a and b, setting the result equal to zero and solving by a and b.

In many cases, however, discrete alternatives are given, also distances often do not correspond to the air-line distance but depends on the road network. Therefore, the solutions generated can only be taken as approximation, and locations close to this optimal point have to be checked.

Allocation of consumption points

Finally, the allocation problem of consumption points to warehouses corresponds to the classic transport problem (Neumann and Morlock (1993), p. 325 ff.): Given are $i = 1...n$ warehouses and $j = 1...m$ consumption points, each consumption point needs the quantity of b_j and each warehouse has the capacity to supplies the quantity of a_i (total demand equals total supply capacity). The cost matrix c_{ij} represents the transport costs per unit and the matrix x_{ij} the quantity transported between i and j. The objective of the transport problem is to find x_{ij} that minimize total transport costs:

$$\begin{aligned}
\text{Min } TC &= \sum_{i=1}^{n}\sum_{j=1}^{m} c_{ij}x_{ij} \\
\text{s.t. } \sum_{i=1}^{n} x_{ij} &= b_j \; (j = 1...m) \\
\sum_{j=1}^{m} x_{ij} &= a_i \; (i = 1...n) \\
x_{ij} &\geq 0 \; (i = 1...n, j = 1...m)
\end{aligned}$$

To solve this problem, the MODI method can be applied, which is a special form of the network simplex method. In a transport tableau, representing the flows from the warehouses to the consumption points, cycles are determined that improve costs and change (increase and decrease) flows by a certain quantity so that constraints stay fulfilled (see figure 4.10). This method is a very efficient way ($O(k^2 a)$, $with\ k = max\{m,n\}\ and\ a = \sum_i^n a_i$) to solve the transport problem (Neumann and Morlock (1993), p.337). Details on the derivation of this method can be found in Domschke (1981).

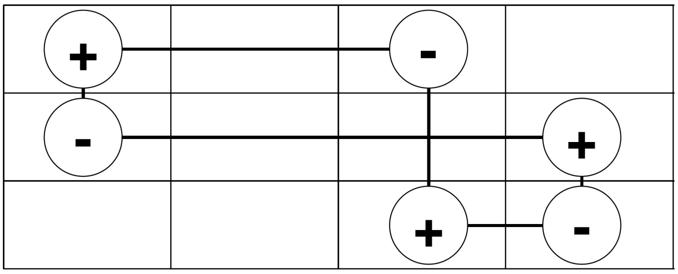

Figure 4.10: Schematic view of MODI approach in a transport tableau (simplified from Neumann and Morlock (1993), p.333)

This description of the allocation problem corresponds to the case of capacitated warehouses. The uncapacitated case is trivial, since customers can just be allocated to the nearest warehouse.

Combined problems and solution procedures

The facility (or plant) location problem and the warehouse location problem in literature are two very closely related problem types that include three of the above described problems: number problem, location problem, and allocation problem.

The warehouse location problem (Baumol and Wolfe, 1958) describes the problem of placing warehouses between the production and customer locations, the facility location problem describes the problem of placing facilities (plants or depots) to serve customer locations. For food retailing, the facility location problem seems sufficient since all warehouses have to be delivered by all producers (at least in a one level structure)[4]. This problem will be discussed in more detail.

As lot size problems, facility location problems can be differentiated by various characteristics, one example is wether facilities are capacitated (see Aikens (1985) for an overview and classification). The simple capacitated facility location problem can be formulated as:

$$\text{Min} \quad \sum_{i=1}^{n}\sum_{j=1}^{m} c_{ij}x_{ij} + \sum_{i=1}^{n} f_i z_i$$

$$\begin{aligned}
\text{s.t.} \quad \sum_{i=1}^{n} x_{ij} &= b_j \ (j = 1...m) \\
\sum_{j=1}^{m} x_{ij} &\leq a_i z_i \ (i = 1...n) \\
x_{ij} &\geq 0 \ (i = 1...n, j = 1...m) \\
z_i &\in \{0,1\} \ (i = 1...n)
\end{aligned}$$

[4] see for example Sharma and Berry (2007) for a differentiation between warehouse and facility location problem

	c_{ij}	=	Cost matrix for transport from facility i to consumption point j
	x_{ij}	=	Quantity delivered from facility i to consumption point j
	f_i	=	Cost of facility i
where	z_i	=	1 if plant is established, 0 otherwise
	b_j	=	Demand of consumption point j
	a_i	=	Capacity of facility i

At the first glance, the description looks very similar to the transport problem. It differs in the additional consideration of fixed cost f_i for warehouses and binary variables z_i expressing that warehouse locations only represent potential warehouses. Also, the first constraint is formulated more general to include the case that less than the capacity of the warehouse is used as well.

Nevertheless, this problem is far more complex, it includes the location and the number problem. Finding optimal solutions for large scale problems does need a lot processing capacity (Beasley, 1988) - the problems in this study will be of a large scale (about 440 potential warehouse locations and 440 consumption regions). Heuristics are therefore used to generate good (not optimal) solutions (see Green et al. (1981) for examples). If the problem of number of warehouses is separated out as proposed before the resulting problem is reduced to location and allocation problems.

Despite the simplification, the problem stays complex. Domschke (Domschke and Drexl (1996), p. 183) proposes for the practical application a heuristic from Cooper (Cooper, 1972) that solves allocation and location problem in turn and thus continuously improves the solution. A similar heuristic was proposed in the area of cluster analysis by Späth, called KMEANS-principle (Späth, 1975). Both, Cooper and Späth show through tests that this approach produces very good results.

Conclusions for SYNTRADE

The question, how to optimize a warehouse structure can be divided into four problems: levels of warehouses, number of warehouses, location of warehouses and allocation of consumption points to warehouses. Combining them results in complex problems, like the facility location problem, that are in most cases difficult to optimize so that simplifying assumptions and heuristics have to be used.

Therefore, for SYNTRADE the problems has to be separated within the heuristic. The level problem and the number problem are solved first, then the location and allocation problem are handled in a combined heuristic.

For the level problem, the "forward area" approach of Hackman can be adapted. For the number problem, a more complex warehouse cost formulation than the one of Tempelmeier has to be used, including lot size models, so that the emergence of different stock levels is described. This is important to model differences between food retailing companies (e.g. discounters and full assortment chains). The problem has to be solved by full enumeration which is feasible, regarding the limited number of alternatives (up to about 35 warehouses). Finally, location and allocation problems can be solved in a combined way, using the well established heuristic of Cooper, in which the MODI method can be used to solve the allocation problem.

A detailed formulation of the heuristic in SYNTRADE is shown in the next chapter.

4.4 Freight transportation models

This section reviews the representation of logistics in freight transportation models. It is not the goal to give a complete overview of models[5], but it will be tried to include the most important recent innovations in transportation modeling that consider logistic aspects. The selection of described models will contain models from different categories like national models or urban traffic models. Besides full blown transportation models, limited models or analysis exist that concentrate on specific aspects of transport generation, wich will shortly be discussed after the review of freight transportation models.

Before starting the review, general model characteristics and the traditional four stage framework for transportation models will be discussed.

4.4.1 Model characteristics and frameworks

As models in general (see section 4.1), freight transportation models can be characterized by their purpose, their scope and the methods used. Depending on the model, all of these can be very different.

Besides these general characteristics, more specific frameworks exist that are used to describe and compare freight transportation models. Mostly used is the structure of the classical four stage transportation model. The following description is oriented at Ortùzar and Willumsen (1990):

Originating from macroscopic passenger transportation models, the four stage model structure (see figure 4.11) is often used for freight transportation. An example for this approach, the freight model for the BVWP (Bundesverkehrswegeplan) in Germany, will be discussed later. The four steps of the framework are:

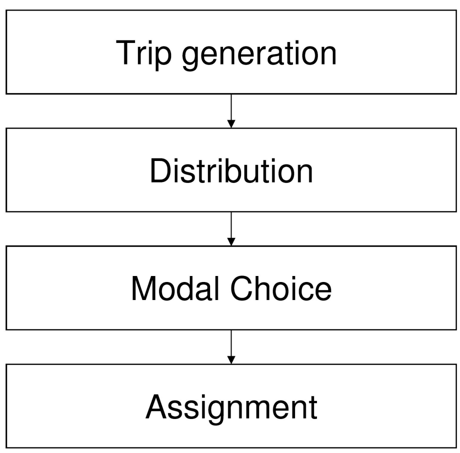

Figure 4.11: Structure of the classic four stage transportation model

- Generation: Transport demand in a traffic cell (region) is generated. To model freight transportation, quantities of goods (in t) or number of trips in urban transportation models are generated.

[5] The reader may refer to projects that try to provide overviews like Expedite Consortium (2002) or ME&P - WSP (2002), to the EU directory MDIR established by the Spotlight project (Spotlights consortium, 2002), to the US freight manual (Beagan et al., 2007) or to review articles like De Jong et al. (2004) or Tavasszy (2006)

- Distribution: Destinations are chosen for the generated demand. In freight transportation models, this contains the split of demand to destination regions and sectors. Thus, macroscopic flows between regions are generated, often by using gravity models.
- Modal split: These flows are transformed into vehicle flows. Therefore, shipment sizes and modes have to be chosen. The mode choice is often modeled with disaggregated logit models.
- Assignment: Vehicle flows are assigned to the network.

Especially for recent disaggregate models including logistics this framework does not fit any more. Therefore Liedtke et al. (2009) proposed a framework that incorporates four additional steps: after the distribution he includes the steps "Transformation of monetary units into metric tons", "Logistic model to map a hyper route choice through distribution systems" and "Shipment size choice" and after the mode choice, he adds "Conversion into vehicle units". Another framework are the market levels, shown earlier in this study (section 3.2) that reflect the different markets that can be distinguished. Such a framework is especially helpful, if market interactions are modeled.

4.4.2 Selected transportation models

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 the above introduced frameworks is beyond the scope of this study. Also, for many cases it is difficult to "press" models in frameworks that do not correspond to their structure and objective. Therefore, the models and their specifics will first be introduced briefly based on the general model characteristics (purpose, scope/structure and method)[6], followed by the analysis of the representation of logistic aspects. This analysis will be oriented at the hierarchy of logistic choices, introduced earlier in this study (see figure 3.9).

ADA approach - applied in Norway and Sweden

Purpose: The "ADA" approach (aggregate - disaggregate - aggregate) was applied for the national freight models in Norway and Sweden. It aims to model national freight traffic including logistic aspects (De Jong and Ben-Akiva (2007) or Ben-Akiva and De Jong (2008)).

Scope: The model approach can be divided into five steps (see figure 4.12). The first step is composed of a model that generates aggregate PC flows between regions. In the second step, these flows get disaggregated to commodity flows between firms. Afterwards, in the disaggregate logistic part, four choices are covered: transport path, mode, loading unit, and shipment size. Then the resulting vehicle flows are aggregated to OD (origin-destination) flows and assigned to the network. The application of the model in Norway includes 500.000 firms (100.000 sending and 400.000 receiving firms) and distinguishes 400 regional zones and 32 commodity types. In total 5 million commodity flows were generated. Transport paths include up to four links and four modes (truck,

[6] The description also depends to a large extend to the information published or available, therefore differences in level of detail may occur

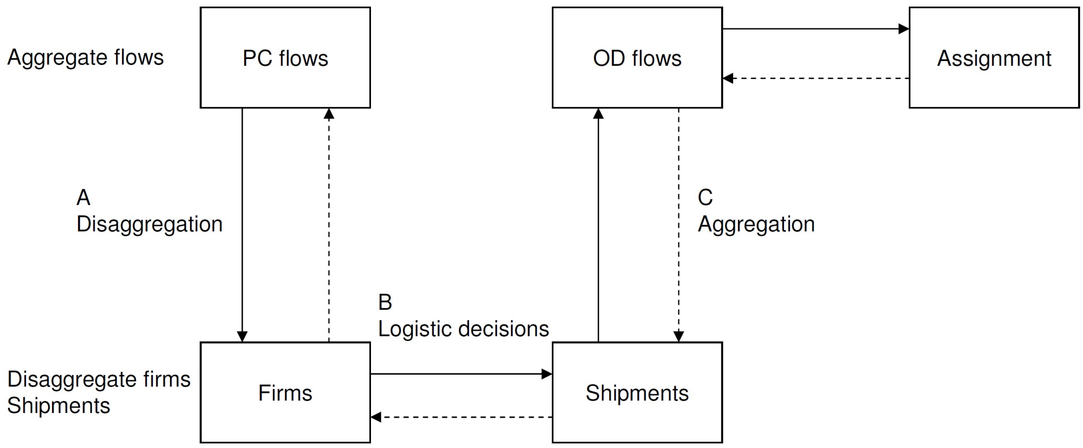

Figure 4.12: Structure of the ADA approach (De Jong and Ben-Akiva, 2007)

train, ship, aircraft) as well as several vehicle types for each mode that are distinguished on each link.

Methods: For the PC flow generation a MRIO model was applied in Norway. For the disaggregation following method is proposed: at first, firm pairs are generated synthetically (e.g. Monte Carlo simulation) or based on sample data, then total flows are distributed to these pairs by gravity models. The logistic decisions are modeled for samples of firm relations (to reduce runtime). The logistic choices in the Norwegian model application are modeled with a deterministic cost optimization involving two steps. In the first step, the optimal transshipment locations are determined (for different transport path types, origin and destination zones). In the second step, shipment sizes and transport chains (composed of legs with different transport modes and loading units on each leg) are determined for specific firm to firm commodity flows by enumerating available options and selecting the one with lowest cost. If disaggregated data is available, an estimation with logit models instead of deterministic optimization models is proposed. In the next step, the resulting vehicle flows are aggregated to OD flows between zones including the consideration of empty runs. Assignment in the ADA approach is done with aggregate methods.

Logistic choices: Logistic locations are assumed exogenous, wholesalers are part of the generated firms. The choice of transport paths including reloading points is modeled explicitly, however warehousing is not part of the model like it is thought of in the supply path choice. Lot sizes for each commodity flow are constant for the overall transport path, a change of lot sizes for the overall bundle is not considered. Mode and shipment size choice are modeled. Routing is not modeled explicitly, but empty runs are considered in the aggregation step.

EUNET 2.0

Purpose: EUNET 2.0 (Williams et al., 2005) is an aggregate model on a national level that aims to model future (freight) traffic flows on the infrastructure. The model tries to include changes in economic activity, as well as changes in logistics into the model system.

Scope: As input, the model takes the national IO table. The flows are broken down to regions with a Spacial IO (SIO) model. This model is extended by dividing the flow from producer to consumer in logistic stages for different commodity categories. It allocates supply paths to the macroscopic IO flows. The flows in trade values are then converted to tonnes, empty runs are added and mode choice is performed. A feedback loop plays back the transport costs into the SIO model. The flows are then converted to vehicle flows (assuming average loads) and assigned to the infrastructure. The model was applied for the Trans-Pennine Corridor in the north of England, it differentiates 31 sectors, 230 geographical zones, 22 groups of commodities for transport, five types of logistic chains and multiple modes.

Methods: The model uses a SIO model extended by the inclusion of logistic stages of flows. Logit segmentation is used to model the allocation of flows to logistic chain types. Mode choice and choice of vehicle size is done by an hierarchical logit model.

Logistic choices: The model works on the level of aggregated flows, thus logistic choices are only modeled for aggregate flows. Locations are assumed as given. Supply paths are chosen within the extended IO model for aggregate flows. Mode choice and lot size choice is modeled integrated for aggregate flows. Vehicle tours are not modeled.

SMILE and SLAM

Purpose: SMILE (Tavasszy et al., 1998) is a model on a national level that aims to model future (freight) traffic flows on the infrastructure for the Netherlands. SLAM (SCENES, 2002) is the logistic module of an EU-level transportation model developed in the SCENES project that uses a similar approach as used in the SMILE model.

Scope: The SMILE model can be structured into three levels:

1. Production, Sales and Sourcing
2. Inventory
3. Transport

The first level describes production, consumption and trade flows on a regional level distinguishing 77 regions, of which 40 are in the Netherlands. The next level contains the choice of distribution channel types. Three channel types are differentiated: direct delivery and the usage of one or two distribution centers. In a first step optimal locations of distribution centers for each origin destination pair and channel type are determined. In a second step flows are assigned to alternative channel types based on the chosen locations. On the last level the transport path for every element of the distribution chain is determined including six different modes (road, rail, inland waterways, air, pipeline, and sea transport). For level two and three 50 logistic families (commodities) are differentiated. In the module SLAM only the choice of distribution channels is modeled, the generation of trade flows before as well as the mode choice and the network assignment afterwards are provided by other SCENES modules. The SLAM module works on a NUTS 2 level.

Methods: The modeling of trade flows is done with make/use tables that explicitly cover production factors for each sector. For the first step of the second level logistic costs, lead time, centrality and availability of modes at the locations are used as decision criteria. The second step is modeled with a multinominal logit model based on logistic costs. On the last level paths are determined based on logistic costs and time. The weights used are specific to logistic families.

Logistic choices: SMILE and SLAM are aggregate models, logistic choices are hence only modeled for aggregate flows not on the company level. Choices covered are supply path choice (distribution channels including warehouse locations) and mode choice. Warehouse locations are chosen for each origin destination pair and channel type, it is assumed that warehouses are potentially available in every region. Lot size distributions are assumed for different logistic families and hence not modeled explicitly. Tour building is not modeled.

INTERLOG

Purpose: The INTERLOG model (Liedtke, 2006) aims to analyze the effect of policy measures and infrastructure improvements on carriers' and shippers' behavior, and the resulting traffic flows.

Scope: Market interaction of agents (shippers and carriers) is simulated incorporating the lot size decisions of shippers as well as the tour building of carriers. The model can be divided into three steps:

1. Generation of an artificial economic landscape with establishments of microeconomic actors (on 3 digit CPA level - differing about 200 sectors)
2. Choice of suppliers
3. Simulation of market interaction with shippers and carriers.

The model focuses on transport of full and partial truck loads in Germany, scenarios of 1000 companies (shippers and receivers) and 200 carriers have been run. The exact time scope is not defined but can comprise several negotiation rounds of transport contracts on the transport market in order to show the stabilization of the system. Traffic is not simulated but described as traffic loads on the network which is continuously adapted based on the tour building. The generation of establishments is based on data on NUTS 3 level, incorporating about 440 regions in Germany, the tours are built on a road network (including Autobahnen and Bundesstraßen).

Methods: For the generation of the artificial industrial landscape "Monte Carlo" simulation is used. For the supplier choice an IO matrix is detailed by an algorithm containing elements of "fuzzy logic" and entropy maximization. The choice itself is again modeled by a "Monte Carlo" simulation with probabilities, considering distances to potential suppliers and inter sectoral flows. Finally, the behavior of agents in the simulation of transport contract negotiation is based on optimization (minimization) of total logistic costs, shippers can adapt lot sizes (frequencies) and carriers can adapt tours.

Logistic choices: The model does include the level of lot size decision and tour building. Other choices on network design, locations, supply paths and modes are not modeled. Locations of distribution centers in trade are modeled as exogenous input as part of the artificial industry structure.

Tokyo model

Purpose: The Tokyo model (Wisetjndawat et al., 2007) aims to describe commercial traffic in the Tokyo metropolitan area.

Scope: The emergence of commercial traffic is modeled on a microscopic level. The model can be divided into six steps:

1. Commodity generation
2. Commodity distribution
3. Delivery lot size and frequency determination
4. Vehicle and carrier choices
5. Vehicle routing
6. Traffic assignment

An artificial economic landscape with microeconomic establishments and commodities is generated in the first step. The study area is divided in 56 zones, thirteen sectors and 8 commodity types are differentiated . In the four following steps, the decisions are modeled out of the perspective of microeconomic actors: supplier choice by recipients, lot sizes and frequency determination, as well as vehicle and carriers by shippers and vehicle routing by carriers (single vehicle perspective). Traffic assignment is done within an aggregated procedure.

Methods: The study relies on very rich data sources, coming from large surveys, a main data source is the Tokjo Metropolitian Goods Movement Survey with a sample of 46.000 firms. Therefore, mostly statistical modeling and only few normative modeling approaches (optimization models) are applied. The artificial economic landscape is generated with a "Monte Carlo" simulation, the amounts of commodities (produced and consumed) are determined based on linear relation to certain production and consumption indicators (determined by a regression analysis). The commodity distributions are modeled based on probabilities determined from survey data and a logit model, incorporating effects of spacial interaction (dependencies of actor behavior on others' behavior). Lot size and frequency are determined based on the linear (or logarithmic) relation to distance (determined by a regression analysis). Carrier and vehicle choice are modeled with a nested logit model, using different costs as variables. Finally, vehicle routing is modeled with the vehicle routing problem (optimization).

Logistic choices: The model incorporates the levels of mode choice, lot size choice and tour building. Lot sizes are, however, only modeled in form of a statistical relationship to distance, not with respect to logistic costs. Logistic locations are part of the artificially generated economic landscape, their emergence (location) is not modeled explicitly.

WIVER

Purpose: WIVER is an urban commercial traffic model that aims to reproduce vehicle flows on transport infrastructure (Sonntag, 1996).

Scope: The model can be divided into four steps:

1. Generation: Determination of number of tours and tour stops at origins and number of destination points for traffic cells
2. Distribution: Connecting origin and destination points according to distance distributions
3. Simulation of tours with the savings heuristic according to efficiency levels (savings niveau)
4. Adaption of traffic to traffic distribution for different day time periods

The model distinguishes between ten origin sectors, seven destination sectors and 4 (road) vehicle types. The model was applied in different German cities, the number of traffic cells was in the range of 100-150 in these cases. Overall commercial traffic is modeled which incorporates freight traffic but also includes other forms of traffic like tours of craftsmen. Therefore, no vehicle loads are modeled but tours with stops.

Methods: The generation of tours, number of stops and destination points is calculated based on trip rates. The distribution is based on a gravity approach that includes the consideration of distance distributions. Tours are built, based on the savings heuristic, which is a heuristic for the vehicle routing problem in operations research (Neumann and Morlock (1993), p. 471).

Logistic choices: The model concentrates on the emergence of tours. Locations and supply paths are not modeled, also lot sizes are only covered in form of different vehicle types. Mode choice is limited to four road vehicle types which are directly allocated to the origin destination sector pairs. Only tour planning is covered directly, it is however modeled out of the vehicle's perspective.

Calgary model

Purpose: This model is an urban commercial traffic model for Calgary. It aims to reproduce commercial vehicle flows on transport infrastructure (Hunt and Stefan, 2007).

Scope: The model distinguishes three types of movements: external-internal movements that are connected to locations outside the study area, fleet allocator movements that are not part of tours, and tour-based movements. The first two are modeled with aggregate approaches, the focus of the model is on the third category. The modeling of tour movements consists of six steps:

1. Tour generation for each zone and allocation to a day time period
2. Choice of tour purpose and vehicle types
3. Determination of precise tour start time
4. Choice of next stop purpose (this is done as long as the stop purpose is not "return to establishment")
5. Choice of next stop location
6. Determination of next stop duration

The model distinguishes between 1447 model zones, five zone types, five establishment categories, five time periods, three tour purposes, three vehicle types and four stop purposes.

Methods: The determination of number of tours per region is based on a functional relation (based on regression analysis). "Monte Carlo" simulation is used for the remaining steps. For three steps the input for the "Monte Carlo" simulation in form of probability distributions is determined by logit models (tour purpose and vehicle types, next stop purpose and next stop location).

Logistic choices: The model concentrates on the emergence of tours. Locations and supply paths are not modeled, also lot sizes are not covered, only within the choice of vehicle type. Mode choice is limited to four road vehicle types. Tour planning is modeled explicitly but not in form of planning (optimizing procedure) but in form of tour building (a tour "grows" by repeatedly choosing the next stop purpose).

GOODTRIP

Purpose: "GoodTrip" (Boerkamps and Van Binsbergen, 1999) is an urban commercial transportation model that was applied to evaluate alternative distribution concepts (traditional distribution, urban distribution centers and underground logistic systems) for the city of Gronningen, based on emissions and vehicle kilometers, tours and stops.

Scope: In "GoodTrip" logistical chains are reproduced. Based on consumer demand, the volume of goods in each zone is calculated. The flows are then determined upstream through retail locations, distribution centers to production facilities based on probabilities that represent the corresponding activities in space. These flows are assigned to vehicles which are then assigned to the transport infrastructure using shortest routes. The application in Gronningen comprised four good categories. Two urban good delivery centers and 49 supermarkets were given as input.

Methods: The model reproduces logistic chains with microscopic commodity flows based on statistical probabilities. Vehicle flows on the infrastructure are generated based on shortest routes. Logistic cost optimization of actors is not modeled as far as can be judged, based on the available literature.

Logistic choices: Choices are not modeled based on actors behavior but on given probabilities for flows. Probabilities are given for locations used, modes, delivery frequencies. Locations of all establishments (warehouses, production facilities and retail stores) are assumed as given. Vehicle tours are modeled explicitly, including restrictions in vehicle capacity and maximum number of stops.

Model of the German BVWP

Purpose: The model implemented for the German infrastructure plan (BVWP) aims to predict future traffic flows on a national level (BVU et al., 2001).

Scope: The (so called micro) model follows the traditional aggregated four step approach as shown in figure 4.11. Additionally, two steps are included: the modeling of import and export, as well as the conversion from good flows into vehicle units after the mode choice. The model differentiates German NUTS 3 regions (about 440), 52 commodity groups, seven modes and 3 lot sizes.

Methods: For the generation of quantities of goods regression approaches are employed, for distribution a gravity model is used and mode choice is done with a nested logit model. The assignment is done with an aggregate procedure together with passenger traffic.

Logistic choices: The model works on the level of aggregated flows. Lot sizes are assumed as given, differentiated by commodity groups. Mode choice is modeled for aggregated flows. Location and supply path choices as well as vehicle tours are not considered.

ASTRA

Purpose: The ASTRA model (Schade, 2005) is a dynamic macroeconomic model that describes the development of the overall economic activity system in Europe, with special focus on transportation, including passenger and freight transportation.

Scope: The model is organized in modules. It comprises many aspects that do not directly describe transport, but are important to describe causes for and effects of transport, like the population module, the macroeconomic module or the environmental module.

The most important modules for the generation of freight transport are the regional economic module (REM) and the transport module (TRA):

The regional economic module (REM) calculates the generation and distribution of transport volume and passenger trips. The national freight volumes are generated with value-volume ratios based on the output of the input output analysis in the macroeconomic module (MAC). The international volumes are based on the foreign trade module. The REM module differentiates 53 "functional" zones[7], 15 production sectors for freight volume generation, three commodity types for distribution, and four distance bands for distribution.

The transport module (TRA) performs the modal split for the transport volumes, generated in the REM module. For freight it differentiates between 3 freight transport modes and four road types for road transport.

Methods: ASTRA is implemented using the system dynamics standard software Vensim. Within the system dynamics framework, it uses various other modeling methods like statistics, to estimate functional relationships between variables. In the REM module and in the TRA module logit models are used to model the choice between regions and between modes. Covering the overall economy and the linkages between its components, feedback loops can be described to explain phenomena of system behavior over time (system dynamics). One example of feedback loops for freight transport in ASTRA includes the effects from modal split, to demand per mode, to invest per sector, to final use per sector, to output per sector, to freight transport volume, to freight distribution and back to modal split (Schade (2005), p. 37). This shows the strength of system dynamics and ASTRA, which is to model complex dynamics of social systems on an aggregate level.

Logistics: ASTRA is an aggregate model, logistic choices are not modeled for "micro" actors. Mode choice is modeled with a logit model for aggregate flows, the other logistic choices are not represented explicitly.

[7] "The 202 NUTS II zones of the EU15 countries are grouped into four different zone types per country according to their population density and settlement patterns. As not all zones exist in every country this amounts in total to 53 entities." (Schade (2005), p.20)

4.4.3 Analysis models with limited scope

Besides these full blown transportation models, other analysis are carried out that concentrate only on specific aspects of transport. These analysis may include large models or just discussions on prototype actors, but all have the objective to generate insights on the overall freight transportation system or at least on a group of actors. Logistic aspects are often discussed this way.

This kind of analysis has a long tradition and often overlaps with literature from logistic optimization, Baumol and Vinod (1970) for example developed an inventory model of freight transport demand, with which the cost optimal transport mode choice is analyzed. Many logistic papers on lot size optimization are based on this work as shown in the section 4.3. A recent example of usage of the inventory framework for overall transportation system discussion is the paper of Blauwens et al. (2006) who uses it to analyze modal shifts. In this context also models should be mentioned that try to reduce complex logistic problems by focusing on the most important cause and effects. Examples for this are the methodolodgy of continous approximation introduced by Daganzo (2005) or models of Geoffrion (like Geoffrion (1979)) as shown in section 4.3.

The number of applied studies that could be mentioned in this context is probably very large. The following examples of recent model developments that go well beyond the optimization of single companies show the diversity:

- The model of Park (1995) describes mode decisions of railway customers in the context of an information tool for railway managers, aiming to analyze market responses. In the model the TLC approach is combined with a complex logit model incorporating latent variables and using revealed and stated preference data.
- The EULOG system (Eberhard, 2000) is a system for European distribution system planning that aims to analyze consequences of political measures on distribution structures. Therefore, distribution structures of individual (representative) companies are modeled.
- The work of Groothedde (Groothedde, 2005) describes a model for collaborative network design. It introduces a new methodology that simulates the development paths of networks. The paths are determined by decisions of organizations whether to join the network or not. The main drivers for this decisions are potential savings and transaction costs for the organizations.

4.5 Conclusions

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 4.13 has to be handled with care since it is very simplified. It shows which kind of logistic choices are represented in the models discussed. 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 con-

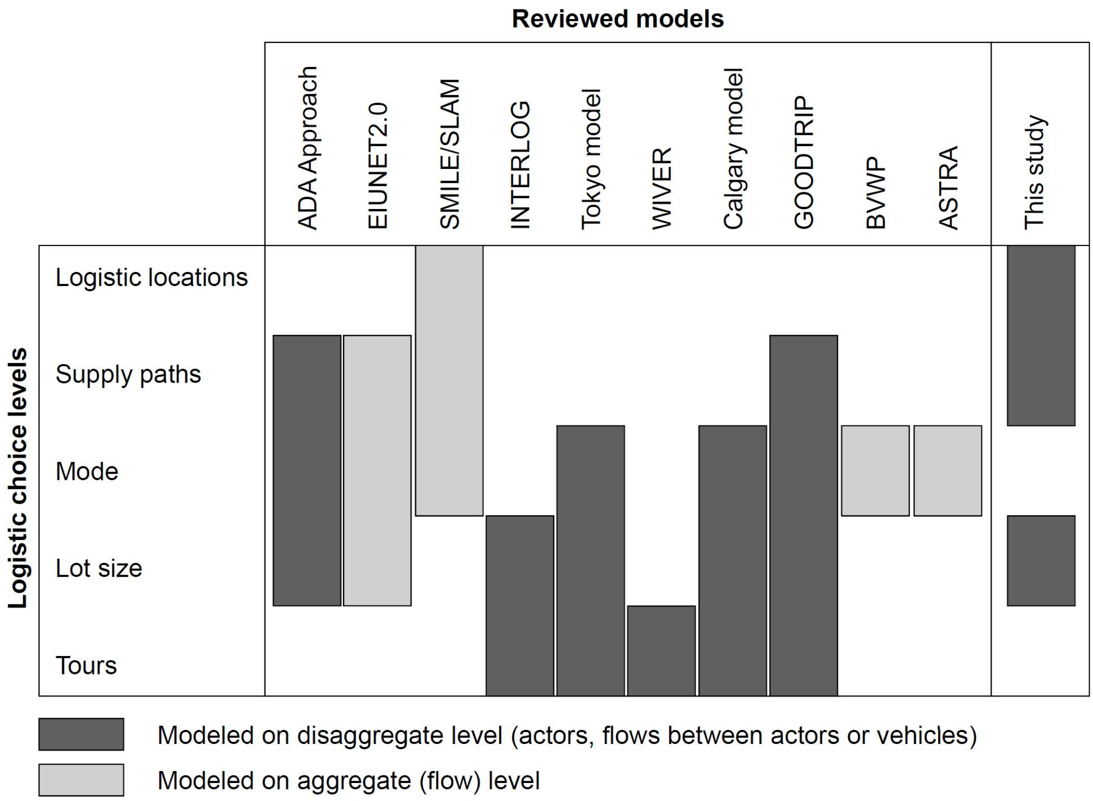

Figure 4.13: Simplified view on logistic choices in freight transportation models

text, 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 as shown in the last paragraph.
- 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 emergence of warehouse locations resulting from distribution channel choice for aggregate flows is modeled in SMILE. Warehouse structures on a disaggregate level (individual companies) are not yet part of any transportation model (to the author's knowledge).

Two reasons why complex logistic structures (containing locations) are not yet modeled disaggregated 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.

5 SYNTRADE - model definition

The last chapter showed that the disaggregated modeling of logistic structures including logistic locations is not yet represented in freight transportation models. Most experts explain this by the heterogeneity in freight transportation which implies an immense data demand, if traditional modeling methods (mainly statistical) are used. On the other hand, it was shown that modeling approaches from the area of logistic optimization exist that can be used to model the emergence of structures and therefore the system functioning. It was also shown in the second chapter that, on a more detailed sectoral level, many data sources exist that are not yet used for transportation modeling. The SYNTRADE simulation model described in this section uses these modeling approaches and data sources to model logistic structures for the food retailing sector. By representing more sectoral specifics, new data sources can be used and by using approaches from logistic optimization, data demand can be reduced. The main focus of the model will be on the sector of food retailing as defined in the second chapter. Nevertheless, the model has to include the distribution of all consumer products into its scope since interdependencies in logistics exist. Therefore, flows that do not pass through the food retailing sector are modeled in a simplified way.

In this chapter, SYNTRADE will be described in detail. An overview of the model has been given in chapter 2, the following sections give detailed descriptions of the model phases and the simulation procedures.

5.1 Input data generation

This section describes the generation of input data for the simulation, including the generation of an artificial economic landscape and commodity flows. Locations for the generated establishments are represented in form of NUTS 3 regions, 439 German and 42 European regions. Distances between the regions were calculated with the Dijkstra algorithm (Dijkstra, 1959) based on road network data. For the simulation the resulting distance matrix dis_{ij} (distance between region i and j) is used. The distances within a region (dis_{ii}) are estimated by taking the average distance between two points in a circle area (see section 4.2.4).

In the following, the generation of the artificial economic landscape, of retail companies and of the resulting commodity flows will be described in detail.

5.1.1 Generation of artificial economic landscape

Before an artificial economic landscape can be generated, some data preparation is done: the economic activity considered is defined, based on national accounting and disaggregated to the model sectors. Open spots in employment data are filled and distributions of establishment sizes are estimated. This is described before the generation procedure will be discussed in detail. Imports, agriculture, logistic service providers and wholesaling will be described separately since data availability implies different representations in the model.

Estimation of economic activity to be considered

The estimation of total economic activity considered is based on data from national accounts (input output statistics). The scope includes all good flows destined for consumption and all flows destined for sectors that use consumer products like restaurants. Data from this statistic is however only provided in an aggregated form, mostly on CPA 2-digit level. The model on the contrary works partly on a much more detailed level, the classification of sectors in the model is oriented to assortments in food retailing and partly contains classes on the 4-digit CPA level (see appendix B.2). Therefore, data from national accounts has to be disaggregated to the detailed level in the model. This is done by using two different data sources, production statistic for the disaggregation for inland production (Statistisches Bundesamt, 2006c) and international trade statistics (Statistisches Bundesamt, 2006a) for disaggregation of imports:

Given is the total supply of goods (in values of purchasing prices) in each aggregate sector s_{as}, divided into national origin s_{as}^{nat} and international origin s_{as}^{int}, based on adapted data (only consumer products) from national accounts. Also, the proportions for the disaggregate sectors for national production $p_{ds}^{as,nat}$ (determined from production statistics) and imports $p_{ds}^{as,int}$ (determined from international trade statistics) are given. Thus, estimations of supply in disaggregate sectors from national production s_{ds}^{nat} and from imports s_{ds}^{int} can be calculated by:

$$s_{ds}^{nat} = p_{ds}^{as,nat} * s_{as}^{nat}$$

$$s_{ds}^{int} = p_{ds}^{as,int} * s_{as}^{int}$$

where
- s_{ds}^{nat} = National supply in disaggregate sector
- $p_{ds}^{as,nat}$ = Proportion of disaggregate sectors on national production in aggregate sector
- s_{as}^{nat} = National supply of goods in aggregate sector
- s_{ds}^{int} = International supply in disaggregate sector
- $p_{ds}^{as,int}$ = Proportion of disaggregate sector on imports in aggregate sector
- s_{as}^{int} = International supply of goods in aggregate sector

Based on these estimations, the estimated proportions of origins (national or international) $p_{nat}^{ds}/p_{int}^{ds}$ can be determined for each disaggregate sector:

$$p_{nat}^{ds} = \frac{s_{ds}^{nat}}{(s_{ds}^{nat} + s_{ds}^{int})}$$

$$p_{int}^{ds} = \frac{s_{ds}^{int}}{(s_{ds}^{nat} + s_{ds}^{int})}$$

To simplify the reading in the following, the differentiation between sector levels and classifications will not be laid out in detail any more. Only the general term of sectors s will be used, referring to the model classification of sectors. For the implementation of a model, however, the matching between different classification clearly represents a difficulty and driver of complexity.

Employment data preparation

Employment data in form of employees per region and sector em_{rs} on a level of NUTS-3 regions and 3-digit CPA sectors serves as input for the generation model. In Germany, such data is available from the employment agency. However, some data points are left out due to confidentiality issues. Since these data points do represent less then four percent of total employees, they can be filled by estimation without significant impact on the overall data quality. For filling the open data spots, the "Furness" method is used twice:

In a first step, employees per NUTS 3 sector on the national level em_s^{nat} and total employees per state em^i are given and open data spots in the matrix of employees per sector and state em_s^i are filled.

In a second step, open data spots of the matrix em_{rs} (employees per region and sector) are filled for each state, using the results from the first step.

Thus, a complete matrix of employees by NUTS-3 regions and 3-digit CPA sectors can be provided.

Estimation of establishment size distribution

For generating establishments with "Monte Carlo" simulation, the distribution of number of employees per establishment is needed. In Germany, the statistical office publishes the number of establishment by establishment size categories on a 4-digit CPA level for producing sectors, also the number of employees in these categories is published. As described by Liedtke (2006), there are three characteristics in this data that have to be reflected in the estimated distribution function:

- For almost all sectors, the lowest category contains most of the establishments.
- For almost all sectors, the average number of employees in the first category is above the average number of the category, the situation is reversed for the second category.
- For almost all sectors, values exist in the highest category, which means that the distribution has to have a long tail.

Liedtke (2006) proposes the following function to model the distribution:

$$f(em) = \frac{1}{N}\frac{\frac{em}{E}^{\beta}}{(\frac{em}{E}+k)^{\beta}}$$

where

f	=	Probability density
em	=	Number of employees
k, α, β	=	Shape parameters
N	=	Normalizing factor
E	=	Scaling parameter

The parameters of this function in this study are estimated for each 4-digit CPA sector. The calibration is done based on the available data, which can be represented in form of probabilities of establishments in the categories and probabilities of employees in the

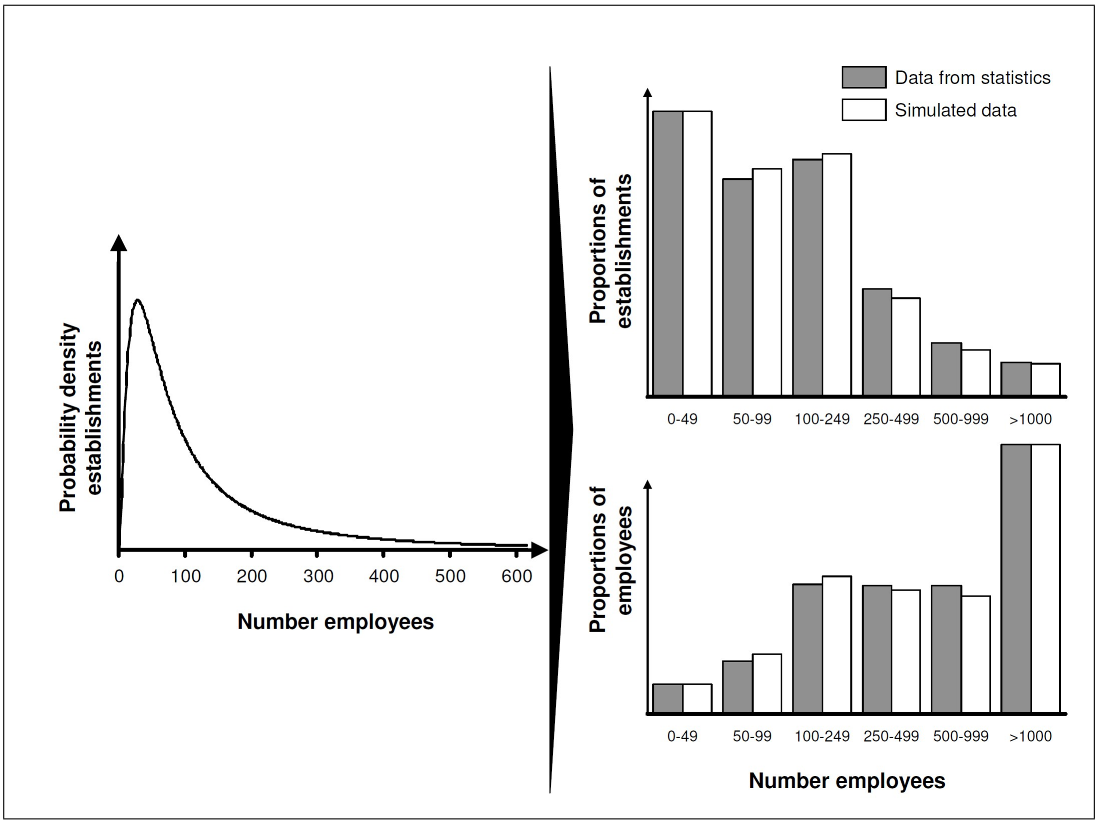

Figure 5.1: Estimation of an establishment size distribution (example CPA sector 2700)

categories. Figure 5.1 shows the available data and the estimated function for an exemplary sector (CPA 2700). The parameters were estimated by minimizing the delta to the statistical data within the categories:

$$Min \sum_{c} | p_c^{est} - \tilde{p}_c^{est} | + \sum_{c} | p_c^{em} - \tilde{p}_c^{em} |$$

where

c	=	Categories
p_c^{est}	=	Probability of establishments in category c from statistic data
$\tilde{p}_c^{em}$	=	Probability of establishments in category c from simulated data
p_c^{est}	=	Probability of employees in category c from statistic data
$\tilde{p}_c^{em}$	=	Probability of employees in category c from simulated data

The modulus of the delta and not the square is taken, since by taking the square, it would be emphasized to avoid higher deltas instead of focusing on a low average delta. To account for the relative size of the deviation, also a weighted delta (based on the proportion) could be taken for estimation. This was not done in this case because of the minor impact on the results and the better interpretability of the proposed estimation.

Parameters were simulated to determine the best fit. The resulting average delta for the estimated distributions is about 3 percent for establishment probabilities and about 1.5 percent for employee probabilities which shows the high fit of the chosen function.

Generation procedure

In this paragraph, the algorithm for the establishment generation is described. It is composed of two steps, first, the establishments are generated, then these establishments are allocated to regions. Both parts are represented in form of flow charts in figure 5.2 and figure 5.3. For reasons of simplicity, the inclusion of matchings between sector classifications in the algorithm[1] and details on handling specific cases within the algorithm are left out.

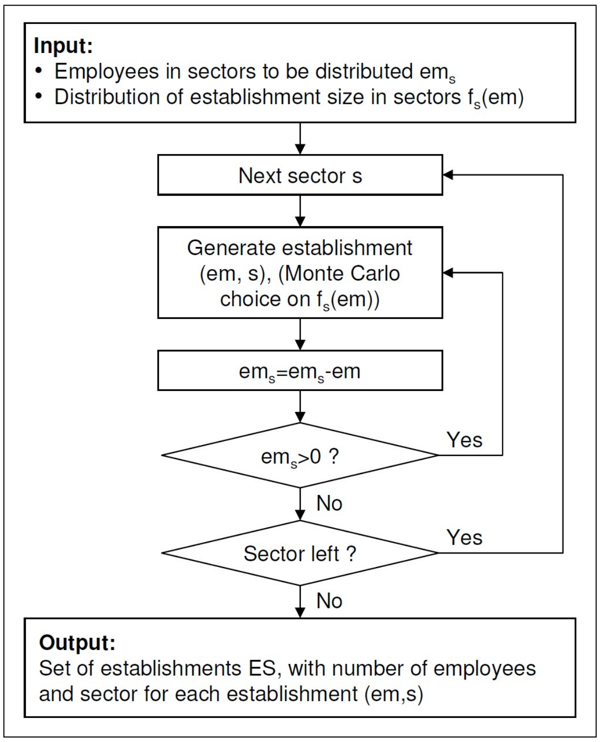

Figure 5.2: Simplified algorithm to generate establishments

As input for the generation of establishments, the distribution of establishment sizes and the number of employees per sector to be distributed are given. This number of employees does not represent the total number employees in each sector, but only the proportion that corresponds to the sector output, destined for consumers or sectors that use consumer products like restaurants.

In the algorithm, establishments are generated with "Monte Carlo" simulation as long as employees to be distributed are left. The distribution of establishment sizes, whose estimation was described in the last paragraph, is used within the Monte Carlo choice process. As output, a set of establishment with number of employees and sector for each establishment is provided. The main assumption within this generation is that establishment sizes are distributed the same way in regions as they are distributed within the overall country.

[1] the model works with a sector classification on the 3- and partly even on the 4-digit CPA level, employment data is provided on 3-digit CPA level, establishment size data is provided on a 4-digit CPA level

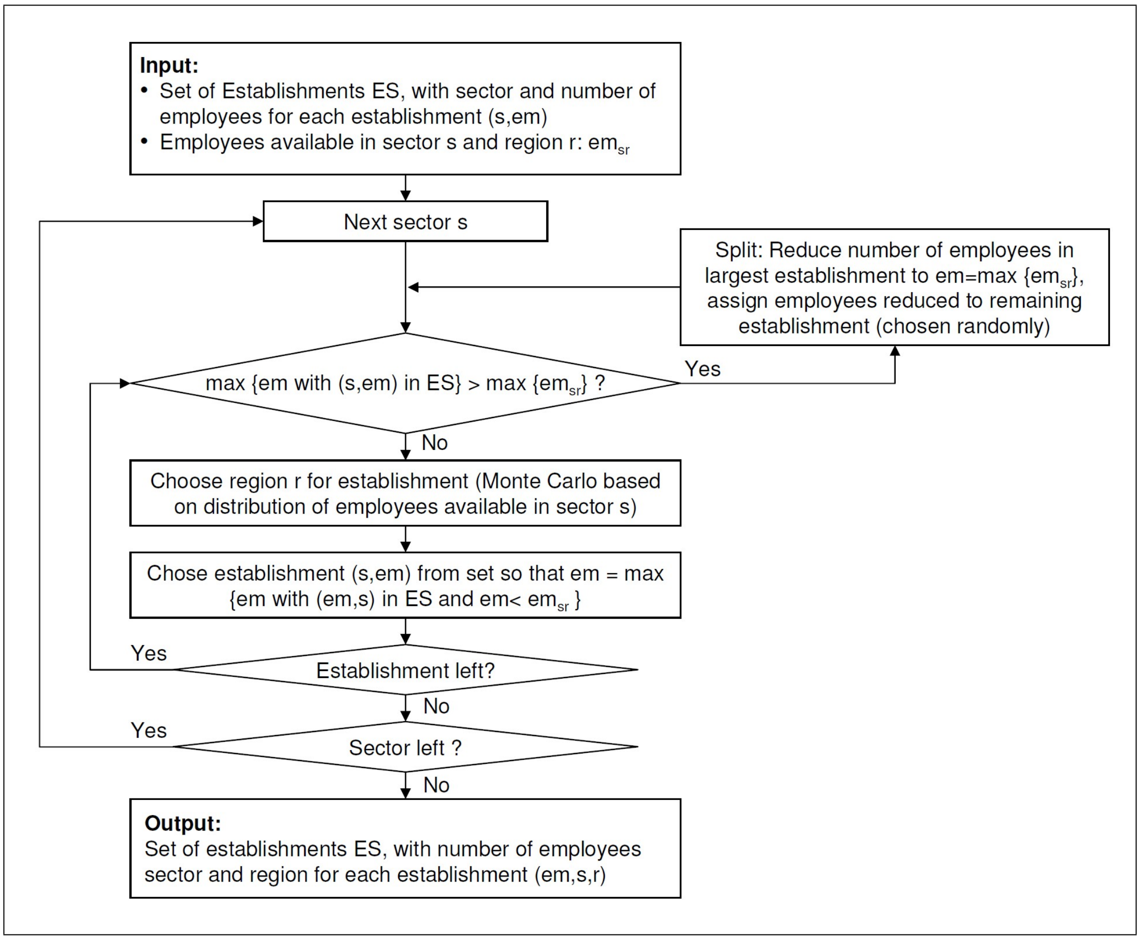

Figure 5.3: Simplified algorithm to allocate establishments to regions

This set of establishments and data on employees, available for each region-sector combination, form the input for the second part of the algorithm which allocates the establishments to regions.

In case the total number of employees has to be allocated to establishments (not only the proportion for consumer goods production) the problem described would be equal to the bin-packing problem.

The model focuses to keep the exact number of employees for the sector-region combinations and also keep changes to establishments as low as possible.

Changes to the number of employees within establishments have to be made if the number of employees of the largest establishments exceeds the number of employees available in any region. In this case the initially generated establishment is split. Two things are done to keep the impact on the overall distribution of number of employees per establishment limited. Firstly, regions that are chosen for allocation get the largest establishment possible. Secondly, in case of a split, the number of employees of the establishment considered is only reduced to the maximum number of employees available

and data from input output analysis used to determine the part of establishment covered in the model is provided on a 2-digit CPA level in any region. As output, the algorithm produces the completed list of establishments with number of employees, sector and region for each establishment.

Despite the splitting, the results in respect to the distribution are still very precise. The resulting average delta (simulated data to statistical data) is about five percent for establishment probabilities and about nine percent for employee probabilities. The delta decreases when large numbers are simulated. If only sectors are considered where more than 50 establishments are simulated (44 of 76 sectors), the average delta drops to three percent for establishment probabilities which is the same as the initial delta of the distribution and to about five percent for employee probabilities. The reason for the higher delta of employee proportions is that usually a small number of large companies get split. This has a higher impact on number probabilities than on establishment probabilities. Still, the distribution of size of the reproduced establishment structure is very close to the initial statistical data.

The turnover t_{ES} for the generated establishments is estimated based on total supply of the sector s_s, determined at the beginning of this subsection, the total number of employees considered in the model em_s and the number of employees of the establishment:

$$t_{es} = \frac{s_s}{em_s} em_{ES}$$

The output of the overall procedure are establishments with employees and turnover that belong to a sector and a region $ES = (em, t, s, r)$.

Representation of imports

Since the scope of the model is limited to Germany, imports are represented in a simplified way. Each sector of each country is represented as one supplying entity, assuming that bundling of products does occur in the originating countries. Geographically, it is assumed that goods from other countries are reloaded in logistic hubs in Germany, if less than truck load is transported. Therefore, for European imports an average distance between German regions is assumed. For non European imports, Hamburg is taken as origin location, since the port of Hamburg represents the main entry point for non European imports in Germany.

Since the model considers only parts of total consumption, imports have to be adapted accordingly. The proportions of imports from a country c in one sector $p_c^{s,int}$ are determined based on international trade statistics.

With these proportions, the supply in sectors originating from imports s_s^{int}, described at the beginning of this section, can be disaggregated to country level $s_c^{s,int}$.

$$s_c^{s,int} = s_s^{int} * p_c^{s,int}$$

These virtual supply entities with information on turnover, region and sector (t,r,s) are added to the list of establishments.

Representation of agriculture

Like imports, also the sectors agriculture and fishing are represented in a simplified way. This can be justified by the tendency to have regional supplier associations in form of cooperatives ("Genossenschaften" in Germany). As for imports, it is assumed that supplying entities exist on the regional level. So each region has a supplying entity for each of these sectors. The quantity thus supplied by each region $s_r^{a/f}$ is calculated based on the proportion of employees, considered in the agriculture or fishing sector in the region $em_r^{a/f}$ to total employees considered in the sector $em^{a/f}$:

$$s_r^{a/f} = \frac{em_r^{a/f}}{em^{a/f}} * s^{a/f}$$

These supply entities with information on turnover, region and sector (t,r,s) are added to the list of establishments.

Representation of LSP and wholesaling

Finally, also LSPs and wholesalers are represented in a simplified fashion. Classifications were designed for logistic markets and wholesale markets that are linked to the model sectors. Only goods from sectors that are linked to the same "logistic" or "wholesaling" markets can be bundled for interregional transport or regional distribution. The classifications limit bundling and make a distinction between different types of goods in logistic and wholesaling possible. Three transport sectors (non food, dry food and cold/frozen food) and sixteen wholesaling sectors are differentiated (see discussion in section 3.3 for details).

The model assumes that in each region one LSP and one or multiple wholesalers of each kind exist.

5.1.2 Generation of retail companies

The food retailing sector is the core of the model, therefore its representation is much more detailed and partly even based on real company data. Not only establishments are generated but companies with their corresponding stores. Turnover of companies is further disaggregated to groups of articles, called article types in the following. Through additional information on these article types, links to the supplying sectors are estimated. Thus, important data on number of suppliers and distribution of turnover per suppliers can be generated. This will be described in more detail as follows.

Company and store data preparation

The model expects data on companies and their stores, including:

- Company turnover t^C
- Split of turnover to store types t_{sty}^C or sales channels t_{sc}^C. General store types were introduced in section 3.3. To include also company specifics (like differences in turnover or number of articles), the notion of sales channel is introduced at this place, which is similar to the concept of store types but specific to companies.
- Stores with locations (on a NUTS-3 level) and affiliation to sales channel. The turnover is assumed constant for all stores of a sales channel.

About 30 companies, 90 sales channels and 440 regions are differentiated resulting in a database with about 30.000 datasets for the store information in regions.

Adequate data on allocation of stores to regions and to companies as well as turnover information on sales channels is available or can be estimated. For the majority of regions (about 350) real data was available for this study, for the remaining regions (about 100) data had to be estimated. However, also for these estimations various control points are available on different aggregate levels:

Let $n^C_{r,st/sc}$ be the number of stores in region r, from company C and of store type/sales channel type st/sc. Aggregate data is available for:

Multiple regions (on NUTS-3 and NUTS-2 level):

$$\sum_C n^C_{r,st} = n_{r,st}$$

For companies:

$$\sum_r n^C_{r,sc} = n^C_{sc}$$

For store types as estimated in section 3.3:

$$\sum_r \sum_C n^C_{r,st} = n_{st}$$

The same also accounts for turnover data.

To fill the open data spots sociodemographic indicators were identified that explain best the distribution of stores. It turned out that indicators connected to number of inhabitants like number of inhabitants delivered better results than GDP or income data. A detailed analysis can be found in Pirk (2008).

Besides turnover and number of stores, also data on article numbers is expected as input. For sales channels where no real data is available, the number of articles is estimated, based on published average article numbers of store types adjusted to the level of turnover of the sales channel under consideration.

As a result, companies and stores can be generated that closely meet data points on the aggregate levels (regions, totals for overall market) as well as data points on company level. Company specific sales channels were introduced to reflect differences in turnover and number of articles in stores, which is important for the resulting differences in the warehouse structures, as will be shown later.

Data disaggregation to article types

The sales channel data is further disaggregated to article types. The model differentiates between 41 article types (see appendix B.1), the classification is oriented at the GS1 standard that is widely used in food retailing. For these article types following data is available or can be estimated (as shown in section 3.3):

- Value density on volumes and weights (EUR/t or EUR/m^3), number of pallets can be used as entity that incorporate both - the pallet number is determined from weight or volume depending on which represents the limiting factor.

- Links (matching) to the corresponding economic sectors that produce these articles. Thus, the linkage between food retailing and sectors is modeled on a very detailed level.
- Proportions of turnover $pr_{at}^{sty,t}$ and articles $pr_{at}^{sty,a}$for different store types. These proportions are taken to disaggregate the turnover and article numbers of sales channels.

The disaggregation of turnover t and number of articles a is done on the level of sales channels:

$$t_{at}^{sc} = pr_{at}^{sty,t} * t^{sc}$$

$$a_{at}^{sc} = pr_{at}^{sty,a} * a^{sc}$$

After this disaggregation, number of articles and turnover on the level of article types has been generated. On this level, data on value densities as well as links to economic sectors are estimated.

Generation of commodity flows

Based on this disaggregate data (especially the article number for article types and sales channels), the model determines number of suppliers and the corresponding turnover with suppliers. Thus, it generates commodity flows. The algorithm is shown in figure 5.4. To represent the fact that retail companies have integrated sourcing for different sales channels, several commodity flows destined to different sales channels are allocated to the same supplier. One commodity flow from each sales channel with the same article type is allocated to a "virtual supplier", the concrete supplier will be chosen in the next model step.

The algorithm first determines the number of total suppliers for a sales channel depending on the number of articles a^{sc}. Stores with high number of articles also have a high diversity in suppliers, imagine for example a discounter and a large supermarket. This is reflected in the model, by using a concave relationship ($0 \prec \beta \prec 1$). The parameters are determined based on the assumption that a hard discounter sources about four articles per supplier and a large supermarket about ten articles per supplier.

In the next step, the number of suppliers for each article type is determined proportionally to the number of articles. For each supplier a commodity flow is generated. The turnover for this commodity flow is determined, based on a Pareto distribution indicating the differences between suppliers in quantities ordered (see section 3.3). Parameter k indicates different courses of the Pareto density function depending on the store type. Six different parameters are assumed within the model (k=1 for hard "Discounter", k=2 for soft "Discounter", k=3 for "SB-Geschäfte", k=4 for "Supermärkte", k=5 for "Verbrauchermärkte" and k=6 for "SB-Warenhäuser"). Thus, the differences in order volume are more pronounced the more articles a store types has.

The generated commodity flow is then allocated to a virtual supplier. If no virtual supplier exists for the article type or all virtual suppliers already have been allocated a flow from this sales channel, a new virtual supplier is generated.

The output consists of a list of commodity flows and sets of commodity flows from virtual suppliers. In the model, about 150.000 commodity flows are generated for 31 companies and 89 sales channels.

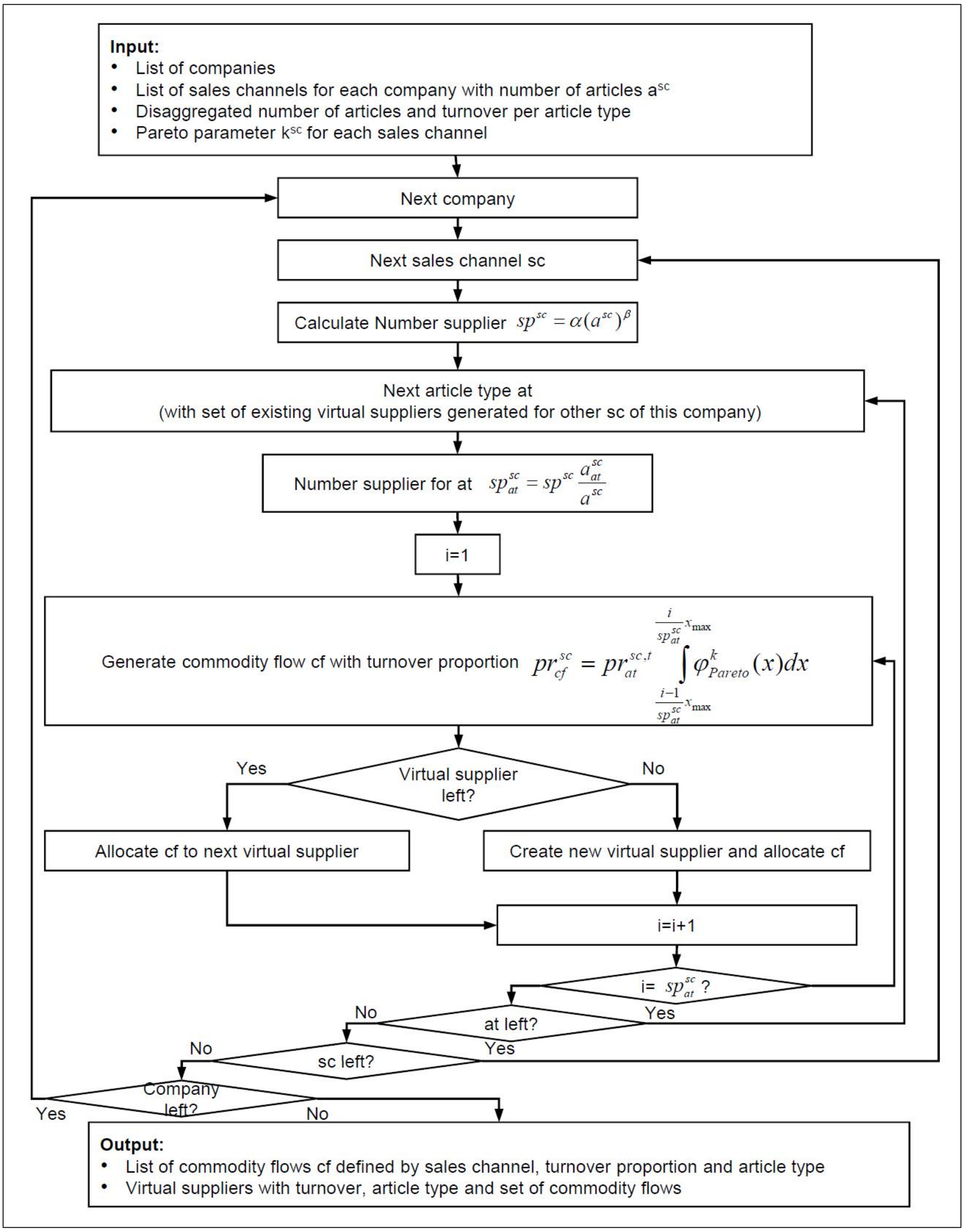

Figure 5.4: Simplified algorithm to generate commodity flows

5.1.3 Supplier selection and generation of region flows

In the next step, the food retailing sector and the economic landscape are connected. The suppliers of food retailing companies are determined by allocating the prior defined sets of commodity flows to supplier establishments, generated before. The remaining supply of consumer products is distributed between suppliers and regions by applying a gravity model and adapting the resulting matrix with the "Furness" method.

Supplier selection for retailing companies

The selection of suppliers for food retailing companies is represented in a simplified way within the model. It is assumed that sourcing is done on a national and international level, suppliers are chosen purely based on turnover, distances to suppliers are not considered. This corresponds to the statements in the interviews that most products are sourced nationally or internationally for the overall company demand. The sourcing of regional products is not considered since it is assumed to be minor and corresponding data is not available. The simplified algorithm is shown in figure 5.5.

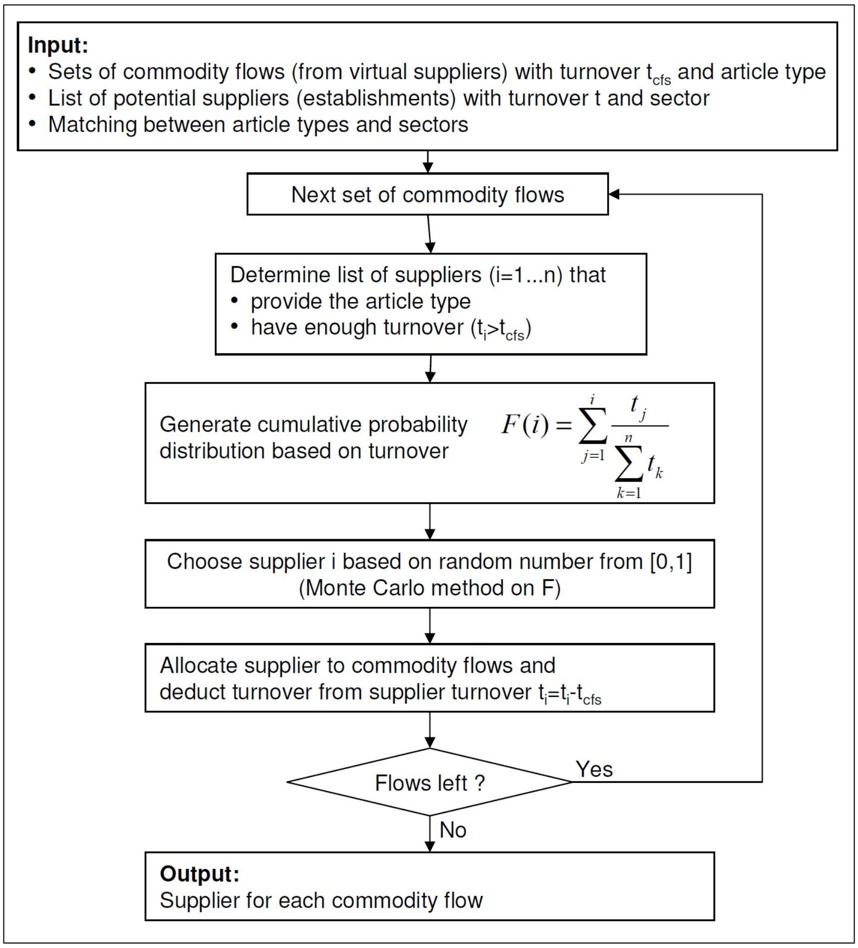

Figure 5.5: Simplified algorithm to simulate sourcing of retail companies

As input, the module expects a list of sets of commodity flows from virtual suppliers and the list of suppliers as well as the matching between the article types and the sectors of the suppliers. In the following steps, suppliers are chosen for the sets of commodity flows based on a "Monte Carlo" like process. Therefore, at first a list of potential suppliers is generated for a set of commodity flows. This list contains all suppliers that have enough turnover left to satisfy the cumulated demand of the flows and are part of a sector that matches the article type. Then, probabilities are generated, based on supplier turnover, and subsumed in a cumulative distribution function F. The supplier is chosen based on a random number and allocated to the flows. The turnover is deducted from the available turnover of the supplier. As result, a supplier is allocated to each commodity flow.

Distribution of remaining consumer products

After having determined suppliers for the food retailing sector, the remaining consumer product demand is distributed between suppliers and consuming regions.

Based on the results of the sourcing decision, the turnover with the food retailing sector can be determined for each supplier. The remaining turnover needs to be distributed to the regions. Through the knowledge on store locations and assortment turnover of the food retailing sector also the demand for consumer products in regions satisfied by the food retailing sector is known. The total demand for consumer products can be estimated based on the IO statistic which includes end user consumption and consumption within sectors. This sector demand d_s can be disaggregated to regions $d_{s,r}$ through sector specific indicators $i_{s,r}$.

$$d_{s,r} = i_{s,r} * \frac{d_s}{\sum_r i_{s,r}}$$

For end user consumption, the number of inhabitants was taken, for consumption within sectors, the number of employees. Reducing this region demand by the demand already satisfied by the food retailing sector, the remaining demand in regions can be determined.

The distribution of the remaining turnover t_j of suppliers j and demand $d_{s,r}$ of sectors s in regions r is modeled with a gravity approach. The initial distribution is given by:

$$t_{j,s,r} = t_j d_{s,r} e^{-\alpha \frac{dis_{j,r}}{t_j}}$$

The deterrence function includes the distance $dis_{j,r}$ between company j and region r as well as the turnover of the company. The turnover is included to represent the fact that for consumer products from larger companies the distances (at least within Germany) do not matter whereas small companies tend to sell rather within their origin region.

To adjust the distribution to column and row totals, the furness approach is used as described in the last chapter. The matrix $T_{j,s,r}$ in the model is large containing more than 17.000 suppliers, about 450 regions and about 30 sectors. The matrix handled contains about 8 million matrix entries (since each supplier belongs only to one specific sector).

The resulting flows from suppliers to regions are referred to as "region flows" in the following.

5.2 Simulation of logistic environment

To this point, only the generation of input data for SYNTRADE was discussed. In this and the following section, the simulation will be defined, describing logistic decisions.

In this section, the simulation of the logistic environment of the food retailing sector is described. This represents the model periphery introduced in chapter 2. The main decision modeled is the supply path decision for commodity flows to food retailing stores and for region flows from suppliers to regions. At first, the paths alternatives will be outlined including the determination of costs connected to these alternatives. Afterwards, the simulation procedure is described in more detail. This is important since sequence and scope can influence the results of this simulation.

5.2.1 Supply path alternatives and costs

The supply path alternatives in the model are shown schematically in figure 5.6. The

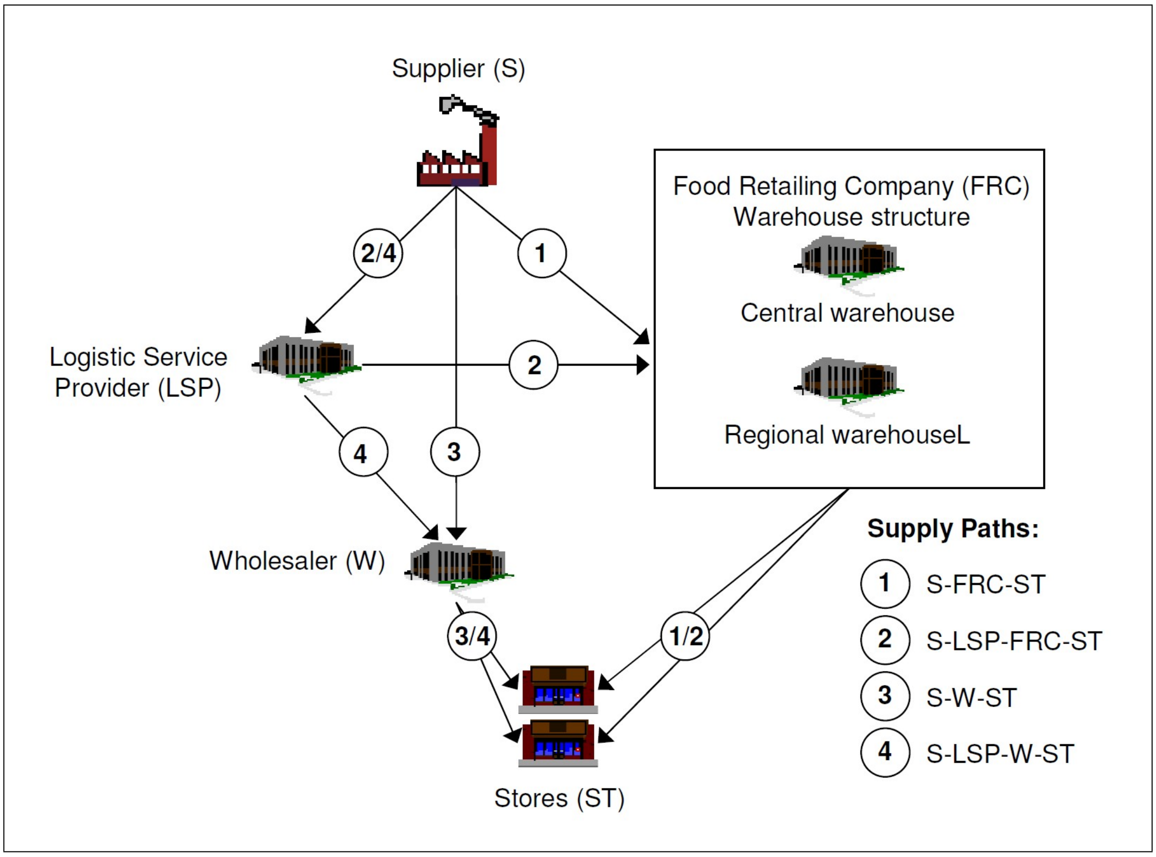

Figure 5.6: Supply paths alternatives

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:

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

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. All cost components will be detailed in the following paragraphs.

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.

Lot size optimization

Lot sizes are calculated separately for each link of the supply path since bundles can be different on each link. This distinguishes this model from recent freight transportation models (like Ben-Akiva and De Jong (2008)). The flows on each link are bundled and the lot size is calculated for the overall bundle, the quantity (number pallets) of this flow is the sum of the quantities of the individual flows and the value corresponds to the sum of values of the individual flows. The result of the calculation is the optimal lot size for the overall flow. The break down of costs to the individual flows, however, can be difficult and will be discussed in a separate paragraph, following this one.

The lot size model for the overall flow consists of two main cost components. The first component represents the costs for storing the good (inventory cost). These costs are part of warehouse costs that will be described in detail in the next section. The storing costs per pallet sc_{pp} comprise the marginal warehouse costs that occur when one additional pallet is stored. Since the model has a midterm horizon and warehouse sizing is therefore changeable, the marginal costs include all warehouse cost driven by the number of pallets. The warehouse costs are formulated in a way that these costs can be isolated (wc_{vpp}). These costs are meant to be variable in the number of stock positions in the warehouse, not in terms of throughput - the throughput costs are covered by the handling costs HC. In addition, the storing costs include costs for capital depending on the value of a pallet v_{pp}. As capital costs the weighted average costs of capital $wacc$ is assumed:

$$sc_{pp} = wc_{vpp} + wacc * v_{pp}$$

The second cost component are transport costs. The costs for a full load truck are determined based on a simple approach including a cost rate $tcr_{inbound}$ and the distance dis:

$$tc_{full} = dis * tcr_{inbound}$$

The cost rates are estimated based on real price data of logistic service providers (transport cost matrices). For distances, the distances between regions are assumed for flows to LSPs and wholesalers. For flows to food retailing companies the weighted average distance between the delivery region and all other regions in Germany is taken. Based on these full costs, lot size Q dependent transport costs are estimated with the approach described in the last chapter:

$$tc(Q, dis) = tc_{full}(dis)(\alpha Q + \beta Q^{\gamma})$$

The total logistic costs considered in the model for a flow of X pallets per year are hence:

$$TLC(Q) = SC + TC = \frac{1}{2} sc_{pp} * Q + \frac{X}{Q} tc_{full}(\alpha Q + \beta Q^{\gamma})$$

This results in an optimal lot size of

$$Q^* = \frac{sc_{pp}}{2X tc_{full} \beta (1-\gamma)})^{\frac{1}{\gamma - 2}}$$

where

Q^*	=	Optimal lot size
sc_{pp}	=	Storing costs per pallet
X	=	Volume of commodity flow (in pallets)
tc_{full}	=	Transport costs for a full load truck
α, β, γ	=	Model parameters

Additionally, a number of constraints are considered:

- The lot size is limited to the maximum capacity of the truck cap_{truck}.
- The lead time has to be oriented at the period of perishability t_{per} of goods. Based on the expert interviews it is assumed that only a third of this time is used for logistics, this time is split by the number of warehouses used on the supply path.

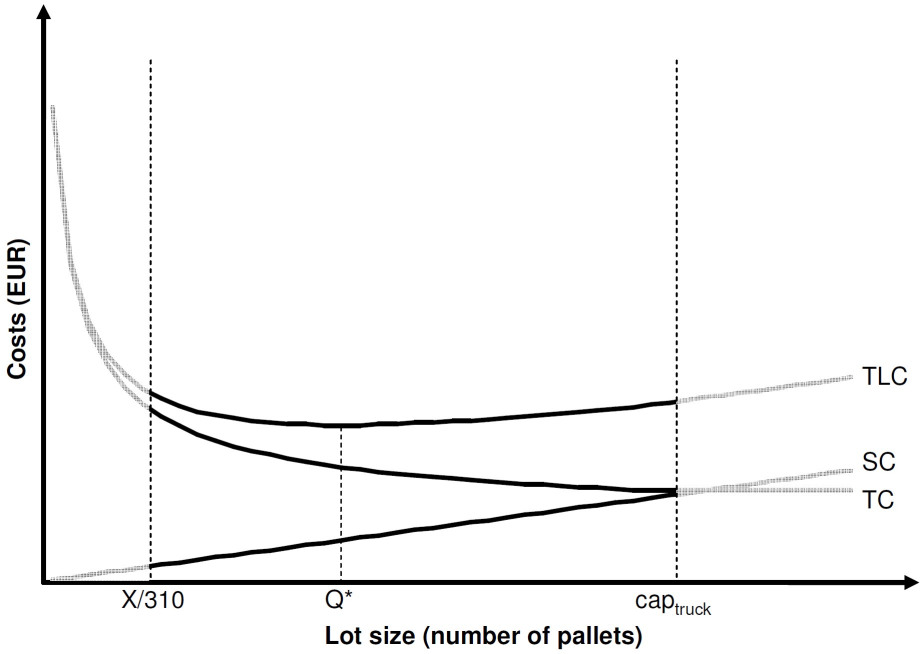

Figure 5.7: Lot size determination

- It is assumed that at least one day is needed for the usage of every warehouse, therefore the batch has to be at least the quantity consumed in one day $\frac{X}{310}$ (assuming 310 days of operation).
- Finally, a minimum lot size of one pallet is assumed.

Summing up the final lot size Q is determined by:

$$Q = min\{cap_{truck}, \frac{X}{310}\frac{t_{per}}{3}, max\{Q^*, \frac{X}{310}, 1\}\}$$

An example of an optimal lot size determination is represented graphically in figure 5.7. Two bounds resulting from the constraints are represented in the graph: a lower bound representing the minimum lot size of the demand consumed per day, and an upper bound representing maximum truck capacity. Also transport costs do not decrease any more, if a lot size larger than truck capacity is chosen. The other constraints can be represented accordingly. The optimal lot size in this example is not concerned by these bounds.

Cost breakdown to individual flows

As described in section 4.3.2, the simplifying approach of the one product case is assumed for the lot size model. This can be done by assuming that "ordering costs" only occur for the general bundle (in form of transport costs) and that the remaining handling costs behave linear to the number of pallets.

The resulting lot size is an optimum for the overall flow. Nevertheless, it can be difficult to break down the costs to individual flows since the marginal costs of a new flow in the bundle depend to a large extend on the existing flows in the bundle. If the breakdown shall be done by full costs, on the other hand, an indicator is needed that distributes the costs according to the part of costs "caused" by the individual flows. The costs are driven by volume (number of pallets) and by value of the flow. If the value per pallet of the flows is equal, the costs can be broken down by the number of pallets, if they are different, however, the costs thus allocated to the flow with higher value would be too low. The similar effect accounts for a breakdown by value.

The economic "correct" indicator for the breakdown of costs are the average marginal costs that each flow causes in regard to the rest of the bundle (Shapley value). For this allocation, the average marginal costs of each flow have to be recalculated each time a new flow joins the bundle. This is not feasible when modeling millions of bundled flows.

As approximation, pallet driven costs are broken down by number of pallets and value driven costs are broken down by value. Thus, the costs for a commodity flow C_{cf}, depend on its volume X_{cf} and its value per pallet v_{pp}:

$$C_{cf} = \frac{X_{cf}}{X} * (TC + wc_{vpp} * \frac{Q}{2}) + \frac{X_{cf} * v_{pp}^{cf}}{X * v_{pp}} * wacc * v_{pp}$$

where

C_{cf}	=	Logistic costs on transport link for commodity flow
X_{cf}	=	Volume of commodity flow (pallets)
X	=	Volume of the overall flow bundle (pallets)
TC	=	Transport costs for flow bundle
wc_{vpp}	=	Marginal long-term warehouse costs per stock position
Q	=	Lot size
v_{pp}^{cf}	=	Value per pallet of commodity flow
v_{pp}	=	Value per pallet of flow bundle
$wacc$	=	Weighted average costs of capital

Still, this is an approximation since through the combined optimization of the overall bundle, high values also lead to higher pallet driven costs. However, this effect is neglectable in most cases.

Finally, an approximation has to be made for the case of different periods of perishability of flows. In this case, the calculation is repeated for different periods of perishability and for each flow the corresponding result of an assumed bundle with equal periods of perishability is taken. Again, this approximation can be justified through the reduction of complexity for the model, otherwise, a combinatorial problem would have to be solved.

Cost calculation within the food retailing company

Two kinds of warehouse structures are differentiated for food retailing companies: warehouse structures that only consist of regional warehouses (one level structure) and structures that consist of regional and central warehouses (two level warehouse structure). The resulting options for supply paths are shown in figure 5.8.

In case of a one level warehouse structure, the costs are calculated based on the lot size model shown before for every regional warehouse. The quantity delivered to one warehouse X_{RW} corresponds to the total quantity delivered by the supplier to the food retailing company X divided by the number of regional warehouses n_{RW}:

$$X_{RW} = X/n_{RW}$$

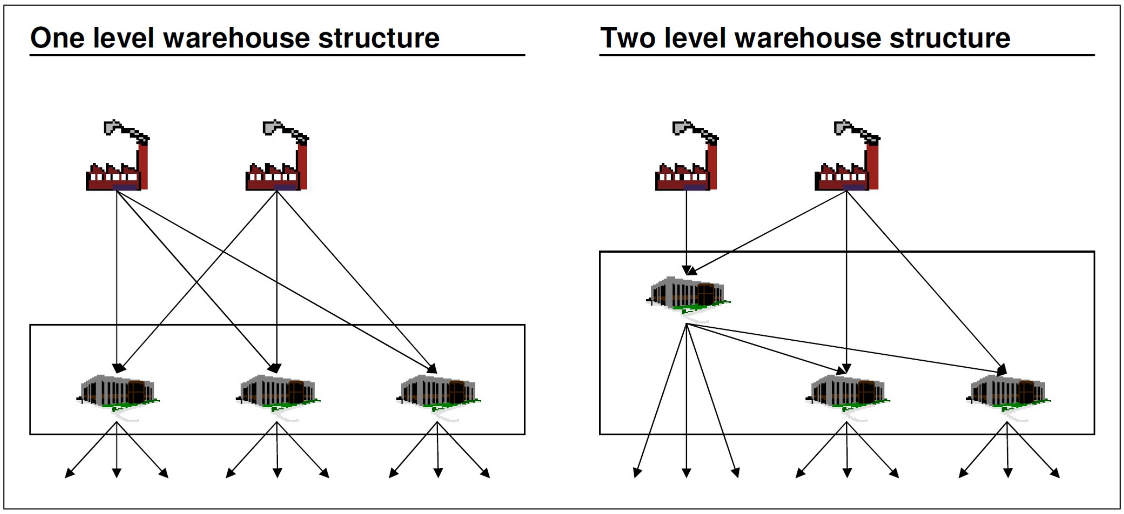

Figure 5.8: Different supply paths within a food retailing company

In case of a two level warehouse structure, two cases are differentiated: the central warehouse can be used or not. In the calculation, the option with lower costs is chosen. If it is not used, the costs calculation corresponds to the one level warehouse structure. If the central warehouse is used, the inbound costs to the central warehouse are calculated based on the lot size model using the total quantity X. For the regional level, cross docking is assumed, meaning that no storage on the regional level has to be considered. The additional costs for this cross-docking CDC_{FRC} include transport costs from the central to the regional warehouse TC_{CW-RW} and handling costs at the regional warehouse HC_{RW}:

$$CDC_{FRC} = TC_{CW-RW} + HC_{RW}$$

For transport costs it is assumed that truck capacity is reduced, as for distribution. For the distance between warehouses, the average distance between two points in a circle (dtl) is taken, where the circle area is defined by the total service area of the retail company. For the handling costs the same costs per pallet are assumed as before.

Details on different warehouse structures will be part of the next section.

Determination of distribution costs

The model estimation for distribution costs is based on average tours as introduced in section 4.2.4. Distribution costs DC consist of transport costs from the warehouse to the first stop tc_{W-stop} and transport costs between stops $tc_{stop-stop}$:

$$DC = 2 * tc_{W-stop} + (n_{stop} - 1) * tc_{stop-stop}$$

where n_{stop} is the number of stops on the tour.

While this equation is applied for wholesalers as well as food retailing companies, the components are based on different calculations. For food retailing companies, the distance between warehouse and first stop have to be modeled in more detail, since this influences significantly distribution costs and the emergence of differences in warehouse structures.

Not the average distance is taken, but different distances from warehouse to stores are modeled. The calculation is oriented at the calculation of an integral, by splitting the distribution area into N annuli as shown in figure 5.9. N circles are defined with radius r_i,

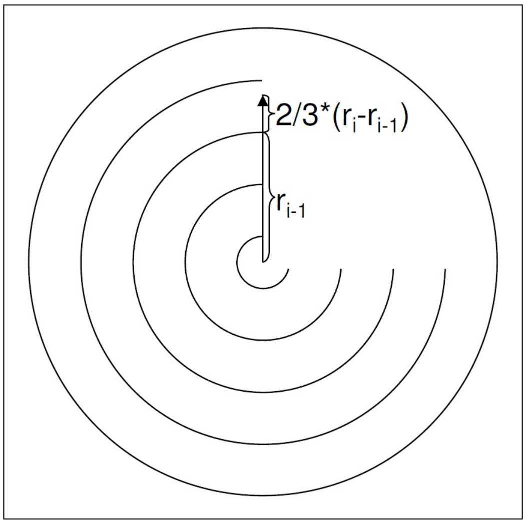

Figure 5.9: Split of distribution area into N annuli

based on the radius of the distribution area $r_{dis_{area}}$:

$$r_i = \frac{r_{dis_{area}}}{N} * i \; (i = 1...N)$$

With this average distances to the first stop for each annulus can be calculated:

$$dis^i_{W-stop} = r_{i-1} + \frac{2}{3}(r_i - r_{i-1})$$

This distance is assumed for the proportion of tours that corresponds to the proportion of the corresponding annulus area. Assuming that A_i is the circle area of cirlce i, the proportion pr_i can be calculated as:

$$pr_i = \frac{A_i - A_{i-1}}{A_N}$$

For retailing companies, the model further distinguishes between a transport cost rate for local distribution $tcr^{FRC,local}_{dis}$ and interregional distribution $tcr^{FRC,inter}_{dis}$. This is done to account for lower transport cost rates for long distances between warehouse and the first stop of the tour. This way, only for the last 50km the local cost rate is applied. The transport costs to the first stop for food retailing companies can be written as:

$$tc^{FRC}_{W-stop} = max\{0, dis^i_{W-stop} - 50\} * tcr^{FRC,inter}_{dis} + min\{50, dis^i_{W-stop} - 50\} * tcr^{FRC,local}_{dis}$$

For wholesalers, the calculation is simplified, by taking the average distance between two locations within a circle area (dtl), using the region area of the wholesaler. Also a single transport cost rate tcr^W_{dis} is applied.

The estimate on transport costs between two stops tc_{St-St} bases on the average distance between two locations $dtl_{average}$ within a circle area A and the transport cost rate for local distribution:

$$tc_{stop-stop} = dtl_{average} * tcr_{dis}^{W/FRC,local} = 0,63 * \sqrt{\frac{A}{n_{stop}}} * tcr_{dis}^{W/FRC,local}$$

The break down of costs to stops, and therefore stores or sales channels, is oriented at the demand (number of pallets delivered). Therefore and for the calculation of number of tour stops it is assumed that all stops have the same demand d_{St} as the store type under consideration. The demand of stores of retail companies is given for different sales channels. The differences in demand between sales channels can lead to different choices of overall supply paths, that is why the supply path choice is modeled on the level of sales channels.

The number of tour stops is calculated considering the capacity of the truck cap_{truck} and an assumed maximum number of tour stops $n_{stop,max}$:

$$n_{stop} = min\{n_{stop,max}, \frac{cap_{truck}}{d_{stop}}\}$$

For the maximum number of stops and for the truck capacity, different values are assumed for food retailing companies $n_{stop,max}^{FRC}, cap_{truck}^{FRC}$ and for wholesalers $n_{stop,max}^{W}, cap_{truck}^{W}$. Also the service area A and the number of tours n_{Tours} differ between distribution by food retailing companies and wholesalers.

For food retailing companies the total service area A_{total} is defined by the sum of all region areas where stores of this company are. The service area of a tour is estimated based on the number of tours n_{Tours}:

$$A = \frac{A_{total}}{n_{Tours}}$$

The estimate for the number of tours results from the division of number of stores n_{St} by average number of stops per tour $n_{stop}^{average}$. Finally, the average number of stops per tour $n_{stop}^{average}$ is determined based on capacity of trucks cap_{truck}^{FRC}, total demand of the food retailing company d_{FRC}, number of stores n_{St}, and number of delivery days per year $days_{del}$. The number is limited to a maximum stop number per tour $n_{stop,max}^{FRC}$ as before:

$$n_{stop}^{average} = min\{n_{stop,max}, \frac{cap_{truck}^{FRC} * n_{St} * days_{del}}{d_{FRC}}\}$$

It is assumed that deliveries to stores by food retailing companies happen daily. The calculated average number of stops differs to the above calculated number through the inclusion of all different store types. This reflects the fact that distribution systems serve several sales channels. For the estimation of costs within a tour, however, homogeneous stores are assumed for simplicity.

For the distribution by wholesaling companies the total service area is defined by the area of the region A_R where the wholesaler is located. Again the service area of a tour results from the division by number of tours of the wholesaler.

The model assumes several wholesalers within a wholesaling sector and a region, if demand is high. For the estimate of number of wholesalers in a wholesaling sector in a region $nw_r^{W-sector}$ a square route relationship to the demand distributed in the region $d_r^{W-sector}$ divided by average demand per stop in wholesaling sector $d_{St}^{W-sector}$ is assumed:

$$nw_r^{W-sector} = \sqrt{\alpha^{W-sector} * \frac{d_r^{W-sector}}{d_{St}^{W-sector}}}$$

with $\alpha^{W-sector}$ as scale parameter for this relationship. It is assumed that all wholesalers in a region serve the overall region. Thus, no split of service area is done.

To determine the average number of stops on a tour of a wholesaler, an average demand per stops is assumed, differentiated by wholesaling sector $d_{St}^{W-sector}$ (see appendix B.3). The number of tours for a wholesaler can now be calculated as:

$$n_{tours}^{W} = \frac{d_r^{W-sector}}{nw_r^{W-sector} * min\{d_{St}^{W-sector} * n_{stop,max}^{W}, cap_{truck}^{W}\}}$$

Finally, a German specificity has to be considered. Most beverages sold by full assortment retailers are delivered in bottles that have to be returned. This is usually done by wholesalers, except for small stores where the food retailing company takes over the distribution and returns the bottles to the wholesaler. Therefore, within the model an extra charge of $c_{brs} = 20EUR$ per pallet is assumed for distribution of beverages via full assortment retailers. This represents the costs of returning a pallet to the wholesaler via the logistic system of the food retailer.

5.2.2 Simulation procedure

According to the chosen supply path several flows are allocated to each transport link. As shown in figure 5.10 this leads to flow bundles for many links.

The lot size model is applied for all links destined for warehouses. The quantity and value assumed for the lot size model are the sum of quantities and values of flows on the respective link. When costs of supply paths for a commodity or region flow are calculated, the additional quantity and value of the flow are allocated to the links in case the actual path did not include the link.

The costs resulting from the lot size are dependent on the other flows already allocated to the link and therefore dependent on the sequence and scopes of decisions modeled.

Figure 5.11 shows the simulation procedure of the second model step. At first, supply paths are allocated preliminarily to commodity and region flows. The indicators used for the allocation of commodity flows are number of pallets delivered per retailer warehouse per day and the period of perishability. Region flows are allocated by determining the point where it becomes cheaper not using the LSP assuming full utilization of trucks by the LSP. In a second step, the supply path of all flows not passing the warehouse structure of the food retailing sector is determined. This is done by supplier and region, the total demand considered $d^{r,s}$ consists of the demand covered by region flows $d_{rf}^{s,r}$ and the demand of all commodity flows supplied directly $d_{cf}^{s,r}$ with $cf \in CF_{direct}$. In a third step, the supply path for each commodity flow is calculated. Step two and three are repeated as long as changes in supply paths occur.

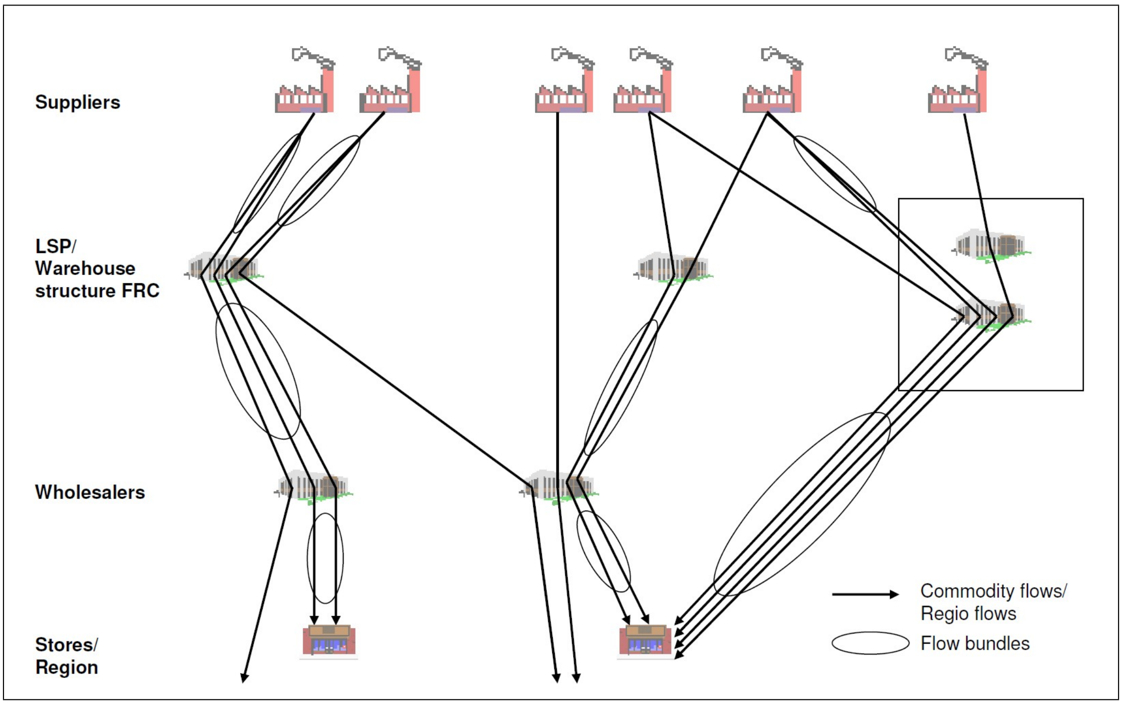

Figure 5.10: Bundles of flows on transport links

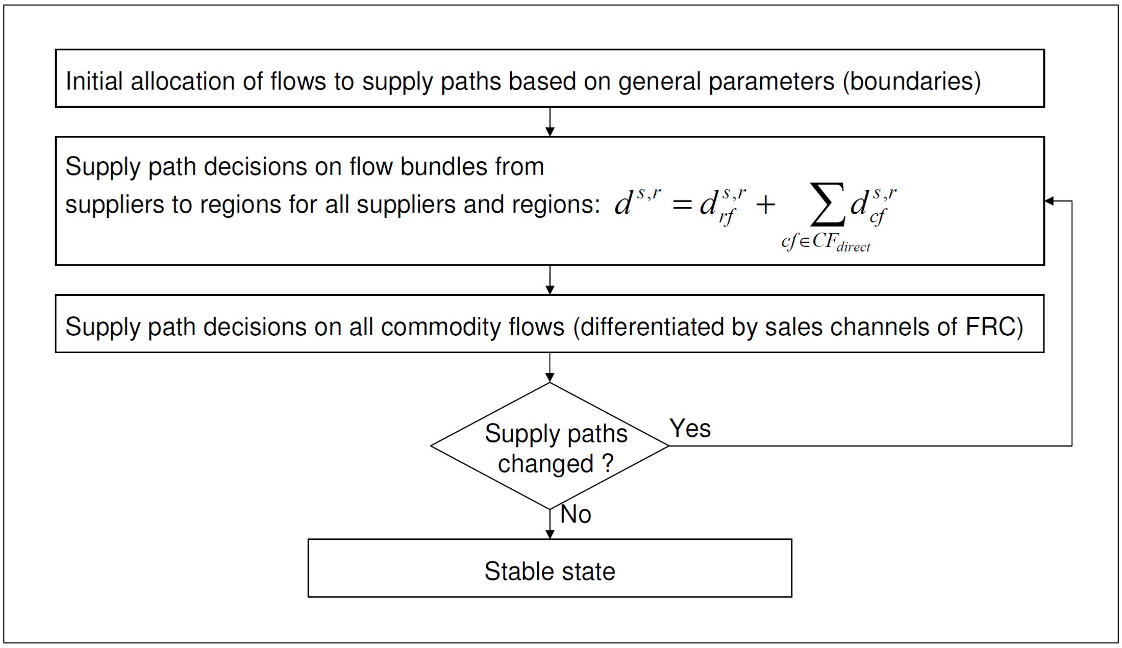

Figure 5.11: Simulation procedure for the model periphery

The result of this procedure is a stable system state. This state can be called equilibrium, of flows: no flow can change its supply path without increasing costs.

This system state or equilibrium is however not unique but results from the initial allocation, the assumed warehouse structure of the FRCs, the sequence of decisions and the decision scopes assumed. The sensitivities of the overall model to different initial system states will be analyzed in chapter 6.

The decision is modeled for individual commodity flows and flow bundles from supplier to region. Other combinations of flows can be imagined, like combinations of flows of a retailer with the same article type or combinations of several retail companies initiated by wholesalers or LSPs. This finally leads to a combinatorial problem which cannot be covered by the model scope. The interviews also showed that decisions for flow bundles from supplier to region and individual commodity flows are common: For the first one, all flows not passing the FRC warehouse structure (including region flows and commodity flows on path 3 and 4) are considered to determine if the path from a supplier to a region does include the LSP or not. This corresponds to the statements from interviews and market observations, that suppliers engage LSPs for certain destination regions. For the second decision, all four supply path options are calculated for overall commodity flows including all regions. This corresponds to the observations in the interviews that a supply path of commodity flows is determined for the overall flow. In case of direct delivery, the decision if path 3 or 4 is chosen is taken individually per region, which corresponds to the structure of the first decision.

An exception is made for beverage flows within the warehouse structure determination in the next model step, described in the next section. This can be reasoned by the fact that beverages represent a significant part of transport volume of a food retailing company (about 30 %). This high proportion causes that a combined supply path decision of many beverage flows can influences the overall distribution costs of the warehouse structure significantly. To find a global optimum for the warehouse structure, potential supply path for combined beverage flows have to be determined in the context of a forward looking decision.

5.3 Determination of warehouse structures

Until this point, the simulated decisions (supply path decisions and lot size decisions) are comparable with logistic decisions modeled in other freight transportation models, except that details like lot sizes for the overall bundle or detailed distribution cost calculation are considered. The "new" aspect in SYNTRADE, however, is the modeling of complex logistic structures like warehouse structures. The simulation of these structures needs a wider scope, since a high fixed cost proportion causes that only local optima are reached if marginal improvements are simulated. Therefore, the optimization heuristic calculates costs for all possible alternatives of warehouse structures and includes all possible aspects changeable by the company. This includes the consideration of possible changes in the environment by assuming a forward looking decision.

This section gives an overview on the heuristic used. Then details of the two phases of the heuristic are discussed. For the determination of number of warehouses and warehouse levels the cost calculation is detailed. For the determination of locations and allocations the procedure implemented is described.

5.3.1 Overview on optimization heuristic

Figure 5.12 gives an overview on the optimization heuristic for warehouse structures. In a first phase, the number of warehouses and the warehouse levels are optimized. Then

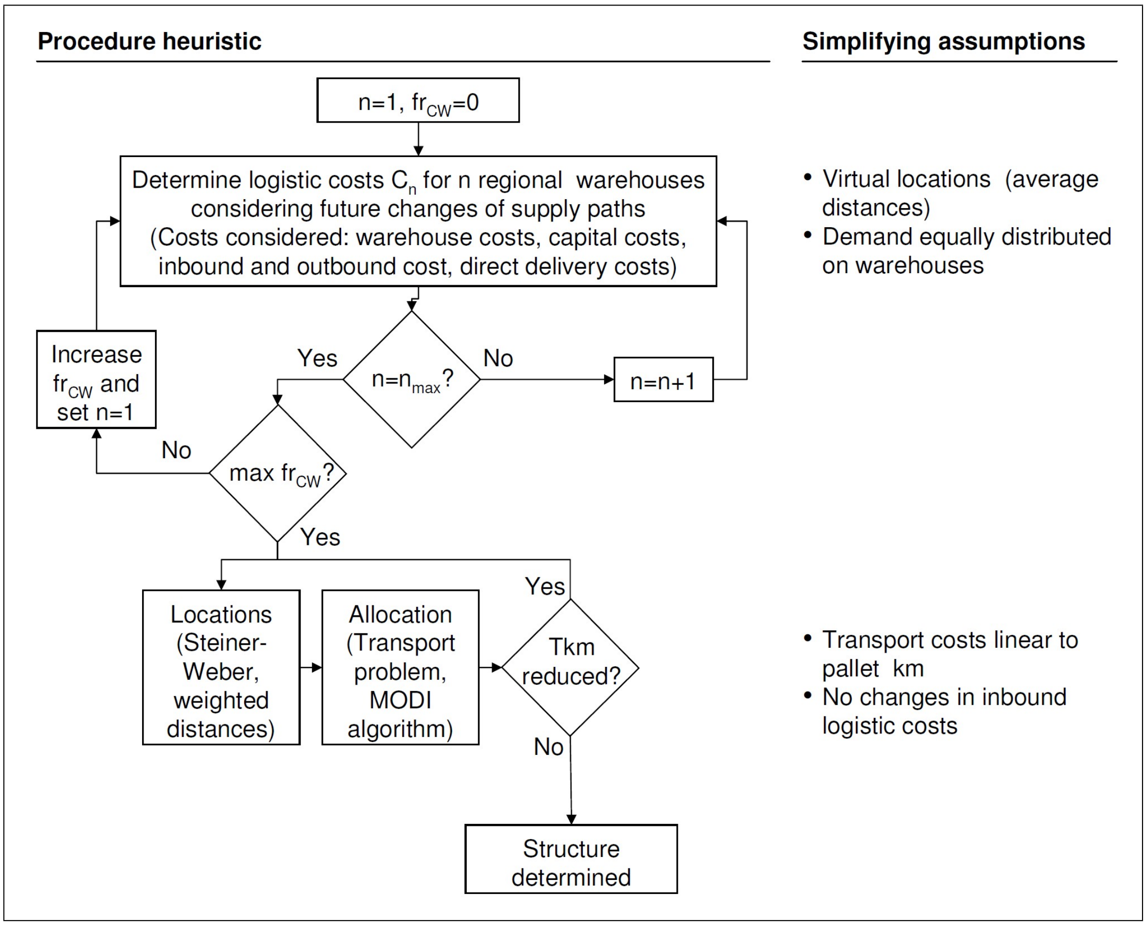

Figure 5.12: Heuristic for the determination of a warehouse structure

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.

In the following paragraphs details on both phases of the heuristic will be outlined.

5.3.2 Logistic costs of the warehouse structure

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:

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

Warehouse costs include fixed costs $n * WC_{fix}$ 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_{cf}^{LSP} have to be considered, including the transport costs and costs within the warehouse of the LSP.

Costs for a central warehouse level TLC_{FRC}^{CW} include costs for individual flows, as for the flows on the regional level, as well as costs for cross docking. This will be detailed later.

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_{cf}^{direct}.

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 5.13. 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

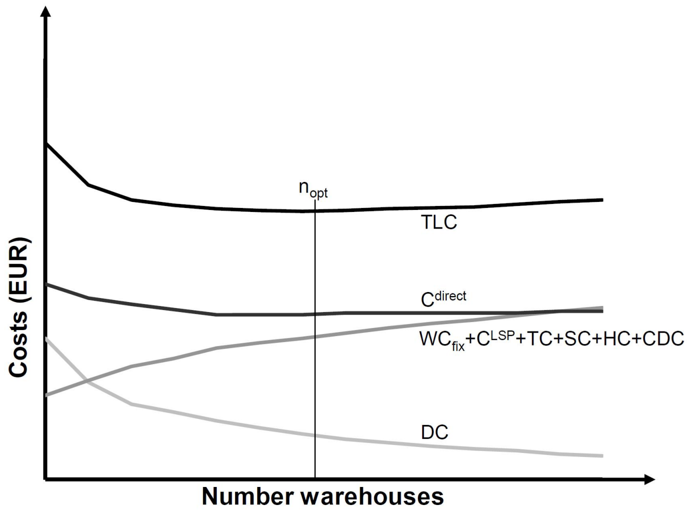

Figure 5.13: Cost components for different warehouse numbers

course shows that more flows are delivered directly, if few or many warehouses are assumed.

Details on costs for direct delivery, on distribution costs and on costs in the context of lot size determination were described in the last section. This paragraph will give some more detail on warehouse costs, costs for the central warehouse level and the forward looking elements within the warehouse structure determination.

Warehouse costs

Total warehouse costs include several of the above discussed cost components. Gudehus (Gudehus (2004), p. 358) differentiates two variable cost components: throughput costs and costs per storing position. This is reflected in two cost components: handling costs comprise the throughput costs driven by the handling cost rate hc and the number of pallets handled n_p. Variable warehouse costs per storing position wc_{vpp}, driven by the number of pallets in stock n_p^{stock}, are included in the storage cost component SC. The storage costs also include capital costs which can also be seen as part of the warehousing costs, they are driven by the weighted average costs of capital $wacc$ and the value v_{pp} and number of pallets. Thus, total warehouse costs can be formulated as:

$$WC = WC_{fix} + HC + SC = WC_{fix} + hc * n_p + wc_{vpp} * n_p^{stock} + wacc * v_{pp} * n_p^{stock}$$

The consideration of variable costs driven by the number of stock positions is important for differences in food retailing since thus the effect of increases in stock on warehouse costs can be shown. Variable in the context of this study is interpreted as long term variable, considering that changes in size of warehouses are possible. This is also assumed for marginal costs used within the lot size optimization.

Warehouse fixed costs are modeled dependent on the number of articles handled n_{at} to reflect differences in warehouse technology between hard discounters and full assortment companies. Hard discounters can use block storage warehouses that do need less investments in warehouse technology.

$$WC_{fix} = \begin{cases} \alpha_{wfc} & if\ n_{at} < 2000 \\ \alpha_{wfc} + \beta_{wfc} & if\ n_{at} >= 2000 \end{cases}$$

Central level costs

A central level can be implemented in different ways: a separate warehouse, integration in existing regional warehouses or even the usage of a LSP. The second option was mentioned in several expert interviews. This form, where no additional warehouse fixed costs occur, is assumed within the model. For distribution to stores, cross docking in regional warehouses is assumed. This way, the additional costs for the central level are those costs that are caused by the cross docking activity.

In the model, three types of central warehouses are differentiated, defined by downstream delivery frequency fr_{CW} (number of outbound transports to each regional warehouse per week). The frequency also determines the articles that can be handled in the central level:

- Weekly delivery, non food articles
- Bi-weekly delivery, dry food articles and non food articles
- Daily delivery, all kinds of articles

The costs for the central level are composed by the inbound and warehousing costs for the flows routed via the central warehouse level $CF_{FRC}^{CW}$and cross docking costs:

$$TLC_{FRC}^{CW} = \sum_{cf \in CF_{FRC}^{CW}} (C_{cf}^{LSP} + TC_{cf} + SC_{cf} + HC_{cf}) + CDC_{CW-RW}$$

The first part is calculated the same way as for regional warehouses with the difference that only one warehouse has to be delivered. Cross docking costs CDC_{CW-RW} include costs for transport to the regional warehouses TC_{CW-RW} and additional handling costs for cross docking that occur in the regional warehouse HC_{cd}.

$$CDC_{CW-RW} = TC_{CW-RW} + HC_{cd}$$

The handling costs are calculated by multiplying the demand expressed as number of pallets n_p^{CW} with the handling cost rate hc.

For the calculation of transport costs the transport cost function for inbound transports (see last section) is assumed, truck capacity is limited to distribution truck capacity cap_{truck}^{dis}. If the lot size is higher than the truck capacity, multiple full truck loads are assumed. This results in following costs for transport between central and regional warehouse:

$$TC_{CW-RW} = n_{RW} * 52 * fr_{CW} * tc(Q, dis)$$

where

TC_{CW-RW}	=	Transport cost from central to regional warehouse
n_{RW}	=	Number regional warehouses
fr_{CW}	=	Frequency (number of outbound transports per week)
$tc(Q, dis)$	=	Transport costs, depending on lot size Q and distance dis

The distance is estimated by the average distance between two locations within a circle area (dtl), taking the distribution area of the retailing company. The lot size Q can be calculated based on the number of pallets handled on the central level n_p^{CW}:

$$Q = \frac{n_p^{CW}}{n_{RW} * 52 * fr_{CW}}$$

The determination of flows handled on the central level is oriented at the algorithm of forward area of Bartholdi and Hackman (2008). At first, supply path decisions for individual flows decide on their potential routing, then the overall rentability of the central level is checked.

During the supply path decision, potential savings sav_{cf} for each commodity flow result out of the cost calculation, assuming that between central warehouse and regional warehouse full truck loads are transported. The additional time required in case of a central warehouse (transport to regional warehouse and cross docking) is assumed to be one day. The perishability time available for logistics within the lot size optimization changes accordingly.

A commodity flow can only be handled central, if the article type requires a frequency fr_{at} that is lower than the downstream delivery frequency of the central warehouse. This results out of the assumption of cross docking on the regional warehouse. If, for example, fresh food is centralized, daily transports have to take place to the regional warehouse to allow daily delivery of stores with fresh products. Thus, the set of commodity flows CF_{CW}^{fr} using the central level differs by the delivery frequency fr_{CW}:

$$CF_{CW}^{fr} = \{cf \mid Sav_{cf} > 0 \; and \; fr_{cf} \leq fr_{CW}\}$$

Having determined the sets of commodity flows passing through the central warehouses, the total costs for the overall warehouse structures can be determined by optimizing the number of regional warehouses as described in the last paragraph. Total costs are calculated four times this way, three times assuming different delivery frequencies for the central level (weekly, bi-weekly and daily delivery) and once for a warehouse structure without central warehouses.

Forward looking elements

For the determination of warehouse structures, future changes in supply paths and logistic costs are considered. This way, the model assumes a forward looking decision of the actor. Supply paths are checked for all commodity flows, individually as well as for the combination of beverage commodity flows. Beverages represent about 30-40 % of total quantity transported, a change from direct to food retailer warehouse delivery influences distribution costs of the food retailer significantly. Therefore, it is not sufficient for this case to analyze single commodity flows.

Besides the supply path decision also other logistic costs are calculated for the assumed future logistic structure. This accounts especially for all costs connected to inbound transport, including storage costs SC and transport costs TC.

5.3.3 Locations of warehouses and allocation of stores

The determination of warehouse locations and allocation of stores to warehouses is modeled in an integrated way. First, the overall integrated procedure will be outlined, then, some details on the application of the MODI algorithm will be given.

Integrated procedure

From the prior steps of the warehouse structure heuristic, the number of (regional) warehouses n_{RW} is given. Furthermore, the demand of the stores in the regions d_r^{FRC} and the quantity supplied from each region s_r^{FRC} can be calculated. The demand in a region is the sum of the demand of the stores of the food retailing company d_{st} in this region:

$$d_r^{FRC} = \sum_{st \in St_r^{FRC}} d_{st} * pr_{via\,FRC}^{SC}$$

where
d_r^{FRC} = Demand of food retailing company in region r
d_{st} = Demand of store st
St_r^{FRC} = Set of stores of the FRC in region r
$pr_{via\,FRC}^{St}$ = Proportion of demand considered

Only demand is considered that is delivered via the warehouse structure of the food retailing company. For simplification, at this place, this is expressed by the proportion $pr_{via\,FRC}^{St}$ specific to the sales channel SC to which the store belongs. The detailed calculation is shown in the last section within the description of distribution cost calculation.

The supply from regions is calculated based on commodity flows cf. The set of commodity flows considered $CF_{r,via\,FRC}^{FRC}$ includes all flows that are destined for the stores of the food retailing company FRC, that origin from region r and that are distributed via the warehouse structure of the food retailing company ($viaFRC$). Thus, the region supply considered s_r is the sum of the demand of these commodity flows.

$$s_r^{FRC} = \sum_{cf \in CF_{r,via\,FRC}^{FRC}} d_{cf}$$

Two problems have to be solved: the locating of warehouses and the allocation of stores to warehouses.

To solve the location problem, the total weighted pallet km are minimized (target value TV), for each warehouse. Therefore the target value is calculated for all possible warehouse regions r_W. The target value is composed of weighted pallet km from inbound transport (to the warehouses) and weighted pallet km from outbound transport (from the warehouses to the stores). The weights are defined by average costs for inbound and outbound transport of the company.

$$\text{Min } TV = \sum_r dis_{r_w,r} * (x_{w,r} * tcr_{out} + \frac{s_r}{n_{RW}} * tcr_{in})$$

where
r_w = Potential warehouse region
$dis_{r_w,r}$ = Distance between warehouse region r_w and demand/supply region r
$x_{w,r}$ = Amount of goods delivered from warehouse w to region r
s_r = Amount of goods supplied from region r
n_{RW} = Number regional warehouses
$tcr_{in/out}$ = Average transport cost rate for in- and outbound transport

The amount of goods $x_{w,r}$ delivered from warehouse w to region r (the allocation) is assumed as given.

This problem corresponds to the "Steiner-Weber" problem. Distances on road networks are used to reflect differences through the usage of highways or natural barriers like the Black Forest. Therefore the usual procedures for solving the "Steiner-Weber" problem that works with direct distances, cannot be used and the problem is solved by full enumeration. Since the number of regions is limited (439 German NUTS 3 regions are considered), this "brute" force approach can be applied. The target value TV is calculated for all possible warehouse regions (r_w).

Within this formulation and within the overall heuristic it is assumed that all warehouses of the same company have equal capacity cap_w. This simplification has to be made to avoid a combinatorial problem.

The allocation problem consists of the determination of the optimal amount of goods delivered from warehouse w to region r $x_{w,r}$. This is the classic transport problem in operations research. It can also be seen as a clustering problem where all regions allocated to the same warehouse form a cluster (allowing the partial allocation of a region). The problem can be formulated as:

$$
\begin{aligned}
\text{Min} &= \sum_w \sum_r dis_{r_w,r} * x_{w,r} \\
\text{s.t.} \sum_w x_{w,r} &= d_r \; (r = 1 \ldots 439) \\
\sum_r x_{w,r} &= cap_w \; (w = 1 \ldots n_{RW}) \\
x_{w,r} &\geq 0 \; (w = 1 \ldots n_{RW}, r = 1 \ldots 439)
\end{aligned}
$$

where
$dis_{r_w,r}$ = Distance between warehouse region r_w and region r
$x_{w,r}$ = Amount of goods delivered from warehouse w to region r
d_r = Demand of goods in region r
cap_w = Capacity of warehouse w
n_{RW} = Number regional warehouses

Total outbound transports are minimized by allocating regions to warehouses, the constraints assure that the demands of all regions get satisfied and that warehouse capacities are respected, that are assumed to be equal for all warehouses. For solving this problem, the MODI method is used. Some details on the application of the MODI algorithm within this study will be given in the following paragraph.

The overall solution procedure of both problems is shown in figure 5.14. In the first step, regions are allocated preliminary to warehouses by region index. Based on these "clusters" the best warehouse locations are determined as shown before. In the third step

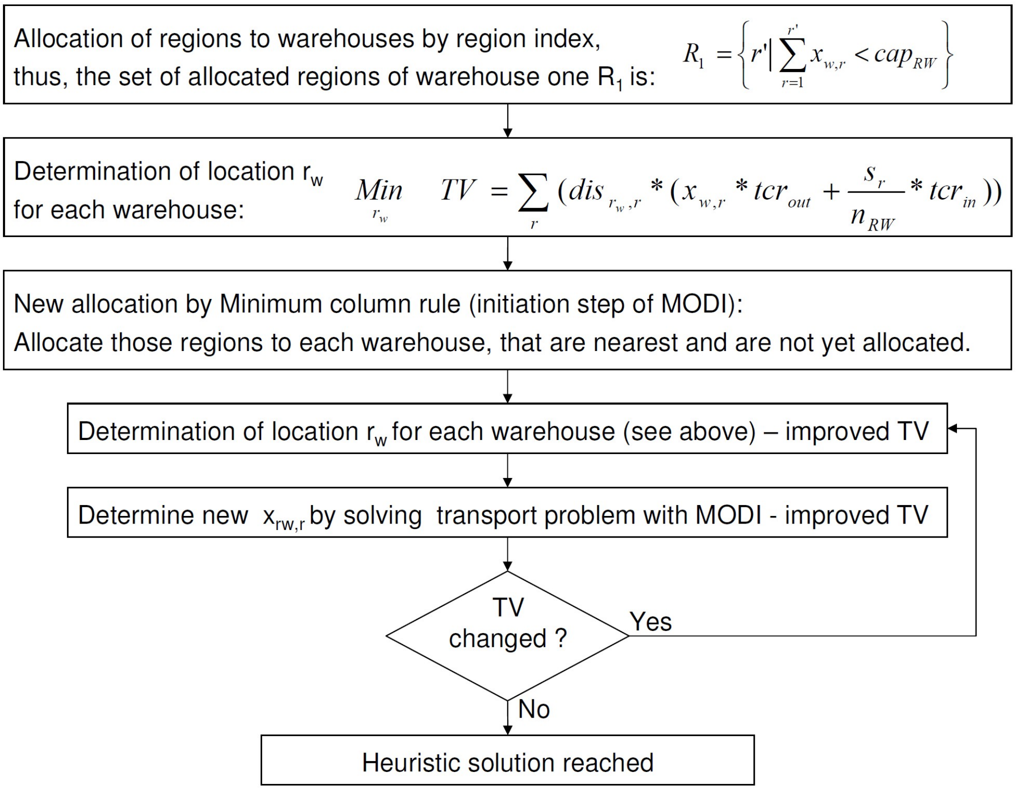

Figure 5.14: Procedure for integrated solution of location and allocation problem

regions are allocated to the nearest warehouse as long as capacity is available. This corresponds to the initial step of the MODI algorithm. Then, the best locations and allocations are determined sequentially. In each step, the target value TV is improved. When the target value stays constant and no more improvement is realized, the heuristic solution is reached.

Application of MODI algorithm

The transport problems that are solved within the model are large, including about 440 regions and thirty warehouses. This results in transport matrices with more than 13.000 entries, requiring efficient algorithms. That is why the MODI algorithm ("modifizierte Distributionsmethode") was implemented instead of using the standard simplex procedure in standard optimization software packages.

Here, only the application within this model is discussed. It is assumed that the algorithm as well as the definitions like transport tableau, base and non base variables are known. A description can be found in Neumann and Morlock (1993) (p. 328 ff.).

The basis for the generation of the transport tableau for the algorithm consists of the warehouse capacities cap_w (column sums), the region demands d_r^{FRC} (row sums) and the distances between warehouses and regions (representing the costs within the tableau). The initial base variables are given by the column minimum rule for the first run and by the last set of base variables from the last run otherwise. The base variables indicate the active paths between warehouses and regions where flows exist $x_{r_w,r} >= 0$ with $(r_w, r) \in B$, for all other paths (r_w, r) are non base variables with $x_{r_w,r} = 0 \; \forall (r_w, r) \in N$.

The MODI algorithms determines cycles in the transport tableau to improve the solution (see figure 4.10). In this context these cycles are changes (increases and decreases) of flows from warehouses to regions. Thus, the algorithms stepwise improves the allocation of stores to warehouses.

5.4 Simulation procedure

The logistic simulation within SYNTRADE includes two phases, phase two and three of the model (see figure 2.1). Phase two simulates the supply path decision for overall consumer goods distribution. It represents the overall system within the model.

Phase three of the model includes more complex optimization of warehouse structures for individual companies. The decision scope is larger, including all commodity flows of the company. The heuristic aims for a global logistic cost optimum for the company. The heuristic includes future changes in supply paths assuming a forward looking decision.

While this second phase represents the detailed optimization of individual companies, the interactions with the overall system happen in the first phase through changes in supply path decisions: Costs of supply paths are determined by all flows bundled on transport links. Thus, flows can influence costs of supply paths of other flows.

The model repeats phase one and phase two as long as changes in supply paths or warehouse structures occur. Therefore, the interaction between warehouse structures and the overall system happens in both ways: through changed supply paths, the volumes handled in warehouses change and so do warehouse structures. Through changes in warehouse structures costs of supply paths change, influencing other flows in the overall system.

The simulation terminates if no changes in supply path or warehouse structures occur. This is an equilibrium: no actor can improve his situation through changing supply paths or warehouse structures. As for the equilibria in the first simulation phase, the overall system state in terms of supply paths is not unique. However, the resulting warehouse structures are stable. This is caused by the convex cost function for the warehouse structure decision (number of warehouses) resulting from the forward looking heuristic used.

6 Model results

This chapter shows the application of SYNTRADE and analyzes the model results.

In a first section, calibration and validation of the model are described. Indicators are defined to show the high fit to existing data. The second section discusses some detailed aspects of the base scenario resulting from calibration. In the third section, two future scnarios are defined to demonstrate possible applications of SYNTRADE. Finally, the last section will summarize the results by outlining the progress of the model compared to the existing modeling landscape in freight transportation analysis.

6.1 Model calibration and validation

To assess the quality of SYNTRADE two aspects can be analyzed. Firstly, the modeled relationships and optimization problems have to reflect the structure of the modeled systems. This was described in the last chapters. Secondly, the model fit can be described, by comparing the output to existing data. This is the goal of this section.

To be able to do both, calibration and validation, the available existing data of companies is split. The data on warehouse structures of five companies and data on supply path proportions is used for calibration. The remaining data, of all other German food retailing companies, is used for model validation.

To make transparent which model parameters are assumed as fix and which are used for calibration, an overview on parameters will be given at first. Then, indicators measuring the model fit, will be defined for different aspects of the model output. Afterwards the calibration and validation of the base scenario will be described using these indicators. Finally, sensitivity analysis for selected parameters and for changes in initial system states will be conducted.

6.1.1 Model inputs and parameters

SYNTRADE uses a large amount of data in form of model inputs and model parameters. This results from the detailed modeling of system functioning. Changes in all kind of data can influence the model results.

Three groups of data can be differentiated:

- Input data, generated in the first model step
- Parameters that are assumed as fix
- Parameters that are variable to a certain degree and used for calibration

In tables 6.1 to 6.3 all important inputs and model parameters are listed.

An overview on the most important input data, the origins of the data, and a reference to the sections with details on the generation procedures is given in table 6.1. This data is either taken directly from data sources or generated in the first model step. It is based on reliable data sources like statistics or company data. This data is assumed as fix and not changeable for calibration.

Parameters in SYNTRADE are mostly needed to determine logistic costs. Most parameters are assumed fix. An overview on the fixed parameters with an indication of the data origin and the assumed values is given in table 6.2. At the end of the table also the

Area	Model inputs	Data origin
Artificial economic landscape	Supplier establishments, with turnover, region and sector (t_{ES},r_{ES},s_{ES})	Derived from statistical data (section 5.1)
	Region demand for each sector $d_{s,r}$	Derived from statistical data and intermediate model results (section 5.1.3)
Food retailing companies	Store turnover for each sales channel t_{sc}	Derived from company data (section 5.1.2)
	Number of stores per company and sales channel in each region $n^C_{r,Sc}$	Derived from company data (section 5.1.2)
	Article type turnover and article number per sales channel t^{sc}_{at}, n^{sc}_{at}	Derived from survey data (section 5.1.2)
Commodity flow generation	Parameter (α) to estimate number of suppliers	Estimation (section 5.1.2)
	Pareto Parameter k, describing distribution of turnover	Estimation (section 5.1.2)
Region flow generation	Parameter for gravity model	Estimation (section 5.1.3)
Geographic data	Region areas A_r	Publicly available
	Distances between regions dis_{ij}	Derived from shortest distances on networks
Article Type data (also applied for sectors)	Value density (for weight and volume) of each article type	Estimation based on statistical and company data (appendix B.1)
	Perishability periods	Estimation (appendix B.1)

Table 6.1: Overview of model input data generated in the first model step

assumptions to generate the initial values for the simulation of the logistic environment are mentioned (second model step).

The initial values can influence the simulation outcome since multiple solutions of flow allocations exist within logistic systems. This results from the concave course of costs caused by bundling for transport and warehousing, as discussed in the last chapter.

The assumption used for the initial region flow allocation is a certain level of utilization for trucks between LSPs and destination regions. For commodity flows, a simple rule is applied:

- If the commodity flow under consideration is destined for a discounter and $t_{per} > 6$ (period of perishability), it is delivered via the food retailing company warehouse. The usage of LSPs depends on the number of pallets delivered by the supplier per warehouse.

- If the commodity flow under consideration is destined for a full assortment company, it is only delivered via the food retailing warehouse, if the number of pallets per warehouse is larger than two and if $t_{per} > 6$ (period of perishability). The usage of LSPs depends on the number of pallets delivered by the supplier per warehouse.

Another initial setting that is assumed for the simulation of the logistic environment, are the existing warehouse structures. Since warehouse structures are only determined within the third model step, initial warehouse structures have to be assumed or taken from a previous simulation round. The initial number of warehouses is calculated by a simple calculation: the total number of pallets distributed is divided by 300.000.

The effect of changes in the initially assumed system states on the final warehouse structures are minor. This will be shown during sensitivity analysis.

Finally, there are model parameters that are variable to a certain degree and can be used for calibration. An overview on these parameters is given in table 6.3. But still, the degree of variability is limited since values have to be plausible.

Area	Model parameter	Value	Data origin
Wholesaler and LSP sectors	Average number of pallets per stop on wholesaler distribution tour $n_{stop}^{average}$	See appendix B.3	Estimation (section 5.2)
	Parameter to determine number of wholesalers in a region α	20	Estimation (section 5.2)
General parameters	Weight per pallet	730 kg	Derived from truck capacity
	Volume per pallet	$2,7m^3$	Derived from truck capacity
	Weighted average costs of capital $wacc$	10%	Estimation
	General truck capacity cap_{truck}	33 pallets	Publicly available data
Warehouse costs	Costs per stock position per year wc_{vpp}	50 EUR	Expert statement
Distribution costs	Distribution truck capacity Retailing Companies: cap_{truck}^{FRC}	22 pallets	Estimation
	Distribution truck capacity wholesaler: cap_{truck}^{W}	8 pallets	Estimation
	Maximum stops on food retailer distribution tour: $n_{stop,max}^{FRC}$	10 stops	Estimation
	Maximum stops on wholesaler distribution tour: $n_{stop,max}^{W}$	20 stops	Estimation
	Additional costs per pallet due to bottle return system: c_{brs}	20 EUR	Costs for cross dock and transport to wholesaler
	Local km for food retailing company distribution: dis_{local}	50 km	Estimation
Transport costs	Inbound transport costs (non distribution) dependent on distance and lot size	See table 4.3	Transport cost matrix, based on company data
Initial region flow allocation	Assumption on utilization of trucks from LSP to region	100%	Estimation
Initial allocation commodity flows	Rules	Decribed in text	Estimation
Initial warehouse structure	Rules	Described in text	Company data

Table 6.2: Overview of fixed parameters in the second and third model step

Area	Model parameter
Warehouse costs	Fixed warehouse costs (all companies) αwfc Fixed warehouse costs (more than 2000 articles) βwfc Handling costs per pallet hc
Transport costs	Cost rate wholesalers tcr_{dis}^{W} Cost rate food retailing company (local) $tcr_{dis}^{FRC,local}$ Cost rate food retailing company (interregional) $tcr_{dis}^{FRC,inter}$

Table 6.3: Overview of variable parameters in the second and third model step

The distribution cost rate of the wholesaler (tcr_{dis}^{W}) is used to calibrate the second model step. This is done depending on the results of the other variable parameters, used to calibrate the third modeling step.

6.1.2 Model indicators

The indicators used to describe the model fit and to calibrate or validate, have to be oriented at available data points. For the application case of this study, this is mainly data on warehouse structures which are the model output of the third step.

For the second model phase, proportions of direct deliveries (supply path 3/4) for food retailing companies serve as indicators, since some data points from expert interviews are available. These proportions can be calculated for the overall food retailing sector, for single companies or even for chosen article types. Also, proportions of number of articles, turnover or number of pallets can be determined, indicating if large or small flows, high value or low value flows are distributed directly. These indicators can vary between companies and also between sales channels because of different warehouse and store structures, including number, locations, articles and turnover of stores.

For the overall model, indicators are oriented at the four components of the warehouse structure problem: the number, the level, the location and the allocation.

The main indicator for the model is the number of regional warehouses (ind_1). Data is available for the overall food retailing sector and individual companies. For the level aspect few data is available, therefore the indicator is limited to the existence of a central warehouse level ($ind_2 \in \{Yes, No\}$). The form of a central warehouse level differs, it can be a separate warehouse, integrated in a regional warehouse or even outsourced. This is very detailed company data that is hardly available. An overview on the first two indicators is given in table 6.4. The existing number of regional warehouses is compared to the simulated number in the base scenario. The calibration of variable parameters is done based on five food retailing companies, in table 6.4 marked with a star (*). The results of the base scenario will be discussed in the next paragraph. For the existence of a central warehouse level only simulation results are shown. Cases, verified by existing data, are highlighted.

Food Retailing Companies	**Number of regional warehouses** (Company data)	**Number of regional warehouses** (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	

Table 6.4: Number of warehouses and warehouse levels

Location and allocation aspects are very interlinked. Data is only available for regional warehouse locations. Therefore, the indicator measuring the model fit of location and allocation, only refers to regional warehouse locations. The indicator ind_3 measures the average of the distances dis_{ij} between the simulated warehouses i and existing warehouses j of a company. The pairs of warehouses that are compared, are established by minimizing the sum of distances. The indicator ind_3 can be calculated by a linear optimization problem:

$$
\begin{aligned}
ind_3 = \text{ Min } \quad & \textstyle\sum_{i=1}^{n_{RW}} \quad m_{ij} dis_{ij} \frac{1}{n_{RW}} \\
\text{s.t. } \sum_{i=1}^{n_{RW}} m_{ij} \quad &= \quad 1 \;\forall i \\
\sum_{j=1}^{n_{RW}} m_{ij} \quad &= \quad 1 \;\forall j \\
m_{ij} \quad &\in \quad \{0,1\}
\end{aligned}
$$

where m_{ij} indicates that existing warehouse i is allocated to simulated warehouse j.

No parameters have to be calibrated by this indicator, since the main factors are distances between regions and "weights", measured in number of pallets in destination (store) regions and source (supplier) regions multiplied by average inbound and outbound costs. Since outbound costs are usually much higher, changes in cost parameters do in general not influence the result.

Since locations change significantly if the number of warehouses changes, it is assumed that the exact number of warehouses is met. Thus, the quality of location and allocation of warehouses can be measured independently from the number and level of warehouses.

6.1.3 Base scenario

The base scenario, presented in this paragraph, results from model calibration. The calibration procedure and the resulting values for the variable model parameters will be discussed first. Then, the model results will be validated by an analysis of the model indicators that compare the model results to existing data.

Model calibration

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 table 6.4. 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 articles of 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.

Validation

The values for variable model parameters resulting from the calibration process, are shown in table 6.5.

Area	Variable model parameters	Value
Warehouse costs	Fixed warehouse costs(all companies) αwfc	0.25 Mio. EUR
	Additional fixed warehouse costs(more than 2000 articles) βwfc	1 Mio. EUR
	Handling cost per pallet hc	6 EUR
Distribution costs	Transport cost rate wholesalers tcr_{dis}^{W}	3,2 EUR
	Transport cost rate food retailing company (local) $tcr_{dis}^{FRC,local}$	2,0 EUR
	Transport cost rate food retailing company (interregional) $tcr_{dis}^{FRC,inter}$	1,2 EUR

Table 6.5: Values of variable parameters in the base scenario

The warehouse fixed costs describe the long term fixed costs per year, like cost for ground, that is neither driven by throughput (considered by hc) nor by stock (considered by wc_{vpp}). Costs for commissioning are not directly considered within the model. The difference between companies with many articles and few articles results from a change in warehouse technology, hard discounter can use block storage warehouses that do need less investments in warehouse technology. The value of 6 EUR for handling cost per pallet hc corresponding to 3 EUR per pallet move (in and out) seems plausible.

The difference between "local" and "interregional" distribution, with the limit of 50 km, is introduced to account for the fact, that retailers with long distribution tours use long distance roads and therefore have lower costs. The value of 1,2 EUR is close to the general full truck cost, which is plausible. The cost rate for the "local" part and for the wholesaler is higher. According to other sources outbound costs are 3 (Toporowski (1996), p. 69) to ten (Geoffrion (1979), p. 106) times higher than inbound costs. Reasons for that can be:

- Lower speed on regional streets
- Higher detour factors on regional streets
- Lower usage of full truck capacity due to fluctuations in demand

- Empty runs on the second part of milk run tours (already accounted for within the calculation of distribution costs)
- Lower vehicle capacity (already accounted for within the calculation of distribution costs)

Considering that the last two factors are already included in the modeling of distribution tours the resulting factor of two is plausible. The difference between food retailing companies and wholesalers can be explained by the fact that the part of urban traffic where the above mentioned factors are especially strong, is higher for wholesaler distribution tours. Also the quantity delivered per stop is less. Thus, costs caused by the higher number of stops are reflected in the higher transport cost rate.

Effects of changes on parameters will be discussed in the next paragraph in the context of sensitivity analysis. The outcome of the base scenario will be described, using the indicators discussed before.

The outcome of the second model phase is shown in figure 6.1. 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,

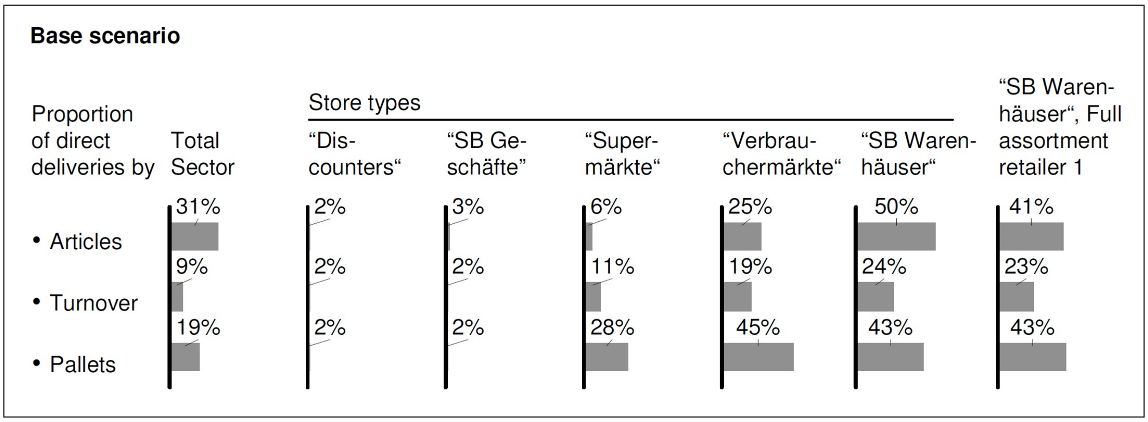

Figure 6.1: Proportions of direct deliveries from the second model step in the base scenario

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.

In table 6.4 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.

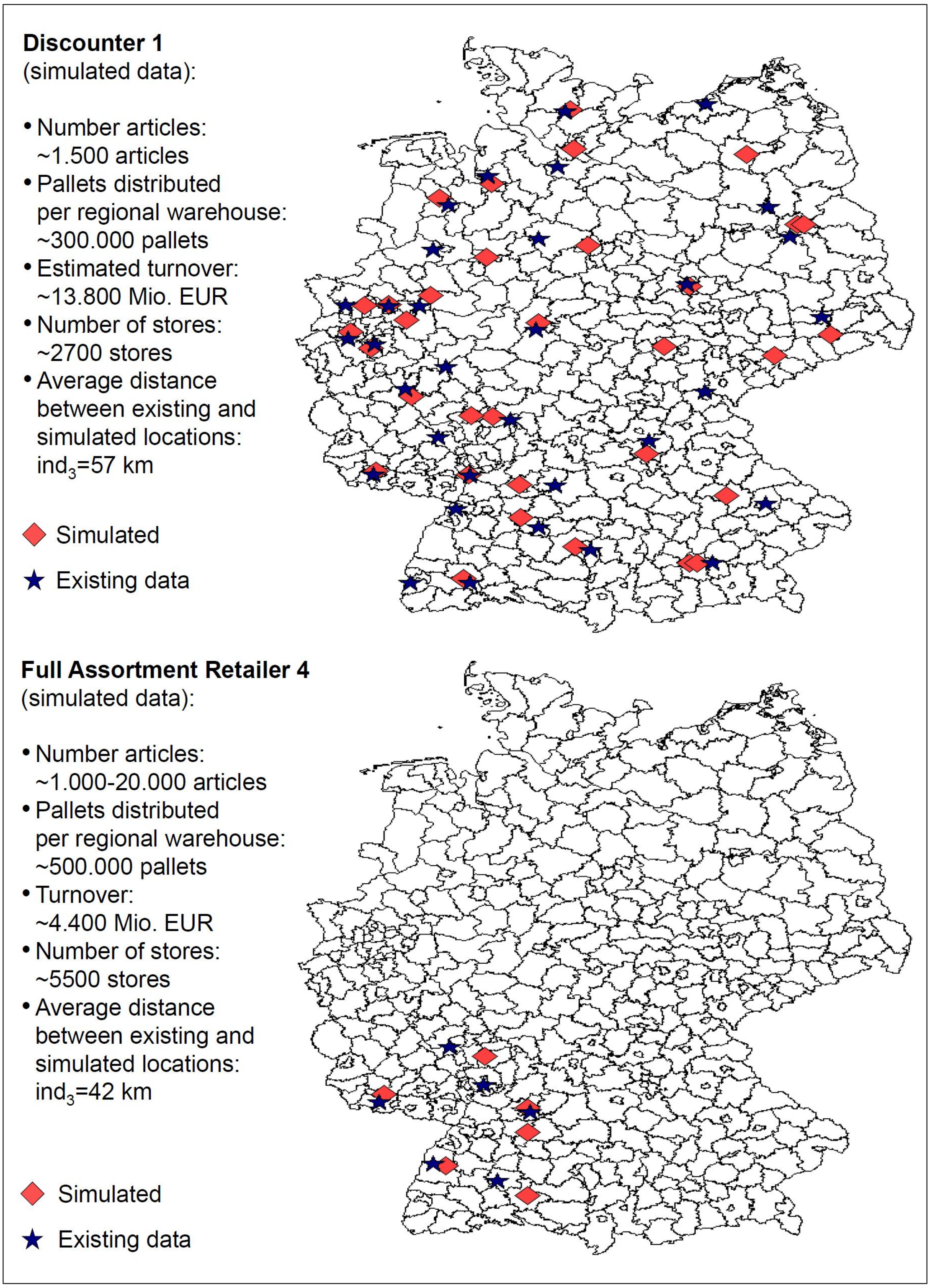

Figure 6.2: Model results for Discounter 1 and Full Assortment Retailer 4

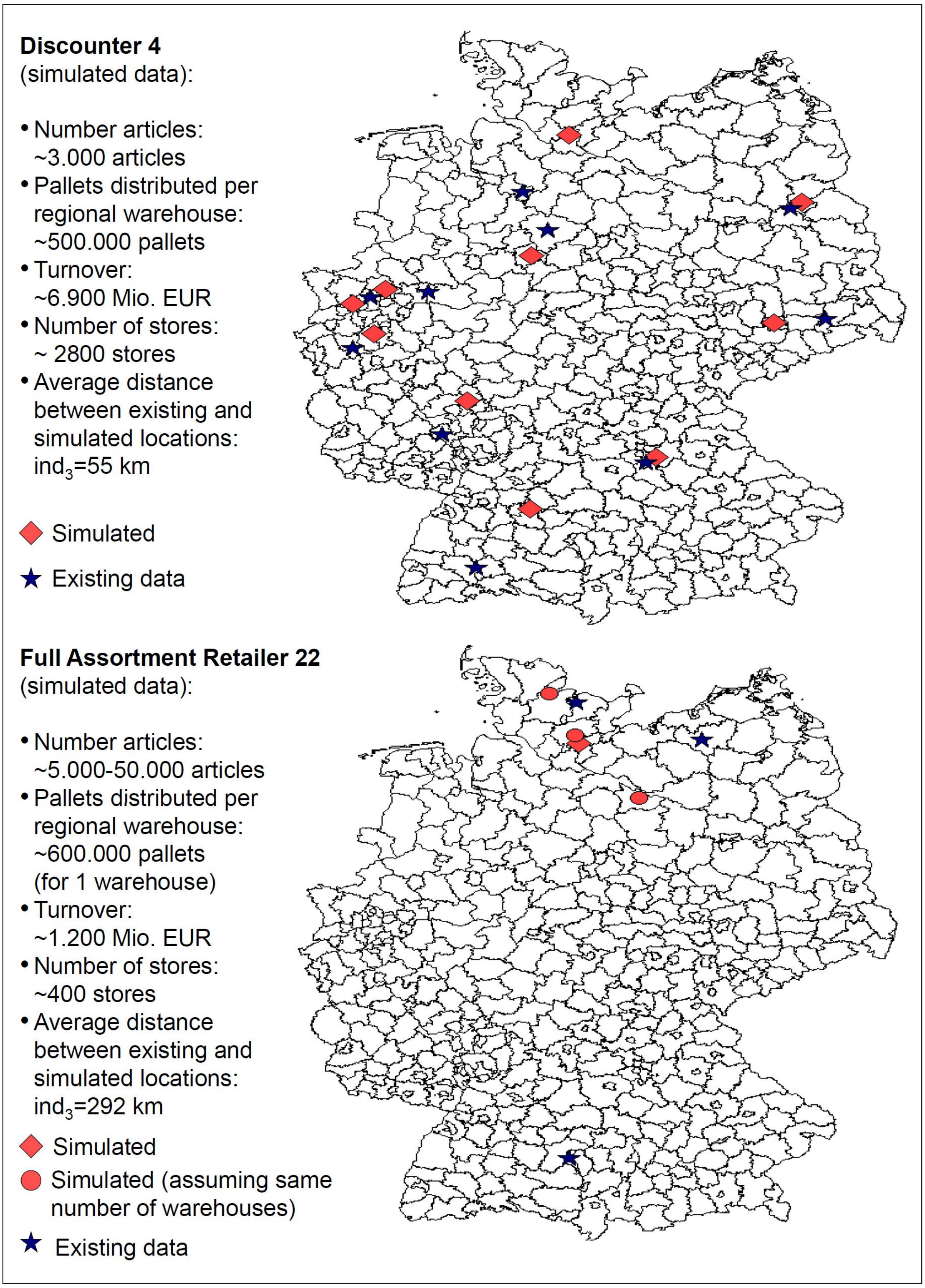

Figure 6.3: Model results for Discounter 4 and Full Assortment Retailer 22

Finally, the average value of the indicator for the location and allocation problem, describing the average distance between existing and simulated warehouses, is about $ind_3 = 60km$ (distances on road network - not direct). That this is a very good result, will be illustrated by some examples. Again, the main difference results from the modeling of equal sizes of regional warehouses within a company.

The results are illustrated by several examples in figure 6.2 and 6.3. The first picture shows the locations of discounter 1, especially near areas with high demand, locations match well, near areas with low demand differences in one locations lead to different allocations of regions to warehouses which has again influences on the other locations.

The differences in the other three examples result mainly from model simplifications or historic facts locations that are not considered within the model. The differences in locations for discounter 4 can be reasoned by different warehouse sizes. The warehouse in Berlin in reality is much larger than the others. Thus, it also delivers to stores in the north of Germany which in the model is done by the warehouse located close to Hamburg. Even more extreme is the example of full assortment retailer 22: The southern warehouse of this retailer has a very small size, resulting of the limited number of stores in the south. The model assumes that all warehouses have the same size and thus does not locate a separate warehouse in the south. Also the assumption of connected distribution area during warehouse structure determination leads to the lower warehouse number.

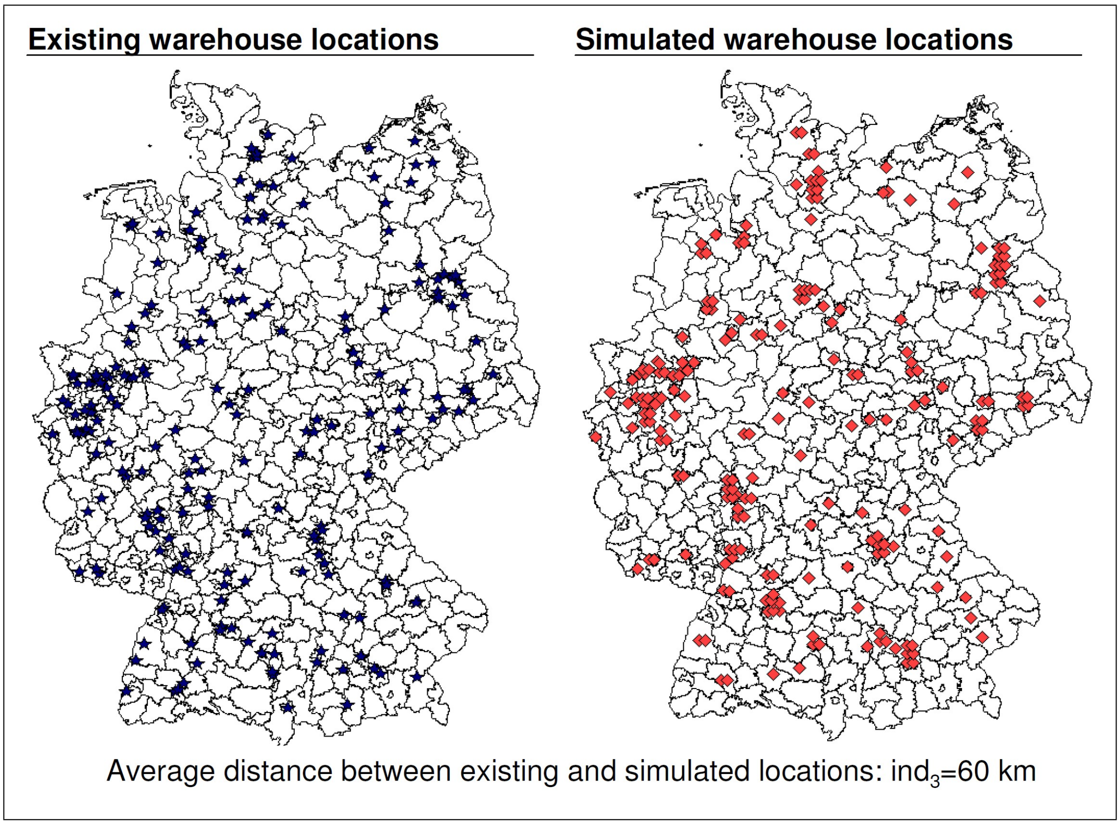

Figure 6.4: Regional warehouses: real data (left) versus simulated data (right)

If these individual differences are not considered, the overall structures are very well met. This can also be seen in figure 6.4, that gives an overview on all existing and simulated warehouse locations.

6.1.4 Sensitivity analysis

The sensitivity analysis serves to demonstrate model behavior to changes in parameters. Effects of changes will be discussed for the most important parameters. Besides parameters, also the effect of changes in system states at the beginning of the simulation will be discussed.

For the parameters, changes from -50% to +50 % to values in the base scenario are assumed. For each parameter change one simulation run was undertaken assuming stable values for all other parameters.

Sensitivities to parameter values

An overview on the results of the sensitivity analysis is given in table 6.6. It shows the proportions of direct deliveries as well as the change to the number of regional warehouses. In general, the number of regional warehouses is affected in all cases. The delta

Model parameter	Indicator	Change of indicators for a change of model parameter by									
		-50%	-40%	-30%	-20%	-10%	+10%	+20%	+30%	+40%	+50%
α_{wfc}	% a_{dir}	31	31	31	31	31	31	31	31	31	31
(Warehouse fix	% t_{dir}	9	9	9	9	9	9	9	9	9	9
costs, for less	% $n_{p,dir}$	19	19	19	19	19	19	19	19	19	19
than 2000 articles)	Δn_{RW}	34	25	22	14	6	-4	-10	-14	-17	-25
β_{wfc}	% a_{dir}	31	31	31	31	31	31	31	30	30	30
(Additional warehouse	% t_{dir}	9	9	9	9	9	9	9	9	9	9
fixed costs, for more	% $n_{p,dir}$	19	19	19	19	19	19	19	19	19	19
than 2000 articles)	Δn_{RW}	23	17	12	9	6	-3	-7	-9	-14	-15
hc	% a_{dir}	34	33	33	32	31	30	30	29	29	29
(Handling costs)	% t_{dir}	10	10	10	10	10	9	9	9	9	9
	% $n_{p,dir}$	19	19	19	19	19	19	19	19	19	19
	Δn_{RW}	6	5	5	4	1	-1	-1	-1	-6	-5
wc_{vpp}	% a_{dir}	30	30	30	31	31	31	31	31	31	31
(Variable warehouse	% t_{dir}	9	9	9	9	9	9	9	9	9	9
costs per	% $n_{p,dir}$	19	19	19	19	19	19	19	19	19	19
stock position)	Δn_{RW}	6	5	3	1	0	-3	-4	-5	-6	-7
$tcr_{dis}^{FRC,local}$ (Transport	% a_{dir}	26	27	28	29	30	32	34	34	36	37
cost rate of food	% t_{dir}	7	8	8	9	9	10	10	11	12	13
retailing company for	% $n_{p,dir}$	15	16	17	18	18	19	20	21	24	26
local distribution)	Δn_{RW}	-35	-33	-25	-22	-13	11	24	32	38	53
$tcr_{dis}^{FRC,inter}$ (Transport	% a_{dir}	27	28	29	29	30	31	32	33	33	34
(cost rate of food re-	% t_{dir}	9	9	9	9	9	10	10	10	10	11
tailing company for in-	% $n_{p,dir}$	18	19	19	19	19	19	19	19	19	22
terregional distribution)	Δn_{RW}	-64	-50	-37	-25	-12	11	19	25	34	35
tcr_{dis}^{W}	% a_{dir}	43	39	37	35	33	29	27	25	23	21
(Wholesaler	% t_{dir}	18	15	13	11	11	9	8	7	6	6
transport cost rate	% $n_{p,dir}$	34	32	25	22	21	18	16	15	13	11
for distribution)	Δn_{RW}	-30	-32	-10	-2	-3	0	4	5	6	11
$tc_{inbound}$	% a_{dir}	25	27	28	29	30	31	32	32	33	33
(General transport costs	% t_{dir}	8	9	9	9	9	10	10	10	10	10
- for inbound transport)	% $n_{p,dir}$	18	19	19	19	19	19	19	19	19	19
	Δn_{RW}	46	36	25	18	7	-7	-14	-20	-26	-32

Table 6.6: Sensitivities of variable model parameters

is caused to a large part by discounters. The reason for this is, that the cost differences for warehouse structure alternatives is smaller, caused by higher number of warehouses of discounters combined with declining savings in outbound costs for higher warehouse numbers. Also warehouse and transport inbound costs are lower for discounters.

For some parameters, the proportions of direct deliveries do hardly change. For the variable warehouse cost components (hc and wc_{vpp}) this is obviously plausible since they affect all supply path in a similar way. For warehouse fixed cost components (α_{wfc} and β_{wfc}) the influence can only be indirect through less transport distance in case of higher warehouse numbers. This influence is reduced by two aspects. Firstly, less warehouses also lead to larger inbound flows which causes less stock and transport inbound costs. Secondly, the costs for interregional outbound transport are relatively low ($tcr_{dis}^{FRC,inter}$) since long distance roads can be used.

In the following, the individual parameters will be discussed further:

Warehouse fix cost parameters (α_{wfc} and β_{wfc}) have similar effects on warehouse numbers. If they are lowered, the number of warehouses increases and vice versa. The effect of lowering costs leads to larger changes because of declining savings in transport outbound costs.

Handling costs per pallet hc occur when pallets have to be unloaded or loaded. This is the case if warehouses of LSPs, wholesalers or food retailing companies are passed. Supply paths where this happens twice, like the delivery via a LSP or a central warehouse are especially affected. For the third model step, the central warehouse level gets more attractive for some retailers if handling costs decrease. This makes regional warehouses less expensive since small flows, causing high transport inbound and stock costs, have not to be handled on the regional level any more, resulting in an increase in the number of regional warehouses. The increase in handling costs on the other hand is not strong enough to abolish existing central warehouse levels. A smaller effect can be seen for the second model step: flows from small suppliers that are routed via LSPs for transport bundling get more expensive, this causes a small decrease of direct turnover and article proportion.

Costs per stock position wc_{vpp} is a main driver within the lot size optimization. An increase leads to smaller lot sizes, leading to increased costs for inbound transports. The number of warehouses decrease accordingly. Since these costs affect wholesalers, logistic service providers and food retailing companies alike, changes in direct delivery proportions are minor.

For all transport cost parameters of food retailing companies, two effects overlap: costs for supply path alternatives as well as warehouse structure alternatives change. This can best be seen for the local distribution cost rate $tcr_{dis}^{FRC,local}$. If the rate is increased, savings for a larger number of warehouses increase and so does the number of warehouses. But also the supply path alternative gets less attractive and less quantity is transported via the warehouses of the retailer.

The model reacts also very sensibly to changes in interregional distribution costs of retailers ($tcr_{dis}^{FRC,inter}$). The supply path proportions of direct deliveries do only change moderately. This is caused by heavily reduced number of warehouses and higher transport distances in case of decreasing cost rates and by the larger number of regional warehouses in case of increasing cost rates.

The transport cost rate for distribution of wholesalers tcr_{dis}^{W} directly effects the proportions of direct delivery. An increase leads to a lower percentage of direct deliveries, a decrease to a higher percentage. Since in the base scenario the proportions for discounters are already very low, an increase does not cause large changes in warehouse numbers which is different for the opposite case.

Finally, changes in transport inbound costs do also have a high effect on the warehouse number. With increased costs, the positive effect of bundling becomes more important, which causes that even with a lower number of warehouses the supply path proportions rest relatively stable.

Sensitivities to changes in initial system states

Besides parameters, initially assumed system states can influence results. In the case of SYNTRADE, supply paths and the number of warehouses are assumed at the beginning of the simulation. Changes in both will be analyzed in the following.

At first, changed initial supply paths are assumed. Instead of applying the described rules, flows are allocated randomly, by assuming different percentages of direct deliveries (10% to 70%). All parameter values, described in the base scenario, are kept. Table 6.7 gives an overview on the resulting percentages of direct deliveries and changes in number of warehouses in the reached stable state.

	Indicator change for change of initial direct delivery proportion by						
Indicator	70%	60%	50%	40%	30%	20%	10%
% a_{dir}	25	25	25	25	25	24	22
% t_{dir}	8	8	8	8	8	8	8
% $n_{p,dir}$	19	19	18	18	18	18	18
$\Delta\ n_{RW}$	1	1	1	1	1	1	1

Table 6.7: Changes in model indicators for random initial supply paths

The model results do not change significantly. However, through the random choice, bundling becomes more difficult for wholesalers since small flows from large supplier, allocated to the wholesalers in the base scenario, are distributed randomly. As the article percentages show, this effect increases if less flows are allocated to wholesalers initially. In all cases, this strengthens slightly the position of retailers. The only change in warehouse structure happens for Full Assortment Retailer 15, who is on the edge between a warehouse structure with two and three warehouses and thus very sensitive to this effect.

Even less changes to the model results occur if different warehouse structures are assumed. Two "extreme" cases are defined. In the first case many more warehouses were assumed - about 100 % more compared to the initial value of base scenario (100.000 pallets per warehouse). In the second case, fewer warehouses are assumed - about 70 % less warehouses compared to the base scenario (1.000.000 pallets per warehouse). Both changes do not influence model results significantly - percentages of direct deliveries change by less than one percent.

These small sensitivities of the model to the initial system states show that the solution in the base scenario is very stable. The forward looking decision procedure and the wide range of alternatives tested within the optimization heuristic of warehouse structures, cause that global optima for individual companies are found. Thus, the modelling of decisions with large scope and convex cost function is an answer to the problem of multiple possible overall system states in logistics.

6.2 Detailed analysis of base scenario results

In this section some model capabilities and limitations will be discussed based on more detailed results from the base scenario. At first, the phenomenon of economies of scale will be shown, using the example of beverages, then the "proximity" of different logistic structures will be demonstrated by the examples of two companies, and finally, the consequences of artificially generated input data will be discussed.

6.2.1 Economies of scale in logistic systems

Concave cost functions of logistic systems, caused by economies of scale, are essential for the understanding of freight transportation. They cause the emergence of logistic mesostructures and cause that the stable state of the overall system is not unique as discussed in chapter 3. The dynamics at the meso level are the main difference between modeling freight or passenger transportation.

Within SYNTRADE concave cost functions resulting from economies of scale ocur at three levels:

- Inbound transport costs: transport costs per pallet decrease for larger lot sizes. The resulting problem to split the costs for a bundle of flows was discussed in the last chapter.
- Warehouse costs: a significant part of warehouse costs are fixed. Thus, the average costs per pallet decrease the more pallets are handled. This is reflected in the warehouse structure optimization.
- Distribution costs: distribution costs per pallet decrease if more pallets are delivered within the distribution tour. A detailed example with data from the model is shown as follows.

Figure 6.5 shows the change of supply paths and the costs for distribution by the wholesaler for the example of flows with beverages of Discounter 7. In this example the transport cost rate of the wholesaler is significantly lowered (by 40 %), so that direct distribution becomes more attractive. The graph on the left side shows all commodity flows with beverages for Discounter 7. Initially a supply path via the retailer warehouse is assumed, the shadings indicate the simulation round (in the second model phase) in which the change happens. The graph on the right side shows the development of wholesaler distribution costs per pallet for an exemplary region as well as the development of total quantity, distributed by the wholesaler.

The change happens sequentially, first, the large flows change the supply path since a certain amount of goods are needed to make the delivery economically interesting, then, other flows follow since the direct path has become more attractive. Besides distribution costs in the regions, other factors influence the choice of supply paths. Small suppliers for example have high costs for transport to the destination regions. This is the reason that some flows keep the supply path via the retailer's warehouse.

This example shows evidently the effect of economies of scale in distribution. This example also shows the potential effect of combining flows for the supply path decision, that was discussed in the last chapter. If several flows are considered at once the change can happen earlier.

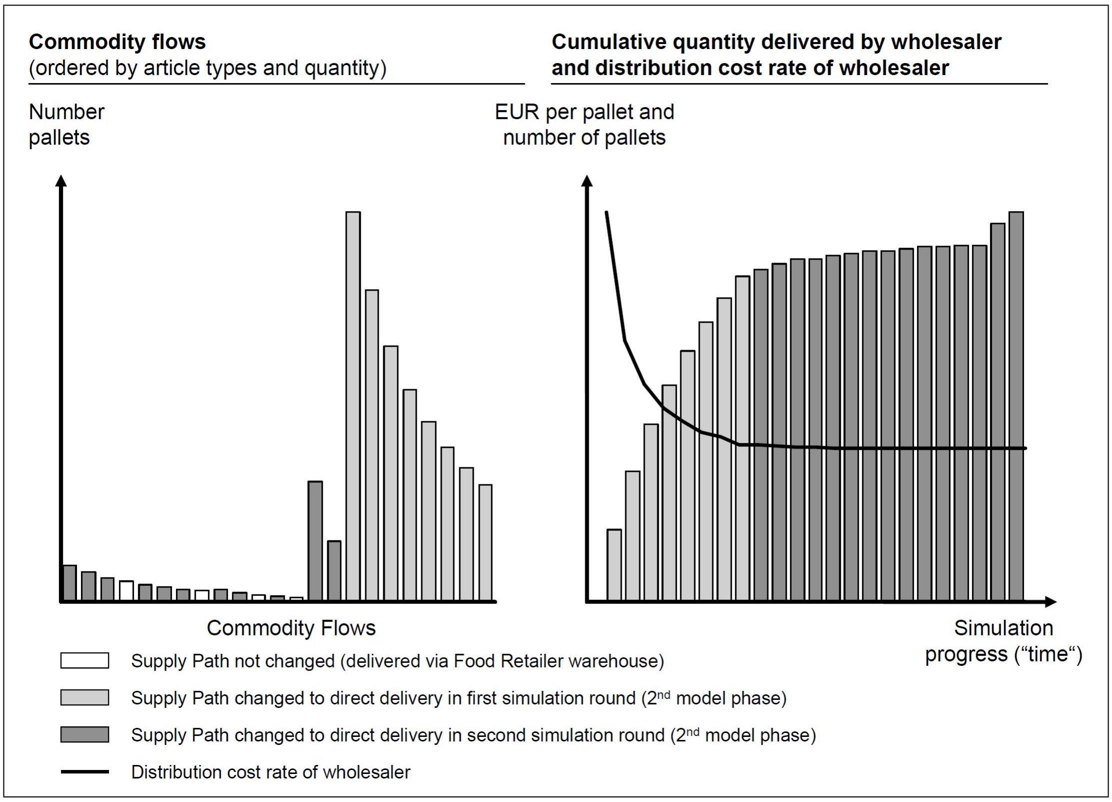

Figure 6.5: Example of economies of scale of a wholesaler in a region

6.2.2 Proximity of logistic structures

An important characteristic of logistic structures to be discussed is the proximity. Contrary to the indicators of the last section that primarily focused on the "shape" of the structures, number of warehouses and locations, the term "proximity" at this place refers to the logistic decisions and the costs of the structure. Structures can be close in terms of costs while their shape and therefore their implications for transportation differ significantly. Two examples will demonstrate this phenomenon.

At first, the costs of two structures for Discounter 7 are analyzed. The first structure comprises 11 regional warehouses, as in the base scenario. The second structure only comprises 8 warehouses, but beverages are delivered directly. In the model this structure occurs if lower wholesaler costs are assumed. The costs for both structures in the base scenario are given in figure 6.6

Overall costs for both alternative are very close, but differences exist in the cost components. The higher costs for direct delivery in the second case equalize the savings within the other cost components. The differences to the base scenario for transport inbound costs and warehouse costs are more pronounced than for outbound costs. The reason is the effect of higher distances to destination regions for the retailer distribution that equalizes the lower quantities.

The consequences for transport are more significant than the difference in costs indicate. The direct transports from supplier to destination regions increase, on the other hand a higher detour has to be accepted for all flows running through the warehouse structure of the retailer since the number of warehouses is reduced. In total, this results in a small

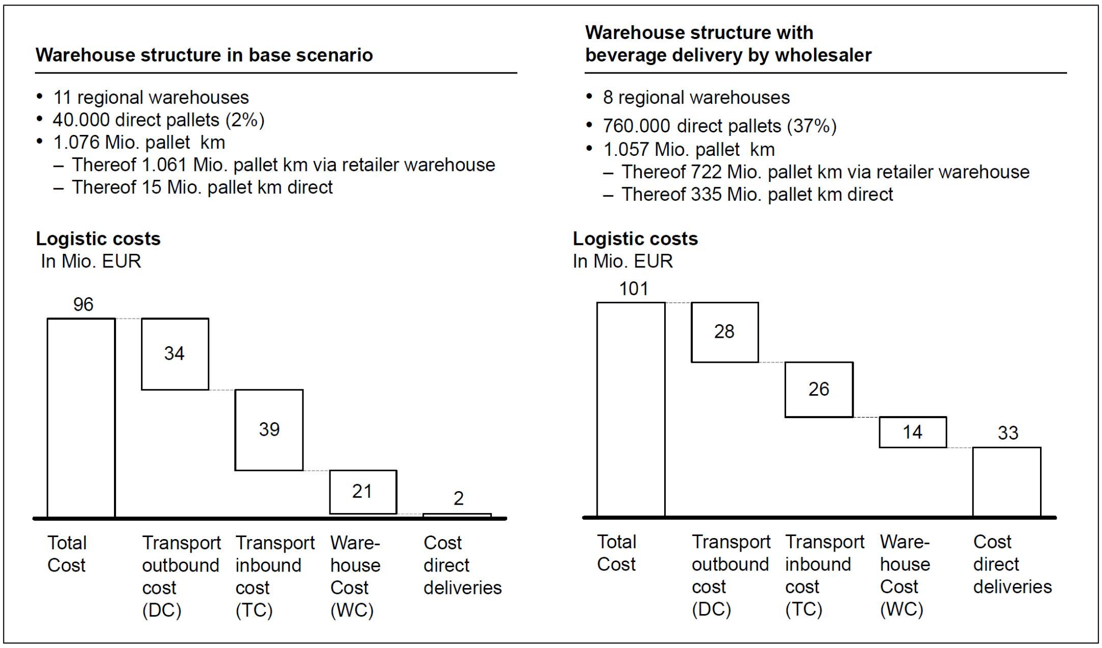

Figure 6.6: Logistic costs for different warehouse structures of Discounter 7

reduction of pkm (pallet km). For vehicle kilometers this can be different, because also lot sizes change. This will be shown in the next example.

As a second example, the central warehouse level of the Full Assortment Retailer 4 is analyzed. Costs, pkm, and distribution of lot sizes are determined for the case with and without a central warehouse level. The results can be seen in figure 6.7. Again, costs are very close, small increases occur for the "decentral" case due to higher inbound transport and warehouse costs, caused by small flows that cannot be bundled any more. The goods transported via the central level are now partially delivered directly and partially delivered via the regional warehouse structure. This "saves" about 9 Mio. pkm. However, this causes also a change in the structure of shipments: the proportion of smaller lot sizes increases.

If this also results in less vehicle km, depends on the capabilities of the transport service providers that are used for inbound transport. This is not part of this simulation model.

From these two examples, two conclusions can be drawn for the modeling of logistic structures:

- For logistic systems, different states can exist, that are similar in costs but differ in shape.
- If only costs are used as decision basis, small changes in cost parameters can lead to major changes in logistic structures for individual companies.

The second point has to be considered for "future" scenarios, in case major changes occur, it has to be decided how likely these changes are in reality or if boundaries like investments avoid sudden changes. This is especially important if only a small number of structures is modeled or if all modeled structures are homogeneous.

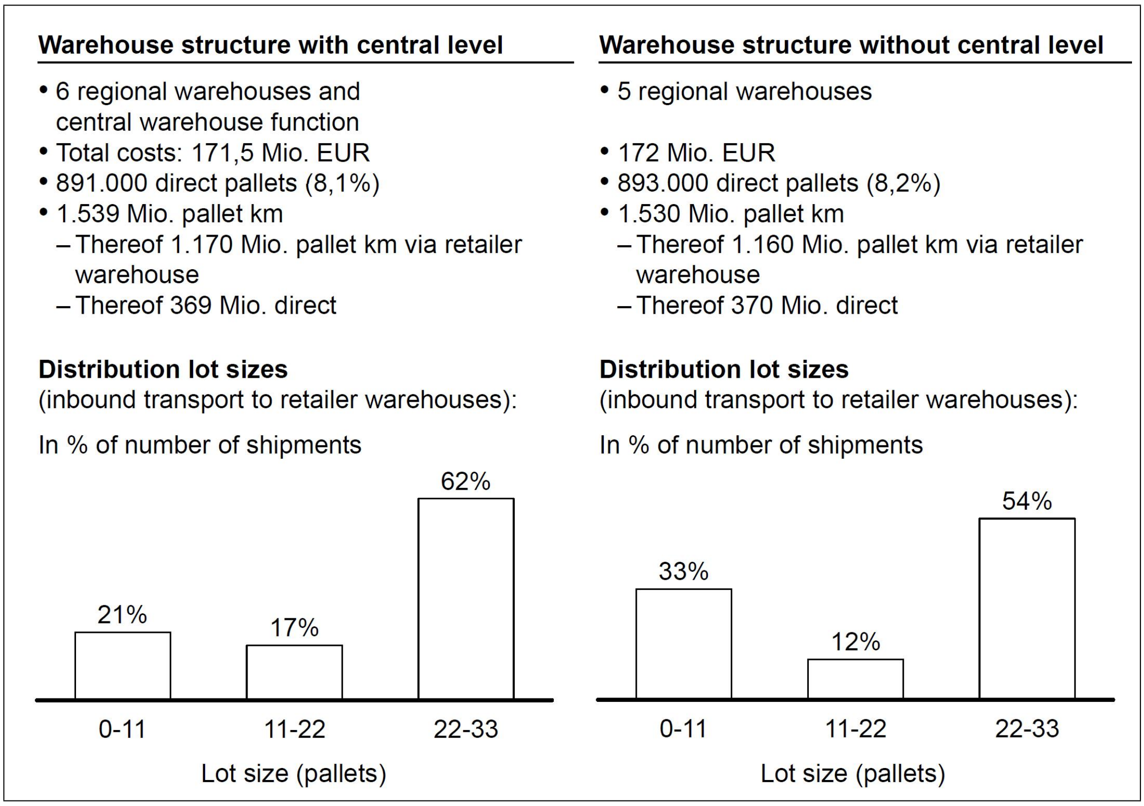

Figure 6.7: Differences in lot size distribution for Full Assortment Retailer 4

6.2.3 Disaggregate model data

The model works with disaggregate data and also produces its results on a disaggregate level. Partly this bases on input data that is generated artificially in the first model phase. Now, the quality and the limitations of this disaggregate data will be discussed. This discussion is focused on data of incoming commodity flows for food retailers and for regions of consumption.

Food retailers

SYNTRADE generates commodity flows for food retailing companies based on statistical data, like distributions of employees in consumer product industry, on sectoral data, like number of articles and turnover per article category, and on assumed model parameters like number of articles per supplier or the Pareto distribution to model differences of suppliers within the same article category. The resulting data is shown in figures 6.8 to 6.10 for the example of Discounter 7. In figure 6.8 an overview on data of all flows as well as some examples of international flows is given.

Figure 6.9 lists all flows of milk products destined for Discounter 7. The data is artificially generated and has a "prototype" character. This means that the data meets the overall statistic of German economy, but only reproduces flows of a "prototype" discounter and not real data. The results shown correspond to what can be expected for such a discounter, examples are fruits and vegetables from the Netherlands and Spain or milk

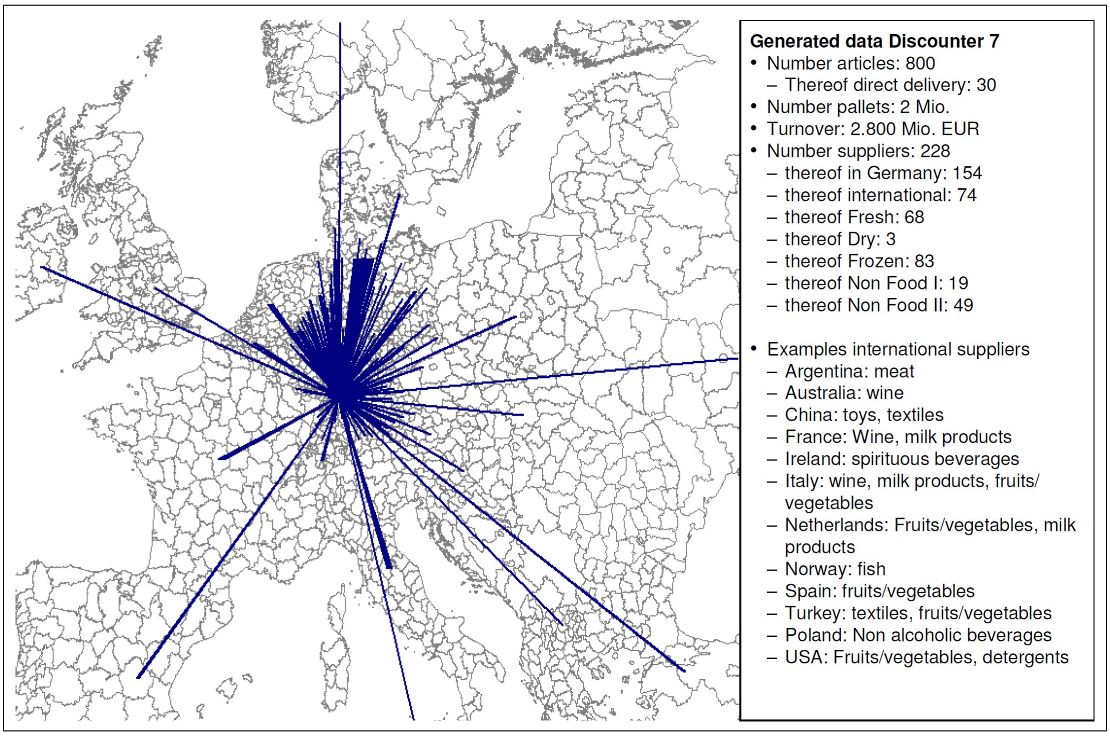

Figure 6.8: Overview on generated data for Discounter 7

products from northern and southern Germany. Such kind of "prototype" data is sufficient for the macroeconomic purpose of this model.

The cumulative distribution of flow sizes is shown in figure 6.10 for turnover and number of pallets.

Three main drivers within generation can be differentiated: the assumed differences of flows within the same article category that are modeled assuming a Pareto distribution, the differences between turnover proportions of article categories originating from sector data , and different value to volume or value to weight ratios originating from estimates, based on statistics.

The left picture shows the result of the first two drivers: the distribution of turnover of flows. The differences are kept low for discounters by assuming a low parameter within the Pareto distribution. The right picture shows the distribution of pallets which results through the connection of the left picture with the ratios. As can be seen, the resulting differences are mainly driven by the ratio data.

It can be concluded that in terms of representing "prototypes", data of commodity flows, generated for the food retailing companies, has a very high quality, only few aspects depend on model assumptions.

Regions of consumption

The resulting flows to the regions are the result of all model phases. Flows from suppliers to regions and flows from suppliers to retailing companies result from the first model phase. Supply paths, locations of warehouses and allocation of regions to warehouse result from the second and third model phase.

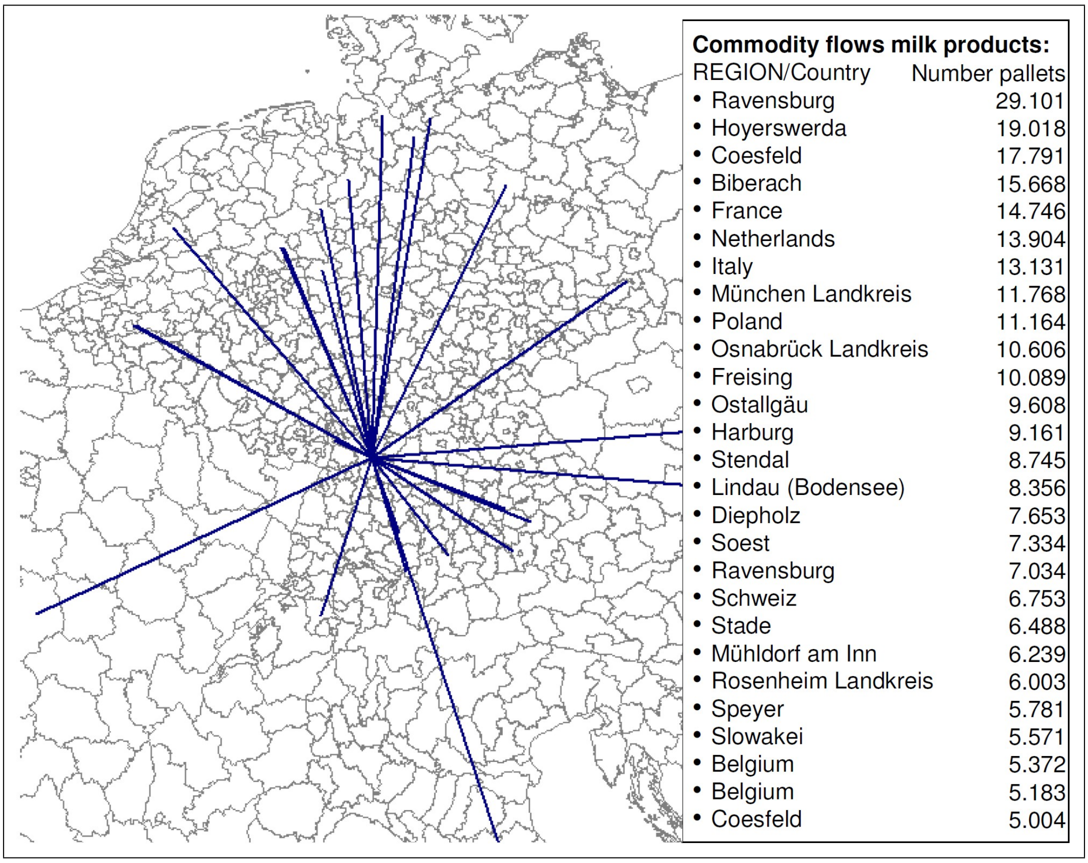

Figure 6.9: Commodity flows with milk products for Discounter 7

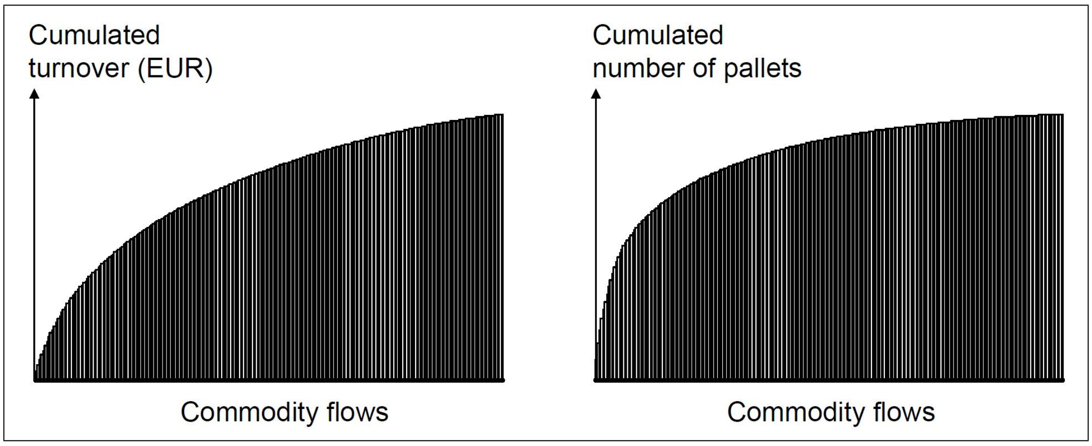

Figure 6.10: Cumulative distributions of commodity flow sizes for Discounter 7

As an example, the aggregated flows in form of number of pallets for the region of Stuttgart are shown in figure 6.11 and 6.12. The data on pallets delivered via food retailer warehouses, shown in figure 6.11 result from the commodity flow data of retailers and logistic modeling. The quality is rather high since this results from the model core.

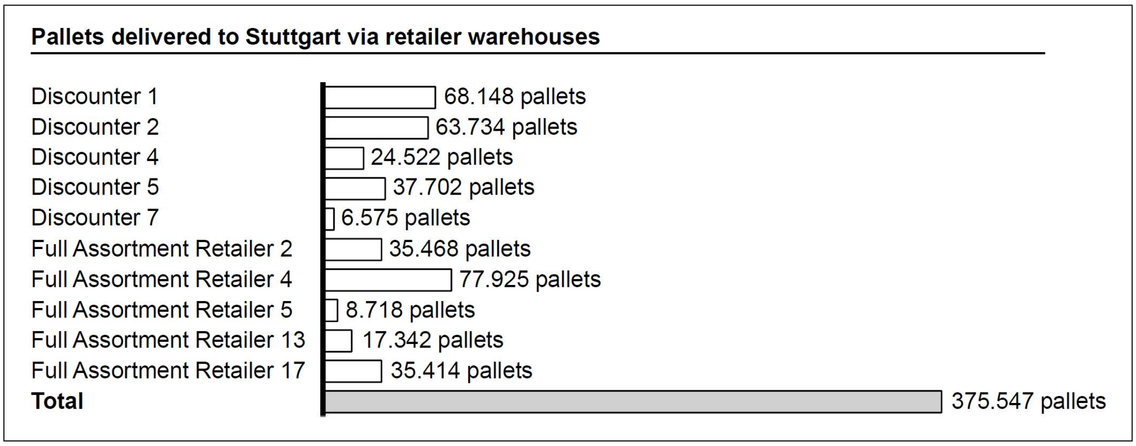

Figure 6.11: Pallets delivered to Stuttgart via retailer warehouses

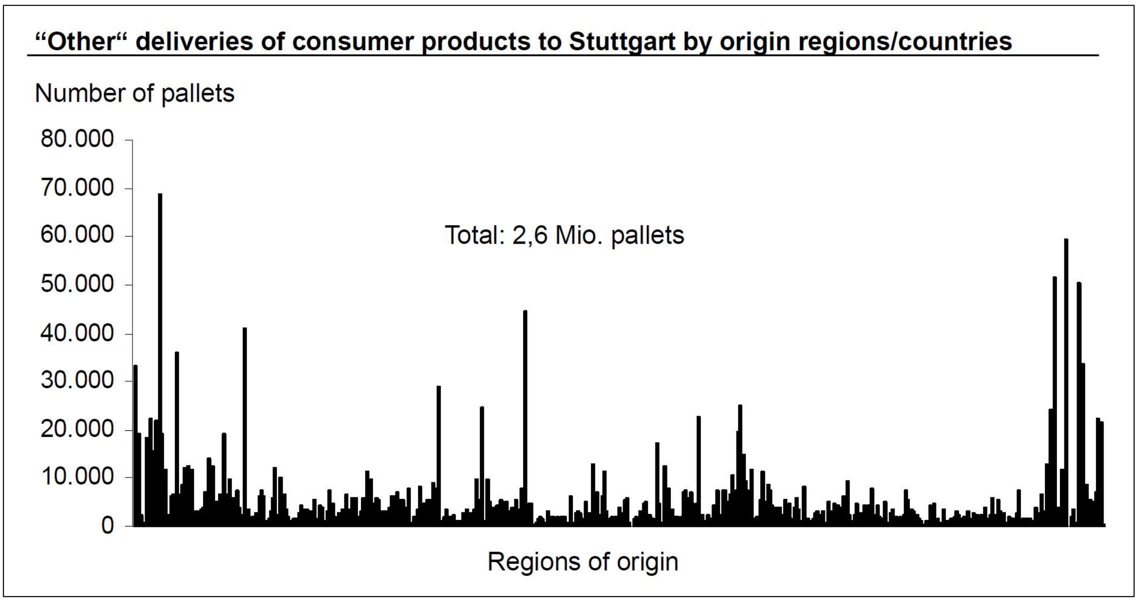

Figure 6.12: Consumer goods delivered to Stuttgart via "other" paths

The consumer goods delivered through "other" paths, shown in figure 6.12, are those commodity flows of the food retailing company delivered directly and all other consumer products, destined for the region.

The second part results from a gravity model in the first model step and a simplified logistic modeling. No interregional logistic structures are modeled, the results therefore have to be handled with care.

As an overall result of the model a transport demand matrix between regions can be defined. However, only the part of flows running through the food retailing sector results from detailed logistic modeling. Besides this matrix with pallet quantities, lot size distributions and distribution tours are generated, as shown in the last and following section. The next step of transportation modeling, the conversion to vehicle flows is not part of SYNTRADE.

6.3 Future scenarios

In this section, two scenarios will show possible applications of SYNTRADE. Firstly, the effect of a sharp fuel price raise on logistics in food retailing will be discussed. In a second scenario, the effects of an increased concentration in the sector will be discussed by assuming a merger of two companies.

6.3.1 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 ($tc_{inbound}$)
- The interregional distribution transport cost rate of retailers ($tcr_{dis}^{FRC,inter}$)
- The local distribution transport cost rate of retailers ($tcr_{dis}^{FRC,local}$)
- The (local) distribution transport cost rate of wholesalers (tcr_{dis}^{W})

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.

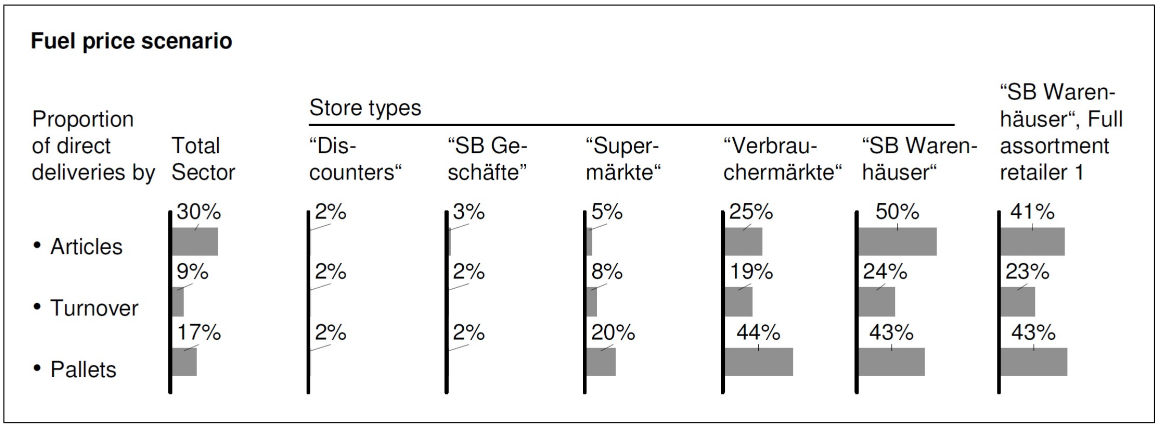

Figure 6.13: Proportions of direct deliveries in fuel price scenario

The model results for the fuel price scenario are shown in figures 6.13 to 6.15 and table 6.8. Only for "Supermärkte" direct delivery changes significantly. This is caused by some food retailing companies that change the supply paths for beverages. However, the attractiveness of direct delivery does not change a lot as the percentages of the other store types show (figure 6.13). This results from the parallel increase of all transport cost rates, in contrast to the changes that could be identified within sensitivity analysis, where only one parameter was changed.

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

Table 6.8: Number of warehouses and warehouse levels

The number of warehouses, on the other hand, changes for many companies (table 6.8). 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.

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 6.14). 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 6.15 shows the overall estimation for transport demand in form of pallet kilometers. 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

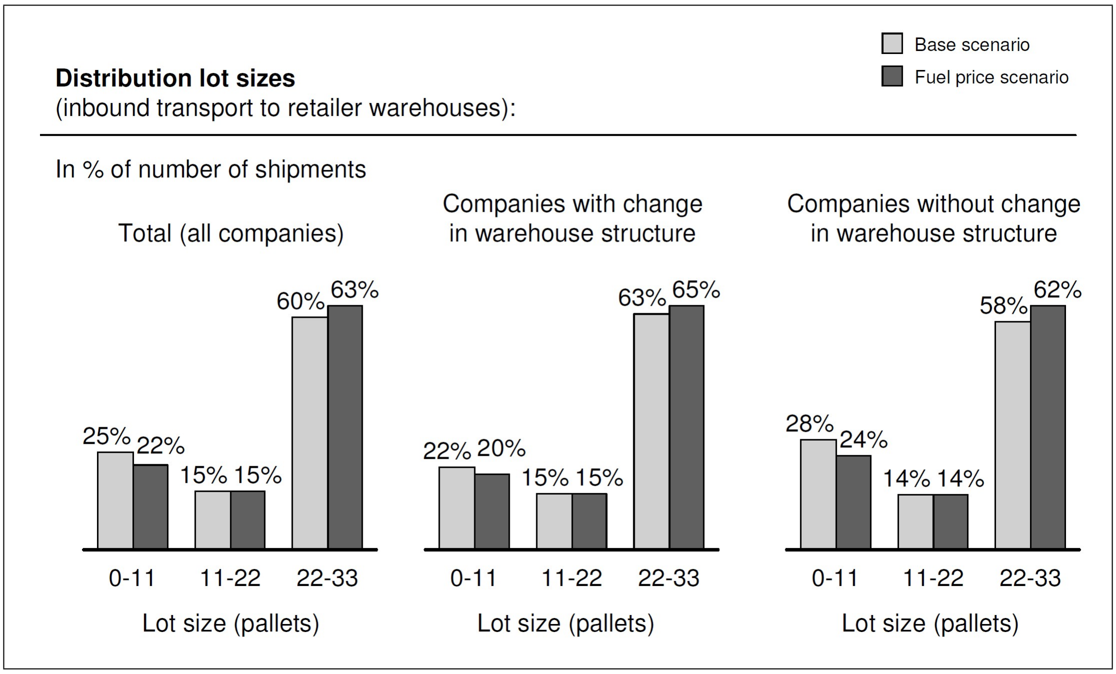

Figure 6.14: Distribution of lot sizes for base and fuel price scenario

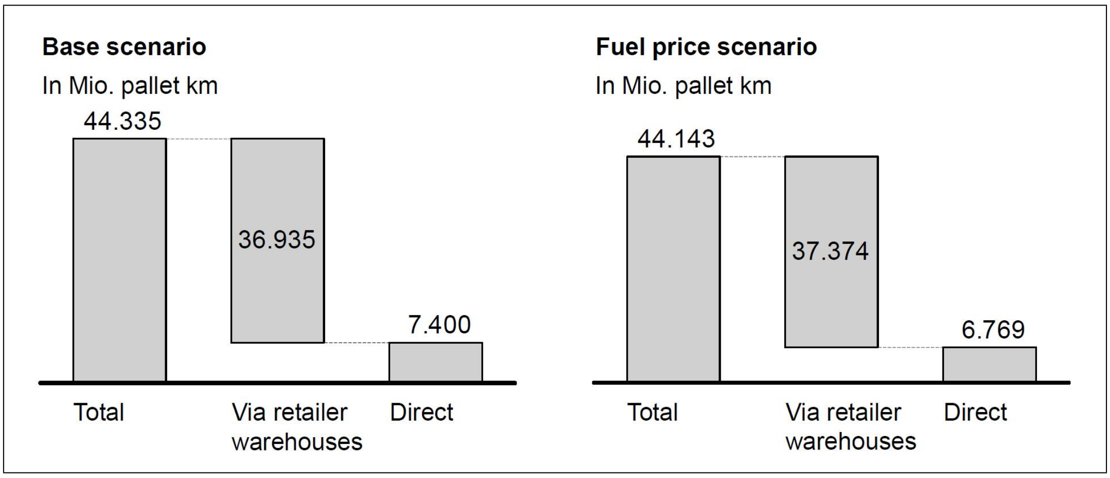

Figure 6.15: Estimation of pallet kilometers for base and fuel price scenario

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 modeling 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.

6.3.2 Merger scenario

In this scenario, consequences of a market consolidation are analyzed, taking the example of a merger of two food retailing companies.

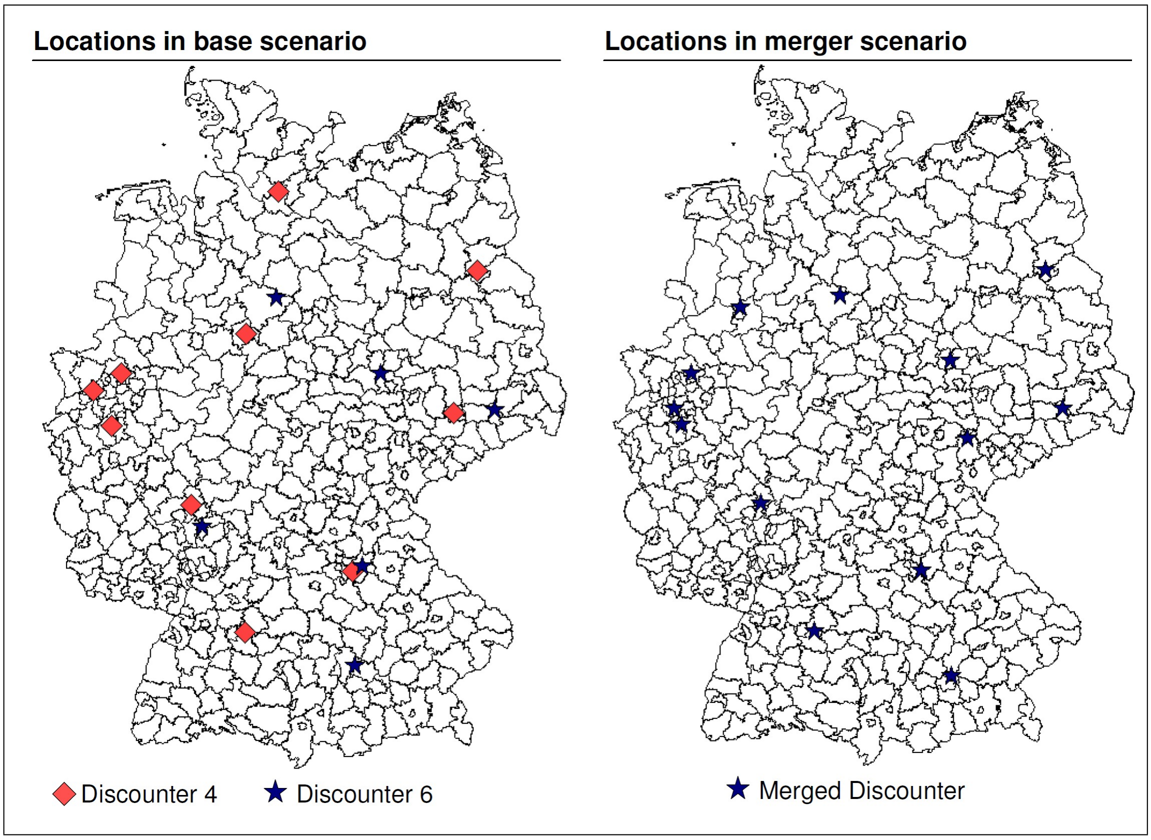

Figure 6.16: Warehouse locations in merger situation

It is assumed that Discounter 4 and Discounter 6 merge their activities. It is further assumed that the two companies consolidate their assortments and that warehouses of the merged company are placed without recognition of the existing locations. Simulated locations in the base scenario and after the merger are shown in figure 6.16. In total, the company reduces the number of warehouses from 16 (10+6) to 13. Especially the warehouses close to areas with high demand (Berlin, Stuttgart, Munich, Ruhr district) stay.

The logistic costs of the company decrease by about 6% (see figure 6.17), the main savings result from outbound costs since distances from warehouses to stores and between stores are shorter. The first leads to less "detour" from supplier to store, the second leads to less kilometers during distribution tours.

This reduction in distances can be seen more directly in the number of pallet kilometers before and after the merger, shown in figure 6.18.

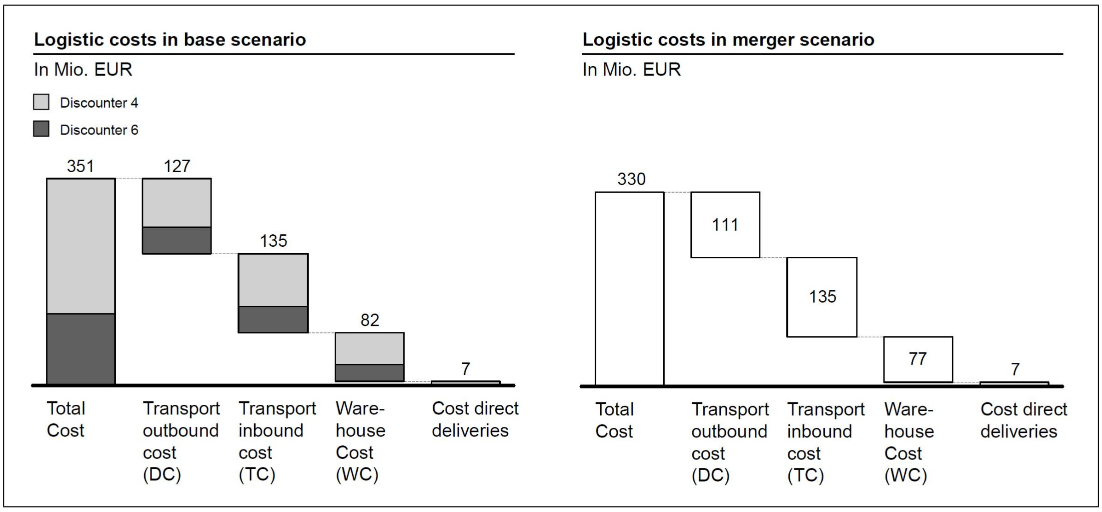

Figure 6.17: Cost comparison for merger scenario

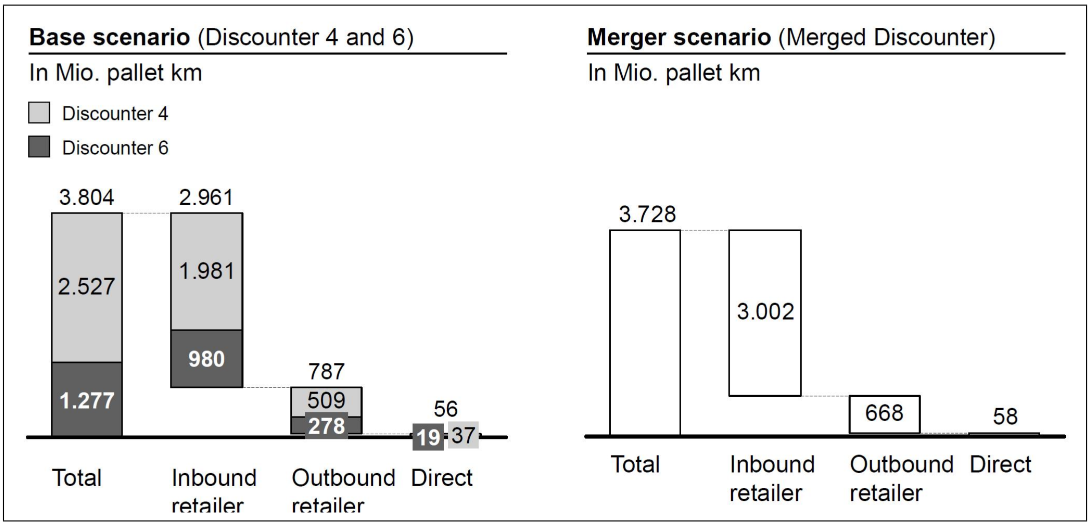

Figure 6.18: Pallet km before and after the merger of Discounter 4 and Discounter 6

Finally, as shown in figure 6.19, the distribution of lot sizes changes, since inbound quantities of flows grow. However, looking at the costs, it is clear that the new company preferred to build more warehouses instead of realizing the savings in inbound and warehouse costs. This results from the optimization since savings in outbound costs are higher than in inbound and warehousing. Therefore the model determines a relatively high number of warehouses for the new company.

This analysis example shows another strength of the SYNTRADE model. Through the disaggregate modeling of the economic activity in the food retailing sector, detailed analysis get possible. For transportation system analysis, this includes changes in economic activity like in the example. Other changes that can easily be modeled, if data is available, are changes in sourcing behavior or the appearance of new actors in the market. Analysis on this detailed level makes the model interesting for logistic research as well. Effects that need the modeling of the overall system, can be analyzed for strategic decisions.

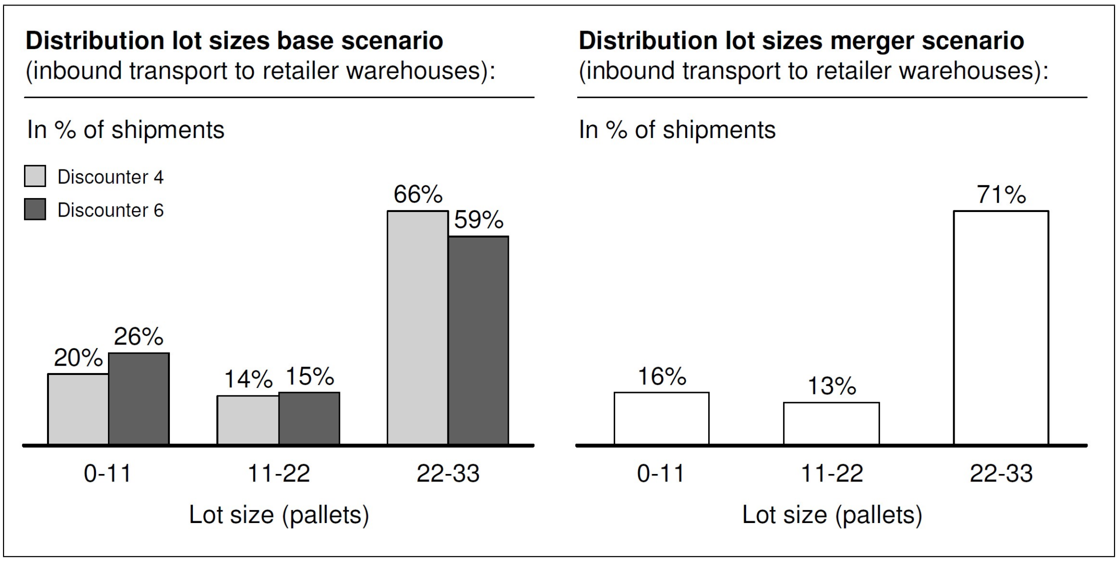

Figure 6.19: Distribution of lot sizes in base scenario and after merger

An example is the effect of direct deliveries on quantities distributed by wholesalers. In some regions, where the retail company has a high market share, it may be interesting to channel commodity flows through the retailer warehouse to avoid advantages for the competitor, using the same wholesaler for direct distribution. These examples demonstrate that SYNTRADE contributes to close the gap between transportation analysis and logistic research.

6.4 Conclusions

The previous sections proved the possibility of modeling logistic structures in a large number for the purposes of freight transportation analysis. Both, the model fit as well as the capabilities of such a model, were demonstrated. The main results will now be summarized in the light of the progress made for freight transportation analysis.

The model fit was shown by the high match to existing structures. Warehouse numbers and locations can be simulated very close to reality. While individual structures are not perfectly met, due to historic backgrounds or model simplifications, the overall picture is very accurate. Also, sensitivities to changes in model parameters show a very plausible model behavior. By modeling a forward looking warehouse structure decision, an optimization problem with a convex cost function is formulated, therefore also the sensitivity to changes in initial system states is very low.

The main progress of the model, compared to existing freight transportation models, is the explicit modeling of the emergence of logistic structures combined with modeling heterogeneous economic activity in the food retailing sector.

The consideration of logistic structures makes supply paths of goods more realistic. Detours via warehouses are modeled. This is a major improvement compared to the traditional macroscopic models. However, this is also realized within new freight modeling systems that consider logistic locations but do not model the emergence of logistic structures.

The real value added of SYNTRADE can be seen when it comes to changes in logistic systems. Through the modeling of heterogeneity within a sector and the modeling of the emergence of logistic structures, the model is less sensible to changes. The fuel price scenario showed this. Besides heterogeneous actors, more "evasion strategies" exist: direct delivery, larger lot sizes, usage of central warehouse levels and increased number of regional warehouses. Without the explicit modeling of the emergence of the structures, the reaction assumed would probably be limited to direct deliveries and lot sizes. This is an important progress of this model compared to the existing modeling landscape in transportation research.

Furthermore, the SYNTRADE model can be of interest for logistic research, as the merger scenario shows. However, it is important to emphasize the limitations of the model for analysis on the company level. Logistic optimization is modeled simplified in several occasions, examples are the assumption of equal sizes of regional warehouses within a company or the scope of the supply path decision. These simplifications are important to realize the large model scope required for transportation analysis.

7 Conclusions and outlook

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 structures with locations has not been part of disaggregate 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 modeling 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 study 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 analysis of the food retailing sector shows several characteristics of the economic activity that have to be reflected in the modeling. Differences in store types like "Discounter" and "SB-Warenhäuser" lead to very different demand structures. The same accounts for the differentiation of types of articles within the assortments, that differ in value density, perishability or sector of origin. The actors modeled have to be defined based on logistic management: stores, spread in space, have to be allocated to "logistic" companies that sometimes differ to the business companies or brands. The main logistic decisions identified for the food retailing sector are the supply path decision and the warehouse structure decision. The scope of the first includes individual commodity flows or combined flows of a supplier destined to a region. The scope of the warehouse structure decision of food retailing companies includes all commodity flows to stores of this company. The data demand for representing these characteristics in the model can, to a large proportion, be satisfied by data sources specific to the sector, or can be generated by estimation procedures. These procedures include the generation of an artificial economic landscape and artificial flows of consumer goods, including flows from suppliers to regions and flows to food retailing companies.

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. Another scenario simulating the merger of two food retailing companies, demonstrates the capability of SYNTRADE to model consequences for logistics caused by changes in economic activity on a very detailed level.

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.

Two possible directions of future research in the area of logistic simulation for freight transportation analysis shall be mentioned at the end of this study: the transfer of the developed approach to other sectors, and the simulation of complicated logistic structures of transport supply that result out of the interaction between logistic systems.

The transfer of the approach to other sectors cannot consist of a direct application of the model, but rather consists of using the same methodology for a model development. This includes the detailed analysis of the sector, as well as the model design including the right choice of the model perspective. The analysis of the sector has to generate insights on the main logistic actors and decisions taken in the sector. Expert interviews can serve as a valuable source of information. Additionally, sources for quantitative data are needed, probably on a detailed sectoral level data sources not yet used for freight transportation analysis become available, as it was the case in this study. For the simulation design, decisions and optimization problems with convex cost functions have to be identified so that the simulation results are stable. Combining this with the insights from the sector analysis determines the level of logistic decisions modeled within the hierarchy of logistic choices and the chosen perspective of the simulation model.

A second potential direction is to focus on the interaction between logistic systems. This is especially important to model logistic structures on the supply side of the transport service market. Building on the INTERLOG model of Liedkte that simulates this interaction for the emergence of vehicle tours, and on the experiences of SYNTRADE that simulates the emergence of warehouse structures, a next step could be to simulate more complex logistic structures on the transport supply side. The difficulty of this endeavor is that the scope of the underlying optimization problem is difficult to define. While the scope of the warehouse structure decision in this study could be based on the set of commodity flows of a food retailing company, the scope for the underlying logistic system of the transport supply side is difficult to determine and depends to a high degree on the market interaction. A simulation model will, therefore, have to focus much more on the explanation of the scopes of logistic systems.

This discussion shows that 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.

A Appendix: Additional definitions of existing models

A.1 Logit models

Given is a choice situation, where an individual n chooses an alternative i out of a set of discrete alternatives C_n. The utility maximization theory assumes that the preferences of individuals for each alternative are captured by the utility value U_{in} and that the individual chooses the alternative with the highest utility. Random utility theory also takes uncertainty into account, representing unobserved aspects, lacks of information or approximations in model definition. The utility of an alternative i for an individual n can be written as:

$$U_{in} = V_{in} + \varepsilon_{in}$$

where V_{in} represents the deterministic part of utility and ε the uncertainty in form of a random term. The possibility that alternative i is chosen, can be described as the possibility that this alternative has maximum utility:

$$P(i \mid C_n) = P[U_{in} \geq U_{jn} \forall j \in C_n] = P[U_{in} = max_{j \in C_n} U_{jn}]$$

The deterministic part of the utility function includes attributes of the alternatives as well as attributes of the decision making individual. Mostly, a linear representation is chosen:

$$V_{in} = \sum_k \beta_k x_{ink}$$

where x_{ink} are the k attributes of the alternative i and the individual n and β_k are the corresponding coefficients, representing the weight of the attributes in the utility function. These attributes are the explanatory variables of the models.

The random part of the utility function (the error terms) can have different forms. Logit models assume a "Gumbel" distribution for ε, probit models, on the other hand, assume a Normal distribution. The basic logit model, the multinomial logit model (MNL) assumes that the error terms are independent and equally "Gumbel" distributed. The cumulated Gumble distribution function can be written as:

$$F(\varepsilon) = e^{-e^{-\mu(\varepsilon - \eta)}}, \mu > 0$$

where μ is a scale and η a location parameter. With this, the probability that alternative i is chosen in a MNL model can be determined:

$$P(i \mid C_n) = \frac{e^{\mu V_{in}}}{\sum_{j \in C_n} e^{\mu V_{in}}}$$

The coefficients (in the linear representation the β_k) are then estimated, based on empirical data. The scale parameter μ is mostly arbitrary defined as $\mu = 1$, which usually does not matter and can be ignored safely (since the β_k will be estimated accordingly). Nevertheless, it can be important for example if utility values from different models are compared (see Bierlaire (1998), p. 211 ff).

By assuming homogeneous populations of individuals, the coefficients are estimated for the overall populations. How critical such an assumption can be in freight transportation becomes clear, when looking at the heterogeneity.

The assumption of interdependence between alternatives is a main source of criticism for logit models. Therefore Nested logit models are designed to capture some correlations among alternatives. Alternatives with similarities, meaning a high correlation in attributes between certain alternatives ($x_{ink} \cong x_{jnk}$), are grouped (nested) and thus subsets C_{mn} are established:

$$C_n = \cup_{m=1}^{M} C_{mn}$$

with

$$C_{mn} \cap C_{m'n} = \emptyset, \forall m \neq m'$$

The decision is then modeled sequentially in several steps. The resulting probability that alternative i is chosen is derived from the probability that the corresponding nest is chosen and the probability that alternative i is chosen within the nest:

$$P(i \mid C_n) = P(C_{mn} \mid C_n) P(i \mid C_{mn})$$

A more detailed mathematical formulation and discussion on nested logit models can be found in Carrasco and Ortúzar (2002).

Further developments of discrete choice models are:

- Cross nested logit models: In this direct extension of Nested Logit Models, each alternative can belong to more than one nest.
- Variable transformation (Box-Cox and Box-Tukey): through variable transformation non linearities in explanatory variables can be modeled (Rothengatter et al., 2006).
- Consideration of many decision parties: Rose and Hensher (2004) defines discrete choice models, including utility components of several decision parties. Thus, they are able to include aspects of cooperation in decision taking into the discrete choice model.
- Probit models: in these models, the random part of the utility function is assumed to be distributed normally. These models can capture explicitly the correlation among alternatives. On the other hand, mathematical formulations get very complex and intractable for a relatively low number of alternatives (Ben-Akiva and Bierlaire, 2003).
- Hybrid / Mixed logit models: These models try to combine the logit and the probit approach. The utility function contains both variables that are distributed normally, as well as Gumbel variables that are independent and distributed identically (Ben-Akiva and Bierlaire, 2003).
- Models with latent variables and classes: These extensions of choice models try to explain influences of unobserved heterogeneity of individuals and alternatives, as well as unobserved variables. Therefore, latent classes of individuals with different choice sets as well as latent variables (besides the explanatory variables), are incorporated in a model. Latent classes and latent variables are modeled in a stochastic way, in contrast to the attributes in traditional logit models that are deterministic (see Walker and Ben-Akiva (2002) for details). As the example of the study of Park (1995) shows, latent variables can be used to tackle the problem of heterogeneity.

A.2 General equilibrium model

Given is an economy with commodities k=1..r, production companies j=1..n and consumers i=1...m. The vector $x_i \in \mathbb{R}^r$ describes the consumption of commodities by consumer i, the vector $y_j \in \mathbb{R}^r$ describes the production of commodities of company j and the vector $p \in \mathbb{R}^r$ describes the prices of the commodities. The general competitive equilibrium can be defined as follows (cited from Ginsburgh and Keyzer (2002), p. 3):

> The allocation $y_j^*, \forall j$, $x_i^*, \forall i$, supported by the price vector $p^* \geq 0$, p must not be 0 for all dimensions, is a general competitive equilibrium, if the following conditions are satisfied:
>
> 1. For every producer j, y_j^* solves $max_{y_j}\{p^* y_j \mid y_j \in Y_j\}$.
> 2. For every consumer i, x_i^* solves $max_{x_i \geq 0}\{u_i(x_i) \mid p^* x_i \leq h_i^*\}$, where $h_i^* = p^* \omega_i + \sum_j \theta_{ij} p^* y_j^*$.
> 3. All markets are in equilibrium, $\sum_i x_i^* - \sum_j y_j^* - \sum_i \omega_i \leq 0$.

where

Y_j	=	Technology set, containing all feasalbe y_j
$u_i(x_i)$	=	Utility level of customer i consuming x_i
h_i	=	Income of consumer i
ω_i	=	Vector of endowments of consumer i ($\omega_i \in \mathbb{R}^r$)
$\theta i j$	=	Share of consumer i in company j

A.3 Input-Output model

Figure A.1 shows the structure of the "Input-Output" table. Y represents the matrix of final

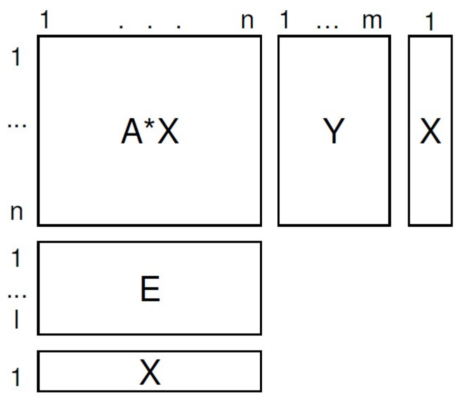

Figure A.1: Structure IO Table

demand, E the matrix of primary input, A*X the matrix of flows between the sectors and X the vector of gross production values of the sectors. Regarding the matrix A isolated, it contains the technical coefficients between the sectors. Gross production values can be calculated by adding all goods and services that are produced either for final demand (Y) or for other sectors (AX), expressed in the equation:

$$X = A * X + Y$$

This equation can be solved for X, resulting in an equation system that can determine the gross production value out of final demand:

$$X = (I - A)^{-1} * Y$$

The matrix $(I-A)^{-1}$ is called the "Leontief inverse". It is now possible to calculate certain scenarios, for example the consequences of a change in final demand on gross production.

A.4 Derivation of distance formula

The average distance between the center of a circle and the points within a circle with radius R can be calculated by solving an integral over the circle area $A := \{(x_1, x_2) \in \mathbb{R}^2 : x_1^2 + x_2^2 \leq R\}$ and dividing the result by the circle area:

$$dwp_{average} = \int_A \sqrt{x_1^2 + x_2^2} d(x_1, x_2) * \frac{1}{\pi R^2}$$

To solve this a transformation to polar coordinates ($A^* := \{(r, \varphi) : 0 \leq r \leq R, 0 \leq \varphi \leq 2 * \Pi\} \subset \mathbb{R}$) has to be undertaken:

$$\begin{aligned} \Phi : \quad A^* &\mapsto A; \\ (r, \varphi) &\mapsto (r * cos(\varphi), r * sin(\varphi)) \end{aligned}$$

With this transformation, the integral can be solved as follows:

$$\begin{aligned} dwp_{average} &= \int_A \sqrt{x_1^2 + x_2^2} d(x_1, x_2) * \frac{1}{\pi R^2} \\ &= \int_{A^*} \sqrt{r^2 * cos^2\varphi + r^2 * sin^2\varphi} * r d(r, q) * \frac{1}{\pi R^2} \\ &= \int_0^R \left(\int_0^{2*\Pi} r^2 d\varphi \right) dr * \frac{1}{\pi R^2} \\ &= \int_0^R 2 * \pi * r^2 dr * \frac{1}{\pi R^2} \\ &= 2/3 * R \end{aligned}$$

But since the real distances on the road network do not correspond to the direct distance just calculated, the result has to be multiplied by a detour factor. Gudehus assumes a detour factor of 1,23 for the German road network. With this in mind, the formula for the average distance published by Gudehus corresponds to the calculated results (Gudehus (2006), p.234, formula 34):

$$dwp_{average} \cong 1,23 * 2/3 * R = 1,23 * \frac{2 * \sqrt{A}}{3 * \sqrt{\pi}} = 0,46 * \sqrt{A}$$

A.5 Additional definitions of lot size models

A.5.1 Dynamic model

The basic single level uncapacitated lot size problem (SLULSP) can be formulated as a linear program (adapted from Rossi (2003), p.26): For the time periods $1 \ldots T$ demand X_t, unit price p, stock cost rate r_{St} and order cost c_{Ot} are given. Order quantity Q_t and stock at the end of the period Y_t have to be determined, the variable z_t describes if an order has been placed:

$$
\begin{array}{lll}
Min & \sum_0^T (r_{St} Y_t + pQ_t + c_{Ot} z_t) & \\
s.t. & y_{t-1} + Q_t = Y_t + X_t & \forall t \\
 & Q_t \leq z_t \sum_{t'=t}^T X_{t'} & \forall t \\
 & Q_t, Y_t \geq 0 & \forall t \\
 & z_t \in 0, 1 &
\end{array}
$$

An efficient solution procedure was published by Wagner and Within (1958).

A.5.2 Lot size model with fluctuations

In this section the representation of fluctuations in static models is presented, see for example Huang and Kücükyavuz (2008) for dynamic models.

One can distinguish models by following decision parameters (Toporowski (1999), p.198):

- s = Ordering point (stock level when order is triggered)
- r = Ordering cycle (time period between two orders)
- Q = Order quantity
- S = Stock level (level to which stock is filled up)

The parameters s and r determine the point of time for the order, whereas the parameters Q and S determine the quantity ordered. The different combinations define model categories ((s,Q), (r,Q), (s,S), r,S)). These or comparable categories are also referred to as stock policies (Gudehus (2004), p.403) or inventory control systems (Within (1957), p. 15 ff).

In the following text, the determination of optimal order quantity Q and safety stock s is shown for (s,Q), assuming a process that triggers the order at a certain stock level s (safety stock) with a fixed order quantity Q (the description is orientated at Toporowski (1999)). In this setup, only the fluctuation of demand during the lead time has to be considered. It is assumed that this demand Y is normally distributed, with expected value μ_Y and standard deviation σ_Y. The relevant costs C can be formulated as:

$$
\begin{aligned}
C &= C_I + C_O + C_R = C_I + C_O + \frac{X}{Q} P(Y > s) c_R \\
&= (\frac{Q}{2} + s - \mu_Y) p r_S + \frac{X}{Q} c_O + \frac{X}{Q} (1 - \phi(\frac{s - \mu_Y}{\sigma_Y})) c_r
\end{aligned}
$$

where

TC = Total costs
C_I = Inventory costs
C_O = Ordering costs
C_R = Risk cost (of being out of stock)
X = Total demand
Q = Order quantity
c_R = Costs per out of stock event
Y = Demand per ordering cycle
s = Stock level when order is triggered
μ_Y = Expected demand per ordering cycle
p = Price per unit
r_S = Cost rate for stock
c_O = Ordering costs
σ_Y = Standard deviation of demand per ordering cycle
ϕ = Cumulative distribution function of normal distribution

Differentiated and solved with respect to Q, which results in a optimal order quantity of:

$$Q^* = \sqrt{\frac{2X(c_O + c_R(1 - \phi(\frac{s-\mu_Y}{\sigma_Y})))}{p * r_S}}$$

Differentiated and solved with respect to s, which results in a optimal safety stock of:

$$s^* = \mu_Y + \sigma_Y \sqrt{2\ln(\frac{Xc_R}{pr_S Q\sigma_Y\sqrt{2\pi}})}$$

As we see, the optimal Q^* is dependent on s and vice versa. Theoretically, the equations have to be solved in parallel with numerical procedures. Solving the equations successively only leads to an approximative solution. The model can be extended by varying risk cost for different out of stock levels. A very common and simpler procedure to determine the safety stock level is to assume a certain risk level without determining it exactly (for example a risk level of 95%).

B Appendix: SYNTRADE Data and Classifications

B.1 Article types

GS1 ID	Description	Estimation value density (in EUR/kg)	Estimation weight per volume (in kg/m^3)	Estimation perishability (in days)
0	Fleisch/Wurst/Fisch/Gefluegel	5,9	500	28
1	Obst und Gemuese	1,1	500	42
2	Molkereiprodukte, Speiseoele, Mayonnaisen, Feinkostsalate, Eier	1,7	1000	42
13	Brot und Backwaren (nurSB)	2,0	345	3
14	Frische Convenience Produkte	5,0	270	28
3	Speiseeis	2,6	465	365
3	Tiefkuehlkost	3,4	265	365
4	Naehrmittel u.a. Backmischungen, Cerealien, Beilagen	3,0	270	365
5	Suppen, Soßen, Gewuerze, Brotaufstrich, Zucker	3,0	270	365
6	Fleisch, Wurst- und Fischkonserven, Marinaden	2,8	860	365
7	Obst, Gemuese- und Sauerkonserven	0,9	860	365
8	Dauerbackwaren, Sueßwaren, Knabbereiartikel	5,9	270	365
9	Babykost	5,0	270	365
9	Reform und Diaetkost	5,0	270	365
10	Wein/Sekt	1,8	850	365
10	Spirutuosen	5,0	850	365
11	Alkoholfreie Getraenke	0,5	850	365
11	Biere	1,0	850	365
12	Kaffee/Tee/Kakao	8,0	360	365
12	Tabakwaren	120,0	87	365
87	OTC	24,9	190	365
15	Wasch, Putz-, Reinigungsmittel, Schuh-/Kleiderpflege	8,9	210	365
16	Hygieneartikel/papiere, Saeuglingspflege, Watte, Verbandstoffe	2,2	100	365
17	Haar-, Haut-, und Koerperpflege	11,3	600	365
18	SonnenundInsektenschutz,Kosmetika,Fußpflegemittel	30,0	100	365
96	Tiernahrung/Tierpflege	5,5	115	365
19-30	Textilien, Heimtextilien, Kurzwaren	10,7	135	365
31-34	Schuhe, Lederwaren, Koffer, Schirme	10,8	125	365
35,51,66	Haushaltswaren, Bilderrahmen, Galanteriewaren	10,0	130	365
36,44,46,64	Camping, Garten, Sport	2,5	145	365
37	Unterhaltungselektronik	27,5	90	365
38,39,65	Elektrokleingeraeteundartikel	8,2	180	365
67	Elektrogroßgeraete	1,6	155	365
40-43	Schmuck, Foto, Uhren, rillen	17,8	100	365
45	Spielwaren	5,0	240	365
52-58	Papier, Buero-, Schreibwaren, Bücher, Zeitungen/Zeitschriften	3,3	200	365
59	EDV, Kommunikation	27,5	90	365
61-63, 72-76	DIY u.a. Werkzeuge, Eisenkurzwaren, Farben, Lacke	6,3	270	365
77-79	Autozubehoer u. sonst. Fahrzeuge, Fahrraeder	3,0	175	365
97-98	Blumen/Pflanzen, Samen, Duengemittel, Insektizide	0,8	590	365
99	Sonst. Non-Food wie Moebel, Sanitaer usw.	2,5	145	365

Table B.1: Model Article Types based on GS1 classification

B.2 Matching of Article Types (GS1) with Supplier Sectors (WZ)

Article Type (GS1)	Supplier sector (WZ)		Article Type (GS1) cont.	Supplier sector (WZ) cont.
0	500		31-34	1920
0	1510		31-34	1930
0	1520		35,51,66	2050
1	100		35,51,66	2520
2	1540		35,51,66	2610
2	1551		35,51,66	2621
13	1581		35,51,66	2861
14	100		35,51,66	2870
14	1510		36,44,46,64	1700
14	1520		36,44,46,64	1800
14	1533		36,44,46,64	1930
14	1589		36,44,46,64	2960
3	1510		36,44,46,64	3640
3	1520		37	2230
3	1533		37	3200
3	1552		38,39,65	2970
4	1560		38,39,65	3100
4	1585		67	2970
5	1583		40-43	3340
5	1587		40-43	3350
5	1589		40-43	3620
6	1510		45	3630
6	1520		45	3650
7	1533		52-58	2123
8	1531		52-58	2210
8	1582		52-58	2220
8	1584		59	2230
9	1588		59	3000
9	1588		61-63, 72-76	2124
10	1591		61-63, 72-76	2430
10	1593		61-63, 72-76	2610
10	1594		61-63, 72-76	2622
10	1595		61-63, 72-76	2623
11	1532		61-63, 72-76	2624
11	1598		61-63, 72-76	2625
11	1596		61-63, 72-76	2626
12	1586		61-63, 72-76	2630
12	1600		61-63, 72-76	2650
87	2440		61-63, 72-76	2660
15	2451		61-63, 72-76	2861
16	2122		61-63, 72-76	2862
16	2451		61-63, 72-76	2863
17	2452		77-79	2510
18	2452		77-79	3430
18	3660		77-79	3540
96	1570		77-79	3550
96	3660		97-98	100
19-30	1700		99	2520
19-30	1800		99	3610
31-34	1910			

Table B.2: Matching of article types (GS1) with supplier sectors (WZ)

B.3 Wholesaling and LSP Sectors

	LSP sector		Wholesaling sector	
Supplier sectors (WZ)	**ID**	**Name**	**ID**	**Name**
100	1	Frische	1	Gemuese Obst Blumen
100, 500, 1510, 1520	1	Frische	2	Fleisch, Fisch
1551, 1552	1	Frische	3	Mopro
1532, 1591, 1593, 1594, 1595, 1596, 1598	2	Nahrungsmittel (Trocken)	4	Getraenke
1581	2	Nahrungsmittel (Trocken)	5	Frische Backwaren
1586	2	Nahrungsmittel (Trocken)	6	Kaffee, Tee
1531, 1533, 1540, 1560, 1582 1583, 1584, 1585, 1587, 1588, 1589	2	Nahrungsmittel (Trocken)	7	Sonstige Nahrungsmittel
1570, 2122, 2451, 2452	3	Non Food	8	Drogerieartikel
1600	3	Non Food	9	Tabak
1700	3	Non Food	10	Textilien
2440	3	Non Food	11	OTC
3340, 3350, 3620	3	Non Food	12	Schmuck, Foto
2230, 3000, 3100, 3200	3	Non Food	13	Elektro, EDV
1910, 1920, 1930	3	Non Food	14	Leder und Lederwaren (Schuhe)
1800	3	Non Food	15	Bekleidung
2050, 2121, 2123, 2124, 2125, 2210, 2220 2430, 2510, 2520, 2610, 2621, 2622, 2623 2624, 2625, 2626, 2630, 2650, 2660, 2861 2862, 2863, 2870, 2960, 2970, 3430, 3540 3650, 3550, 3610, 3630, 3640 3660	3	Non Food	16	Sonstiges (Non Food)

Table B.3: Matching of supplier sectors (WZ) with LSP and wholesaling sectors

C Appendix: Expert Interview Documentation

C.1 Interview guideline

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Interviewleitfaden
"Logistische Entscheidungen auf der Sektorrelation Lebensmittelherstellung- Lebensmittelhandel"

Verantwortlich:	Hanno Friedrich, Universität Karlsruhe, Institut für Wirtschaftspolitik und Wirtschaftsforschung
Forschungsprojekt (Dissertation):	Logistische Entscheidungen in der Güterverkehrsmodellierung
Interviewziel:	Nachvollziehen des Vorgehens bei logistischen Entscheidungen, zur realitätsnahen Abbildung der Logistik in der Güterverkehrsmodellierung
Zielgruppe	Betriebe aus dem Lebensmittelhandel und der Lebensmittelproduktion
Ablauf Interview / Ziel Leitfafden	Der Leitfaden dient als Orientierung, er soll nicht das Interviewergebnis oder den Interviewverlauf vorgeben. Die Fragen und vorformulierten Hypothesen sollen nur als Orientierungspunkt dienen, falls beim Interview ein solcher benötigt wird.

Die Daten werden nur für akademische Zweck verwendet und streng vertraulich behandelt. Auf Wunsch werden sie nur anonymisiert erfasst.

Sie erreichen mich unter 0175/318 3912, friedrich@iww.uni-karlsruhe.de

Figure C.1: Interview guideline cover sheet

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Interviewleitfaden
"Logistische Entscheidungen auf der Sektorrelation Lebensmittelherstellung- Lebensmittelhandel"

Teil 1: Vorbereitung Interview/Einleitende Fragen

Beschreibung Interviewter Betrieb
- Wirtschaftssektor
- Wirtschaftsrelationen auf denen aktiv (Wirtschaftssektor Kunden/Lieferanten)
- Güterströme, die in Entscheidungen einbezogen werden
- Produkte der Güterströme (Wertedichte, andere Charakteristika)
- Größe Betrieb (Umfang Güterströme, evtl. Mitarbeiter, Umsatz)
- Einbindung in Unternehmensverbund (soweit relevant für logistische Entscheidung)

…

Beschreibung Interviewter
- Position
- Zugehörigkeit Betrieb (in Jahren)
- Berufstätigkeit/Ausbildung (in Jahren)

Figure C.2: Interview guideline part 1: Preparation

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Interviewleitfaden
"Logistische Entscheidungen auf der Sektorrelation Lebensmittelherstellung- Lebensmittelhandel"

Teil 2: Entscheidungen und Verantwortliche (Wer/Was ?)

Frage	Entscheidungsbereiche	Hypothese	Indikatoren (nachprüfbare Fakten zur Bestätigung der Hypothese)
Wer fällt relevante logistische Entscheidungen ?	Einkaufs-Rahmenverträge/Bestellverfahren (Frequenz Inbound)	Entscheidung durch Einkauf Handelskette/Verkauf Hersteller, determiniert teilweise Bedingungen Transport von Herstellern (z.B. Lieferfrequenz)	
	Lagerstandorte, -struktur (Stufigkeit)	Handelskette (Geschäftsleitung, Logistik)	
	Policies (Richtlinien, z.B. kleine Geschäfte werden einmal pro Woche angefahren etc.)	Handelskette	
	Einbindung Güterströme in Distributionsstruktur	Filiale, Hersteller, Handelskette (Netzwerkplanung)	
	Planung Fahrten Inbound - von Herstellern (Transportmarkt)	Hersteller (im Rahmen Einkaufsvorgaben)	Transportbestellung/-durchführung durch Zulieferer
	Planung Fahrten Outbound - zu Filialen (Transportmarkt, Frequenz)	Handelskette (Netzwerkplanung), evtl. Verhandlungen mit Filialen	
	Planung Verkehre zwischen Lagern	Handelskette (Netzwerkplanung)	
	Operativ transportierte Mengen	Filiale durch Bestellung, aggregiert durch Handelskette an Hersteller (entsprechend Einkaufsrahmenbedingungen und Vorgeben Planung Transporte)	
	Operative Disposition	Handelskette	

Figure C.3: Interview guideline part 2: Responsibilities

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Interviewleitfaden
"Logistische Entscheidungen auf der Sektorrelation Lebensmittelherstellung- Lebensmittelhandel"

Teil 3: Rahmenbedingungen (technisch, organisatorisch)

Frage	Bereiche	Hypothesen	Indikatoren (nachprüfbare Fakten zur Bestätigung der Hypothese)
Wie ist die Abfolge der Entscheidungen (gegenseitige Beeinflussung)		1. Lagerstandorte/-struktur, Rahmenverträge Einkauf 2. Policies 3. Einbindung Güterströme in Netz 4. Planung Verkehre 5. Operative Durchführung	
Welche technischen Gegebenheiten beeinflussen die Entscheidungen?	Datenverfügbarkeit	IT Systeme bei Handel zwischen Filialen und Zentrale nicht integriert	
		Getrennte IT Systeme zwischen Handel und Herstellern	
		Austausch aggregierter Zahlen mit Herstellern (keine Original POS Daten)	
	Nutzung IT Systeme	IT Systeme nur Entscheidungsunterstützend	
	Produktionsformen	Saisonale Produkte, ansonsten keine Rahmenbedingung für Handel (Massenprodukte unabhängig von Produktionsrythmus)	
	Transportmittel/-gefäße	Keine Determinante für Planung (Größe LKW Resultat der Planung)	
Welche anderen Rahmen-bedingungen beeinflussen die Entscheidungen?	Konsumschwankungen	Nachfrage Volumen (über aller Produkte) stabil, bis auf einzelne Tage im Jahr (Weihnachten), saisonale Schwankungen bei einzelnen Produkten	
	Verderblichkeiten	Frischeprodukte: 5 Tage Eintritt Handelskette bis zu Verkauf	
	Kooperationsverhalten	Gemeinsame Optimierung in Handelskette	
		Verhandlungen, d.h. keine gemeinsame Optimierung zwischen Handelskette und Hersteller	

Figure C.4: Interview guideline part 3: Surrounding conditions

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Interviewleitfaden
"Logistische Entscheidungen auf der Sektorrelation Lebensmittelherstellung- Lebensmittelhandel"

Teil 4: Wie wird entschieden (Einflussgrößen)?

Frage	Bereich	Faktoren/Hypothesen	Indikatoren (nachprüfbare Fakten zur Bestätigung der Hypothese)
Welche Produktkategorien werden unterschieden / getrennt behandelt (z.B. ABC, XYZ Produkte)?		Verderblichkeit Produktanforderungen	Beispiel: Frischeprodukte, Tiefkühlprodukte, Trockenprodukte, Getränke (unterschiedliche Transporte)
Welche Einflussfaktoren gehen in die Entscheidungen ein / wie wird entschieden ?		Es wird mit durchschnittlichen Kostengrößen gerechnet (Lagerkosten, Transportkosten, Bestellkosten, Risiko/Fehlmengenkosten)	
	Frequenz/Bestellverfahren in Einkaufs-Rahmenverträge/Bestellverfahren (Annahme Menge bekannt), Planung Fahrten Inbound - von Herstellern (Transportmarkt)	Minimierung Logistikkosten auf Relation Hersteller-Lager - Mindestbestellmenge Hersteller - Lagerkosten - Transportkosten - Bestellkosten - Servicelevel (Risikofestlegung für Lieferzuverlässigkeit)	
	Lagerstandorte, -struktur (Stufigkeit)	Minimierung Logistikkosten auf Relation Lebensmittelkette-Filialen - Lagerkosten - Transportkosten - Bestellkosten - Flexibilität (Lead Time)	
	Policies (Richtlinien, z.B. kleine Geschäfte werden einmal pro Woche angefahren etc.)	Erfahrungswerte (keine expliziten Modelle)	
	Einbindung Güterströme in Distributionsstruktur	Mehrkosten vorhandene Struktur versus Logistikkosten direkter Transport (durch Hersteller)	
	Planung Fahrten Outbound - zu Filialen (Transportmarkt, Frequenz)	Minimierung Logistikkosten auf Relation Lager-Filiale - Lagerkosten - Transportkosten - Bestellkosten - Risiko/Fehlmengenkosten	
	Planung Verkehre zwischen Lagern (Transportmarkt, Frequenz)	Minimierung Logistikkosten auf Relation Lager-Lager - Lagerkosten - Transportkosten - Bestellkosten - Risiko/Fehlmengenkosten	
	Operativ transportierte Mengen	Nachfrage, momentaner Bestand (Auslösung Bestellung durch bestimmten Bestand)	
	Operative Disposition	Minimierung Verspätungen	

Figure C.5: Interview guideline part 4: Decision process

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Interviewleitfaden
"Logistische Entscheidungen auf der Sektorrelation Lebensmittelherstellung- Lebensmittelhandel"

Optionaler Teil 5: Beispiele Güterströme

Voraussetzung	Input 1: Betrachtete Güterströme	Input 2: Alternativen	Output
Gewähltes Beispiel (Entscheidungssituation) ist abgrenzbar d.h. bestehende Lieferfrequenzen, Lagerstrukturen, Transportmittel sind durch betrachtete Güterströme begründbar	Distanzen (z.B. zwischen Hersteller und Filialen) (km)	Transportmittel (Kosten, Kapazität, Zuverlässigkeit)	Gewählten Alternativen
	Wertedichte der Güter (EUR/t)	Lagerpunkte/-Stufigkeit (Abstände zu Herstellern/Filialen, anderen Lagern)	
	Menge/Volumen pro Zeiteinheit (t, Stellplätze)	Bedienfrequenzen	
	Verderblichkeit		
	Konsumschwankungen		
	Out of stock Kosten		
	Bedingungen Produktion		
	Andere Rahmenbedingungen		

Figure C.6: Interview guideline part 5: Examples

C.2 Documentation Expert Interviews

ERGEBNISSE INTERVIEW DISCOUNTER A (1/3)

- **Interviewee**
  - Leitungsposition in Logistik
  - Berufserfahrung: bei Discounter seit 2000, unter anderem 1 Jahr bei zentraler Logistik (vorher Speditionskaufmann, Studium)
- **Produkteinteilungen/Sortiment**
  - Ca. 1.500 Artikel
  - Unter üblichen Sortimenten bestehen Produktwarengruppen, eine feinere Unterteilungshierarchie z.B.: Non Food -> Chemie -> Kosmetik, Waschpulver, Putzmittel
  - Typische langsam drehende Artikel: OTC Over the Counter (z.B. Arzneimittel)
  - Weitere wichtige Produkteigenschaften:
    - Mindesthaltbarkeit (MHD)
    - Logistische Eigenschaften
      - Sperrigkeit
      - Überbauartikel, d.h. auf Palette kommissionierbar mit anderen Artikeln
- **Aktionen**
  - Aktionen werden mit allen Artikeln gefahren - mit einige Artikeln jedoch sehr oft (zum Beispiel Cafe, Nutella)
  - Aktionsware wird teilweise zweimal in Laden aufgestellt, um Umsatz zu fördern
  - Aktionen laufen zentral koordiniert, es gibt 3-4 Werberegionen in Deutschland
  - Für Distributionslogistik sind Aktionen irrelevant, da Fluss insgesamt stabil (außer wenn spezielle Anforderungen z.B. sperrig Artikel)
  - Aktionen im Handel als Mode
    - Handel momentan auch Aktions-getrieben, evtl. nur eine "Mode"
    - Gefahr bei Aktionen: Nachlass von 20-30% auf Produkte -> Konsumenten kaufen nur noch zur Aktionszeit -> indirekter Preisverfall
- **Niederlassungen/Lagerstruktur**
  - Der Discounter ist in Niederlassungen organisiert, sie sind logistische und administrative Zentralen für die angeschlossene Filialen
  - Gebiete sind eindeutig aufgeteilt, d.h. keine Überschneidungen
  - Starke Wachstum bei Lagern in Deutschland
  - Lagerstruktur in Deutschland teilweise historisch gewachsen
  - Vorgehen bei Bestimmung neuer Lagerstandorte:
    - Auswahl zwischen einigen Alternativen
    - Berechnung bester Standort auf Basis von Filialumsätzen
    - Standortentscheidungen letztlich teilweise stark subjektiv (Vorlieben) oder politisch (z.B. Subventionen) geprägt
  - Neue Lager entsprechen dem aktuellen Lagerstandart des Discounters (Größe, Aufbau, Technik etc.)
  - Früher Standard 25.000 m^2, Lager heute 35.000m^2 Lager
  - Durchlauf in Lagern abhängig von Lagerstandard (nicht nur m^2 - man kann auch hoch stapeln)
  - Durchschnittlich ist Durchlauf bei heutigem Standard ca. 2000 Paletten pro Tag
  - Handling in Lager wird von zwei Seiten vorgenommen
  - Bei der Neuerschließung eines Landes existieren beide Konzepte: Big Bang flächendeckend und zunächst eine Region

Figure C.7: Interview results with discounter A (1/3)

ERGEBNISSE INTERVIEW DISCOUNTER A (2/3)

- **Einkauf/Inbound Logistik**
  - Der Geschäftsführer der Niederlassung bestellt eigenständig (ist Dispositionsverantwortlich, d.h. verantwortlich für Bestände)
  - Inbound Logistik wurde in letzter Zeit sehr stark auf eigene Beschaffungslogistik umgestellt:
    - Aufbau von Crossdocking Standorte
    - Lieferanten liefern dann frei Crossdocking
  - Kooperation mit Herstellern
    - Wenig Kooperation mit Herstellern (z.B. kein ECR)
    - Gegenbeispiel (Ausnahme): Kooperation bei logistischer Planung bei eigenem Hersteller
  - Entscheidung Strecke/Lager (insbesondere im Ausland):
    - Berechnung Kosten vorher/nachher:
      - Schwierigkeit bei Berechnung: Kostenkalkulation teilweise nicht transparent (Grundgröße normalerweise Kosten pro Stellplatz)
      - Kapitalkosten in Rechnung enthalten
      - Weiterer wichtiger Faktor: bessere Versorgung bei eigenem Lager (da auch bei Störfällen die Versorgung der Filialen oberste Priorität hat)
    - Fast alles wird über Lager gefahren, Beispiele für Ausnahmen: Frisches Brot

- **Bestände**
  - Verantwortung über Bestandskosten
    - Bei Warenmanagement/-controlling/-disposition
    - Diese sind bei Vertrieb (Niederlassung) oder Einkauf angesiedelt
    - Vorteile wenn bei Vertrieb: Einbezug von Logistikkosten und Abschriften (Fokus Einkauf auf Preis, Fehlartikel)
  - Filialbestände
    - Lager in Filialen (keine Frische), im Unterschied beispielsweise zu anderem Discounter (lagert in Regalen in Filiale)
    - In Filialen wird kein Sicherheitsbestand gelagert
  - Entscheidung Reichweite/Sicherheitsbestand
    - Disposition ist verantwortlich für Sicherheitsbestand
    - Vorgehen:
      - Bei 30% der Artikel können keine einfache Regeln abgeleitet werden (zum Beispiel bei sensiblen Artikeln wie Frische)
      - Bestellung an Person gebunden (mit Erfahrung)
      - System gibt Bestellvorschläge und zeigt momentane Reichweite an
      - Artikel werden zu bestimmten Tagen bestellt
  - Mindesthaltbarkeit
    - Tagesartikel verfallen sehr schnell: z.B. Frischeartikel wie Obst, Gemüse
    - Ziel: das meiste der Zeit sollte bei Kunden verbleiben
    - Beispiel Umgang mit Restlaufzeit bei Discounter: Jogurt wird 5 Tage vor Verfall aus Verkauf genommen

ERGEBNISSE INTERVIEW DISCOUNTER A (3/3)

- **Outbound Logistik (Tourenplanung)**
  - Durchschnittliche Entfernung von Filiale zu Lager in Deutschland: ca. 50 km (schwankt - in skandinavischem Land beispielsweise sehr viel mehr)
  - Ladengrößen in Deutschland sind bei Discountern mittelgroß im Vergleich zu Belgien (teilweise sehr klein) oder Skandinavien (groß)
  - Ladungsträger
    - Teilweise kommen Artikel auf vollen Paletten in Filiale (ca. 80-100 Artikel) – abhängig von Von Filialgröße (m^2)
    - Andere Artikel kommen in Kollis
  - Tourenplanung
    - In Deutschland hat Discounter heute Niederlassungen/Zentrallager mit individueller Tourenplanung basierend auf Rahmentourenplan
    - Tourenplanung zu 80% fix (Rahmentourenplan), zu 20% flexibel nach Umsatz der Filialen
    - Zentrale Logistik bewertet von Zeit zu Zeit die Rahmentourenpläne der Niederlassungen
    - Jede Filiale wird jeden Tag beliefert, jeden Tag Frisch, Trocken teilweise nur jeden zweiten Tag
    - In Deutschland fahren LKW Touren mit 1-3 Filialen
  - Leistungsmessung der Niederlassungen:
    - Transportkosten/Umsatz, Logistikpersonalkosten/Umsatz, Auslastungen LKW, Paletten pro LKW
    - Problem: unterschiedliche Filialumsätze
    - Investitionskosten werden beim Benchmarking nicht berücksichtigt

- **Schwankungen**
  - Abnahmeschwankungen sind teilweise länderspezifisch (Bsp. Zucker in Tschechien zu bestimmten Feiertag, Schmand zu Midsommer in Skandinavien)
  - Problem Schwankungen in letzten Jahren (Beispiel Wasser): selbst wenn Hersteller liefern konnten, war keine Transportkapazität vorhanden -> deswegen betreibt Discounter Vorsorge durch Aufbau von Außenlagern um in Regionen nicht Out of stock zu laufen

- **Transport/Verkehrsmittelwahl**
  - In Deutschland:
    - LKW 40 t (teilweise gekühlt, teilweise ungekühlt)
    - Waren werden teilweise zusammen (in Kühl LKW) teilweise getrennt geliefert (sehr fein optimiert)
    - In Distribution werden fest gebuchte LKW eingesetzt
    - Kein eigener Fuhrpark
    - Zentrale Logistikabteilung stellt Niederlassungen Portfolio an Logistikleistungen zur Verfügung (kauft Logistikdienstleistungen ein)
  - Nutzung Verkehrsmittel für andere europ. Länder: Schiff, Rad+Schiene
  - Spanien: Waren werden in der Saison in Lager gefahren

- **IT System**
  - IT System basierend auf Kassendaten (z.B. für Bestellvorschläge) ist in Test

Figure C.8: Interview results with discounter A (2/3) and (3/3)

ERGEBNISSE INTERVIEW DISCOUNTER B (1/2)

- **Interviewee**
  - 10 Jahre Berufserfahrung (seit 1997), Bereichsleiter Logistik Cross Docking Europe und Logistiksysteme
  - Arbeitserfahrungen: ECR, operative Logistiksysteme, Lagersteuerung, Fuhrpark, Aufbau Logistik in zwei Ländern in Osteuropa
  - Erfahrungen sowohl bei Supermarktkette als auch bei Discounter
- **Sortimente**
  - 5 (6) Sortimente: Frische, Trocken, Molkereiprodukte, Fleisch/Geflügel, Tiefkühl, (Pfandflaschen – Ausnahme, nur für einzelne Regionen)
  - Anzahl Artikel: ca. 2500 logistische Artikel (teilweise in festen Verhältnissen gemischt verpackt, d.h. in Filiale bis zu 3000 Artikeln)
- **Einkauf/Sicherheitsbestand**
  - 80% der Ware (auch für europäisches Ausland) wird über Zentrale verhandelt
  - Länderorganisationen entscheiden welche Artikel sie listen wollen
  - Einkauf international, z.B. landwirtschaftliche Produkte aus Osteuropa
  - Einkauf sehr stark bei Discountern (Preisvorgaben) – führt teilweise zu Beschränkung der Interessen der Logistik
  - Keine explizite Kalkulation der Logistikkosten bei Einkauf, Verrechnung Logistikkosten allgemein gehalten (nicht Produktspezifisch)
  - Lagerbestand für Trockensortiment Deutschland ca. 1 Woche
  - Verantwortung Bestände bei Disposition (Region) und Einkauf nicht bei Logistik
  - Sicherheitsbestände basierend auf Erfahrung der Disponenten (diese sind einzelnen Produktgruppen zugeordnet)
  - Logistikkosten der Zulieferer sind in Preis enthalten
  - Lieferfristen ca. 3 Tage bei Frische, 5 Tage bei Trocken, nur bestimmte Tage an denen Lieferant liefert
- **Transport Inbound (Zulieferer-Lager)**
  - Meist Volladungen (Beispiel Ausnahme Maggi), da Logistik oft als Zugeständnis bei Preisvorgaben durch starken Einkauf
  - Zulieferung durch Lieferanten, kein Interesse an Übernahme, da sonst Logistik zu komplex (siehe Metro)
- **Lager**
  - Dimensionierung Lager: Anzahl Artikel determiniert Notwendigkeit Raum für Zugriffsflächen, Kommissionierraum, Lagerplatz, Zusätzlich weitere Flächen um Lager
  - Es existiert bestimmte Lagergröße/Arbeitsvolumen bei dem Lager effizient arbeitet
  - Lagerfläche zwischen 30,000 und 40,000 m^2
  - Verkehrsaufkommen je Lager 42-70 LKW/Tag teilweise 2 Touren, d.h. bis zu ca. 100 LKW Ladungen pro Tag
  - Wird ein neues Lager errichtet/ersetzt, dann wird die gesamte Lagerstruktur für die angrenzenden Regionen neu kalkuliert (z.B. Zuordnung Filialen zu Lagern)
  - Entfernungen zwischen Lager und Filialen unterschiedlich bei Discountern abhängig von Umsatz Filialen und Filialdichte (z.B. 50 km bei Aldi, bis zu ca. 250 km bei Discountern mit niedrigerem Umsatz/Filialdichte)
  - Standort: in Städten Grundpreise sehr teuer, deswegen Standorte verkehrsgünstig außerhalb des Städte
  - 2 Schichten Mo-Fr, Sa 1-2 Schichten, So 1 Schicht (Obst/Gemüse, Fleisch/Geflügel) Potential für 3 Schichten in Feiertagswochen, z.B. Ostern/Weihnachten)

ERGEBNISSE INTERVIEW DISCOUNTER B (2/2)

- **Transport Outbound (Lager-Filialen)**
  - Ausschließlich Belieferung von Discount Filialen
  - Logistiksysteme der Discounter heute in der Regel unabhängig, früher existierten teilweise auch Mischformen mit anderen Vertriebslinien
  - Distribution nur auf Palette, Unterschied zu Supermärkten (dort in Kollis), Systeme früher verzahnt, heute komplett getrennt
  - Keine extra Fahrten bei out of stock Situationen (Lieferung bei nächster Tour), Ausnahme: Computer (Aktionsartikel und Neueröffnungen)
  - Frequenzen (abh. Von Umsatz und örtlichen Gegebenheiten):
    - Frische täglich
    - Trocken, Tiefkühl 3-4 mal pro Woche
    - Mopro 4-5 Mal pro Woche,
  - Gemeinsamer Transport der Sortimente (d.h. tägliche Anlieferung)
  - Alle Sortimente werden über eigene Logistik abgewickelt
  - Brot direkt über den Lieferanten angeliefert
- **Transportmittel**
  - Transporte in Deutschland über LKW (Dienstleister)
  - Dem Dienstleister werden keine eigenen Rücktouren gestattet (da Termindruck - zweite Tour) und Entsorgung von Filiale
  - Nutzung Bahn für Transporte in ein Land in Osteuropa – ca. 40 Filialen in diesem Land (Crossdocking Österreich):
    - Einzelwagentransport (Größenordnung 20 Wagen pro Woche), 30-50% des Trockensortiments für diese Länder, kein Kühlsortiment,
    - Einzelwagen werden täglich abgeholt
    - Argumentation: LKW 48h-4 Tage, Bahn 10 Tage mit hohen Schwankungen, aber in Osteuropa sehr billig
    - Schwankungen bei allen VM hoch, deswegen hohe Lagerbestände in osteuropäischem Land (3-5 Wochen),
    - 1 Lager für gesamtes Land
    - Auch andere Discounter nutzen Bahn/Schiff für Ausland: Beispiel Seefracht und Bahn nach Griechenland
  - Gleisanschlüsse an Lager in Deutschland werden nicht genutzt
- **Störungen**
  - Risiko Verspätungen bei Transport: Verplanung Verräumkräfte, Out of stock bei Frische
  - Einplanung zusätzliche Zeiten in Touren: Entladezeiten, Pausen, Gegebenheiten Filiale, Filialrestriktion (z.B.
  - Starke Schwankungen bei manchen Produkten (Beispiel Out of stock Situationen bei Wasser im Sommer, durch Lieferschwierigkeiten bei Zulieferer)
  - Keine Kategorisierung der Produkte nach Käuferverhalten bei Out of Stock Situationen - (z.B. Übergang des Käufers von Orangen zu Kirschsaft)
- **Sonstiges**
  - IT noch nicht integriert (aber geplant), d.h. insbesondere Abverkäufe pro Filiale werden durch IT System nur gruppiert dargestellt
  - Logistik bei Discountern erfährt Aufwertung im Vergleich zu Logistik bei Supermärkten
  - Keinen Datenaustausch (insbesondere kein Austausch POS Daten) mit Zulieferern

Figure C.9: Interview results with discounter B

ERGEBNISSE INTERVIEW VOLLSORTIMENTER A (1/3)

- **Betrachteter Betrieb:** Zentrallager
- **Größe:** ca. 40.000 m², bedient alle angeschlossenen Kunden in Region
- **Belieferungsdistanz:** bis zu 150 km
- **Umschlag je Tag:** Bis zu 4000 Rollbehälter
- **Kategorisierung Kunden** (2006 für gesamte Region, insgesamt ca. 1.500 Einzelhandelsstandorte):
  - C&C: ca. 40.000 Artikel, ca. 25 Filialen
  - Verbrauchermarkt: durchschnittlich 3.500m², bis zu 25.000 Artikel, ca. 70 Filialen
  - Gr. Supermarkt: durchschnittlich 1.200m², 12.000 bis 15.000 Artikel, ca. 350 Filialen
  - Supermarkt: durchschnittlich 600m²
  - SB-Geschäft (Kleinabnehmer): 100-600m², ca. 5.500 Artikel
- **Anzahl Artikel in Lager:** ca. 14.000
- **Sortimente (Kategorien Produkte):**
  - Trocken (Lebensmittel und Non Food)
  - Tiefkühl (gelagert bei -25 bis -30 Grad Celsius)
  - Grünes Sortiment (Obst und Gemüse) - eigentlich zwei Temperaturbereiche und Kartoffeln
  - Weißes Sortiment (Milch und Milchprodukte etc.)
  - Gelbes Sortiment (Käse)
- **Produktkategorisierung durch Logistik (unabhängig von Sortimenten):**
  - A Artikel: Hochvolumige Artikel (Schnelldreher)
  - B Artikel: Artikel mit spezieller Behandlung (Bsp. Besenstiele)
  - C/D: Kleinvolumige Artikel
- **Genutzte Verkehrsmittel:** LKW
- **Interviewpartner:** Ehemaliger Leiter Logistik und Prokorist, 40 Jahre Berufserfahrung

ERGEBNISSE INTERVIEW VOLLSORTIMENTER A (2/3)

Ausgangssituation

- **Alte Lagerstruktur:** drei Lager
  - 1. (kleinstes) Lager (nur A Sortiment - bekam B und C aus 2. Lager und D aus 3. Lager)
  - 2. Lager (A, B, C Sortiment - bekam D aus 3. Lager zugeliefert),
  - 3. Lager das größte (A, B und D Sortiment - bekamen C aus 2. Lager)
  - Gründe für Struktur waren Platz und Logistikrabatte (Zulieferer mussten teilw. nur ein Lager beliefern, z.B. Dr. Oetger oder Maggi)
- **Alternativen:**
  - Zentrallager
    - Neues Lager
    - Altes Lager ausbauen (z.B. 1. Lager)
  - Alte Lagerstruktur beibehalten
- **Artikelstruktur:**
  - ABCD Artikel (siehe vorne)
  - ca. 14.000 Artikel
  - Verschiedene Sortimente (Trocken, Tiefkühl, Weiß, Grün, Gelb)
  - Bei ca. 120 Artikeln kein Ausweichartikel (z.B. Kandes bei Ostfriesen, Mehl, Zucker)

Entscheidung Lagerstruktur

- Detaillierte Kostenbetrachtung, unterstützt durch Berater und Softwaretool
- Betrachtete Kosten
  - Transport
  - Lager
  - Personalkosten
  - Bestands/Kapitalkosten
  - Logistikrabatte (keine großen Vorteile gegenüber vorheriger Struktur)
  - Bruchkosten (weniger Bruch durch neue Technik (Kastenlager))
  - Fehlkostenvermeidung (durch Scannertechnik, bessere Kontrolle (des Lieferanten bzw. des Spediteurs)->jede Palette wird gewogen)
- Optimale Lage Zentrallager bestimmt über Schwerpunkt der Transportvolumina

Neue Lagerstruktur

- Zentrallager mit zwei Bereichen:
  - Palettenlager (alle Artikel bei denen Umschlag pro Tag größer als eine Palette oder die nicht kastenfähig) – ca. 1000 Artikel
  - Kastenlager (langsam drehende und kastenfähige Artikel) – ca. 13.000 Artikel
- Es existiert Lagerzone und Kommissionierzone
- Sammler packt von Palette oder aus Kasten in Rollbehälter
- Kasten passt auch in Rollbehälter, aber Seitengitter von Rollbehälter braucht Platz -> deswegen besser Kästen mit Rollen (Vorteil in LKW 4 nebeneinander statt 3)
- Zum Versand werden verschiedenste Behälter genutzt: Rollbehälter, TK Behälter, Einzelpalette (80x120), 1/2 Palette (80x60), 1/4 Palette (40x60), Kasten Rollbehälter 40x60
- Vorteile Struktur: nur Artikel, die benötigt werden, sind in Zugriffszone, andere werden beispielsweise oben in Regalen eingelagert („benötigte Artikel" werden tägl. in Zugriffszone gefahren)
- Kasten werden alle gescannt (Waagen checken das Gewicht ob auch genau so viel entnommen wurde) – keine Reklamation von Kunden mehr zugelassen
- Dynamische Kästen fahren nach Picking zurück in Lagerzone, Statische Lager bleibt immer (Palettenlager)
- Bestände heute genauer -> dadurch Einsparung von ca. einem Tag Bestand (früher wurden Bestände in Ladezone bereits ausgebucht)
- Wichtige Artikel (120 Artikel, bei denen kein Ausweichartikel besteht) werden in mehreren Gängen gelagert (falls Maschine ausfällt)

Vergleich mit anderer Region:

- Umschlagpunkte (reiner Umschlagpunkt oder mit Lager für A Artikel)
- Nachteile bei Umschlagpunkten:
  - Ware muss teilw. mehrmals angefasst werden (hohe Kosten!)
  - Eventuell Rollbehälter nicht voll (Schlechte Ausnutzung Transportkapazität)
  - Einsparung bei Logistikrabatt nicht bei A Artikeln (deswegen macht Modell nur mit Umschlagpunkten mit Lagern für A Artikel Sinn)

Figure C.10: Interview results with full assortment retailer A (1/3) and (2/3)

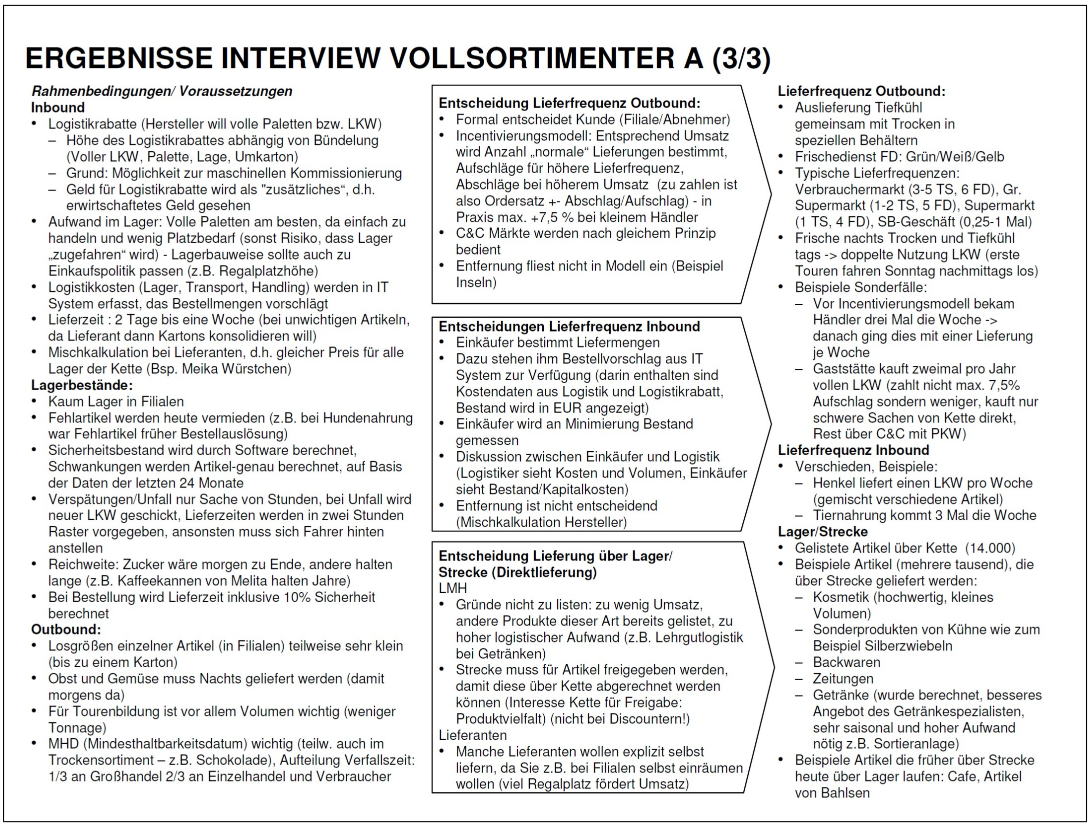

Figure C.11: Interview results with full assortment retailer A (3/3)

ERGEBNISSE INTERVIEW VOLLSORTIMENTER B (1/2)

Gegebenheiten Handelskette an die Interviewtes Unternehmen angeschlossen ist

- Artikelliste von >20.000 Artikeln
- Lieferungen hauptsächlich aus einem Zentrallager (Entfernung ca. 130 km)
- Einzelne spezialisierte Lager (Bsp. Tiefkühlartikel, Drogerieartikel) liefern über Zentrallager
- Getränke werden getrennt ausgeliefert (Getränkegroßhändler der Kette)
- Beliefert Filialen mit Rollis (diese müssen leer wieder zurückgefahren werden)
- Auslieferung (zumindest von Trockenprodukten) mit 40t Fahrzeugen – Kapazität: ca. 50 Rollis bei zweistöckiger Beladung
- Starke IT Integration mit Kette (IT bekommt POS Daten)

Interviewtes Unternehmen

- Wirtschaftszweig: 52.11 Einzelhandel mit Waren verschiedener Art, Hauptrichtung Nahrungsmittel, Getränke und Tabakwaren
- Umsatz (2006): 40,5 Mio. EUR
- Mitarbeiter in Filialen: 308
- Filialen (Anzahl Mitarbeiter, Anzahl Artikel):
  - Filiale 1 (44, 25.000),
  - Filiale 2 (15, 14.000),
  - Filiale 3 (22, 18.000),
  - Filiale 4 (20, 19.000),
  - Filiale 5 (25, 17.000),
  - Filiale 6 (17, 17.000),
  - Filiale 7 (25, 12.000),
  - Filiale 8 (26, 17.000),
  - Filiale 9 (38, 18.000),
  - Filiale 10 (76, 35.000)
- Eigene Fahrzeuge: Zwei 7,5 t LKW, damit werden Blumen und regionale Ware (Obst/Gemüse) (April bis September) aus Region, bzw. vom Großmarkt gefahren (2 mal wöchentlich erster Teil Filialen, 3 mal wöchentlich 2. Teil Filialen)
- Angeschlossen an Handelskette, aber selbstständiger Lebensmittelhändler (handelt auch autonom)
- Produkte in Filiale gehören der Filiale (kein VMI oder Kauf auf Kommission)
- Unterscheidung (Klassifizierung) Produkte: Trocken, Kühl, Tiefkühl, Spezielle Produkte (z.B. Getränke insb. Bier, frisches Brot)

Interviewter, Interviewsituation

- Filialleiter Filiale 1
- Berufserfahrung (>15 Jahre) als Mitarbeiter und Filialleiter in mehreren Filialen
- Interview in Filiale
- Ca. 1,5 Stunden
- Freies Gespräch, orientiert an vorformulierten Themenblöcken/Fragestellungen
- Ablauf:
  - Einführung in Forschungsvorhaben (Powerpoint Folien (ca. 10 min)
  - Situation und Überblick Unternehmen (30 min)
  - Entscheidungen und Vorgehen bei Entscheidungen (30 min)
  - Rahmenbedingungen und außenstehende Entscheidungen (20 min)
- Weitere Quellen: Hoppenstedt, Creditreform Deutschland (Firmenprofile), Internetseite Unternehmen

ERGEBNISSE INTERVIEW VOLLSORTIMENTER B (2/2)

Rahmenbedingungen/ Voraussetzungen

- Anzahl Mitarbeiter: 44
- Anzahl Artikel: 25.000
- Geschätzter Umsatz Filiale (Anteilig nach Mitarbeitern): ca. 5,5 Mio EUR
- Anzahl Einwohner Gemeinde (zur Bestimmung Anzahl Kunden, kein weiterer Lebensmittelmarkt): 3860
- Verbrauch/Absatz pro Woche:
  - Trockenprodukte (Kette): 45 Rollis
  - Kühlprodukte (Kette): 36 Rollis
  - Tiefkühlprodukte (Kette): 8 Rollis
  - Getränke (ohne regionale Biermarke): 10 bis 15 Rollis (teilweise nur 5 Rollis im Winter)
- Schwankungen:
  - Im Allgemeinen sehr gering
  - Bei speziellen Produkten (Bier) und bei Aktionen
  - Augrund räumlichen Beschränkungen (keine Stellplätze in Gang) und Unternehmenspolitik weniger Aktionen in Filiale
- Kaum Verspätungen bei Lieferungen (genügend Zeitpuffer und Flexibilität bei Personal)
- Anlieferungen von Zentrallager (Distanz: 130 km)
- Bestellvorlaufzeit: 24 h

Vorgehen Entscheidung Nutzung Netzwerk Handelskette (Sicht Filiale):

- Produkte aus Produktliste Handelskette werden (zum Ordersatz) bei Handelskette bestellt, restliche über Lieferanten (Nachteil Mindestbestellmengen) oder selbst abgeholt
- Berechnung Kostenabschätzungen nicht bekannt

Vorgehen Entscheidung Lieferfrequenz:

- Sehr stabil, wird langfristig festgelegt (Verhandlungen ca. einmal pro Jahr)
- Anzahl Lieferungen von Handelskette abhängig von Umsatz
- Incentivierungs-Modell: Bei höherer Lieferanzahl wird Beteiligung Handelskette an Umsatz höher

Vorgehen Entscheidung Bestellung:

- Zeitnah (entspr. Vorlaufzeit und Lieferfrequenz)
- Ausgelöst durch „Regalverantwortliche“ (nicht automatisch obwohl IT System vorhanden)
- Regel: Out of Stock (insb. bei kritischem Produkten wie regionalem Bier) verhindern (lieber früher bestellen), Vorratshaltung minimieren

Belieferungskanäle

- Großteil über Handelskette (Zentrallager)
- Ausnahmen:
  - Getränke über Getränke Großhändler der Handelskette
  - Regionales Bier direkt über Getränkegroßhändler des regionalen Bierherstellers
  - Brot (4 Rollis täglich) über Tochterfirma der Handelskette – direkt da Verfallszeit sehr kurz
  - Tiefkühlbrot (dreimal pro Woche)
  - Säfte aus Region (Palettenweise), unregelmäßig (Problem Mindestbestellmenge)
  - Blumen, Obst/Gemüse aus Region (Selbstabholung aus Großmarkt) 2 mal wöchentlich

Lieferfrequenzen Handelskette

- Trocken: 2 mal pro Woche
- Frisch (Anlieferung Nachts): täglich
- Tiefkühl: Wöchentlich
- (Beispiel kleine Filiale: gleich bis auf Trocken nur einmal wöchentlich)
- Getränke: zweimal wöchentlich (regionales Bier)

Lagehaltung/Bestellmengen

- Kaum Lager: nur für regionales Bier, und wenige Trockenartikel sowie Rollis
- Vorräte in Regalen und Schubladen unter Regalen
- Keine festen Bestellpunkte bei Bestandsmengen (sehr Artikelabhängig, z.B. bei manchen Drogerieartikel wird erst nachbestellt wenn nur noch geringe Anzahl vorhanden)

Figure C.12: Interview results with full assortment retailer B

ERGEBNISSE INTERVIEW VOLLSORTIMENTER C (1/3)

- **Interviewpartner**
  - Leiter Abteilung für Lieferantenverträge bei Logistiktochter - 4 Jahre Berufserfahrung in Unternehmen sowie vorherige Berufserfahrung in Gebiet (Consulting)
  - Leiter Abteilung für Warenkoordination bei Logistiktochter (Betrieb der Lagern und Koordination zwischen Einkauf/ Kategorienmanagement und Lagern) - 10 Jahre Berufserfahrung in Unternehmen
- **Belieferte Geschäftstypen:**
  - Cash and Carry Märkte (Artikel: ca. 20.000 Food und 30.000 Non Food)
  - SB - Warenhäuser (Artikel: ca. 70.000 – je 35.000 Food und Non Food)
  - Verbrauchermärkte
  - Supermärkte (20.000-30.000 Artikel)
- **Logistik in Handelskette**
  - Einkauf und Logistik sind zentral als Querschnittsfunktion in eigenen Gesellschaften organisiert
  - Abgrenzung Einkauf und Logistik
    - Einkauf: Verhandelt mit Lieferanten Rahmenbedingungen bezüglich der Ware
    - Logistik: Verhandelt die Logistikkonditionen
  - Abgrenzung Logistik und SCM:
    SCM (Informationsbezogen) und Logistik (physischer Warenfluss) getrennt
  - Logistiktochter
    - Als logistisches Service- und Kompetenzzentrum steuert die Logistiktochter die Warenströme über standardisierte Lieferwege für alle Vertriebsmarken (siehe Lieferwegentscheidung)
    - Eigener Fuhrpark (ca. 200 LKW) wird für gut ausgelastete Rundtouren genutzt, ansonsten werden Dienstleister genutzt
    - Leistungsmessung Logistiktochter an Lieferbereitschaftsquote (98,8%),

ERGEBNISSE INTERVIEW VOLLSORTIMENTER C (2/3)

- **Inbound Logistik (Hersteller-Handelskette)**
  - Abnahmemengen werden simuliert und Bestellmengen daraufhin so festgelegt, dass Reichweite bei max. drei Wochen liegt
  - Lieferfrequenzen Inbound nicht beliebig tief möglich, da Palettenaufkommen am Eingang bewältigt werden muss
  - Logistikrabatte: Weinig bei Frischeware (da wenig Möglichkeit zur Optimierung), viel bei Trocken
  - Bestellzeiten sind 1-3 Tage bei Frische, und 3-6 Arbeitstage bei Trocken
  - Waren werden international in Länderorganisationen zu einem Großteil lokal eingekauft
- **Lagerhaltung**
  - Lagerstrukturen und Lieferfrequenzen aus Lager sind relativ statisch, dynamisch hingegen die Wahl der Lieferwege je Lieferant und Vertriebsmarke
  - Lager bedienen alle Vertriebsmarken (Abhängig von dem gewählten Lieferweg für Zulieferer und Vertriebsmarke)
  - Lager sind auf bestimmte Sortimente spezialisiert
  - Artikelanzahl in Lagern unterschiedlich (Beispiele: Lager A ca. 12.000, Lager B ca. 7.000)
  - Deswegen wird teilweise aus den Lagern über Huckepack geliefert (d.h. vorkommissionierte Artikel für die Ware aus einem Lager werden an anderes Lager geliefert, das diese dann auf Tour zur Filiale lädt)
  - Ostern und Weihnachten werden in der Prognose von Verkaufsdaten explizit behandelt (höhere Lagerbestände)
  - In Deutschland ist eigentlich Versorgungssicherheit gegeben, d.h. keine Sicherheitsbestände wegen potentieller Lieferschwierigkeiten bei Produzenten (anders jedoch international)
- **Outboud Logistik (Lager-Filiale)**
  - Es werden alle möglichen Sendungsarten genutzt (teilweise Lieferung sogar über Paketversand (Arzneimittel aus Lager über Paketdienstleister)
  - Frische wird früh am Vormittag bzw. teilweise Nachts angeliefert

Figure C.13: Interview results with full assortment retailer C (1/3) and (2/3)

ERGEBNISSE INTERVIEW VOLLSORTIMENTER C (3/3)

Voraussetzungen/ Rahmenbedingungen

- Es existieren 3 (bzw. 4) mögliche Lieferwege (siehe Folie) :
  - Direktbelieferung: entweder organisiert vom Lieferant oder der eigenen Beschaffungslogistik
  - Zentrallager: Ware geht in Besitz der Handelskette über, Filialen werden über Lager bedient, Lieferant bzw. Beschaffungslogistik beliefert Lager
  - Cross Docking, zwei Möglichkeiten:
    - Vorkommissioniert durch Lieferanten, in Cross Dock nur Aufsplittung (Koordiniert durch Logistiktochter), Bestellung durch Märkte
    - Konsolidierte Menge wird geliefert, in Cross Dock wird kommissioniert, Ware geht in Besitz der Handelskette über,
- IT System liefert Logistikkosten auf Artikelebene
- Logistikkosten, insb. Kosten aus Lager, werden Lieferanten spezifisch berechnet

Vorgehen Entscheidung

- Kosten der vier Lieferwege je Vertriebslinie und Lieferant werden durch Simulation prognostiziert
- Es wird ein Businesscase für Vertriebslinie und Lieferant berechnet, um den richtigen Lieferweg zu finden
- Lieferanten werden dazu aufgefordert ihre Logistikkosten offen zu legen
- Frachtkostentausch und Lieferkonditionen werden mit Lieferant ausgehandelt/ festgelegt
- Auch Lieferqualität und Versorgungssicherheit sind Teil der Diskussion mit Lieferanten
- Für die Aufteilung der Synergien bzw. Kosten- und Umsatzeffekte zwischen Lieferant und Handelskette aus der Organisation der Logistik durch die Handelskette werden mit den Lieferanten individuelle Vereinbarungen je nach Lieferweg getroffen.

Ergebnis der Entscheidung

- Lieferwege in Vertriebslinien
  - Cash und Carry Märkte: vor allem Tiefkühlartikel (aber auch Trocken und Non Food Artikel) gehen über Lager (da kein hoher Umschlag), ansonsten hoher Durchsatz, ganze Paletten, hoher Anteil Beschaffungslogistik
  - SB-Warenhäuser: ca. 60% wird über Lager geliefert (ca. 40.000 Artikel), einzelne Artikel werden direkt geliefert (über alle Sortimente verteilt),
  - Verbraucher-/Supermärkte: ca. 90% wird über Lager geliefert (ca. 20.000-30000 Artikel)
  - Fachmärkte laufen über Beschaffungslogistik, nicht über Lager!!
- Mehrweggetränke laufen immer über Direktbelieferung (Strecke)
- Cross Docking
  - Vorkommissioniert: Frischeprodukte und schnell drehende Trocken-/non Food Artikel
  - Nicht vorkommissioniert: im Wesentlichen für C&C Märkte
- Lieferantennummern
  - Normalerweise erhält jeder Lieferant je Vertriebslinie eine Lieferantennummer (Vereinzelt mehrere Lieferantennummern pro Lieferant bei großen Lieferanten)
  - Eine Lieferantennummer wird immer genau einem Lieferweg zugeordnet

Figure C.14: Interview results with full assortment retailer C (3/3)

ERGEBNISSE INTERVIEW KAFFEE HERSTELLER (1/3)

- **Interviewte Person / Unternehmen**
  - Interviewte Person
    - 5 Jahre Erfahrung in Unternehmen (Mitglied der Geschäftleitung des Geschäftsbereich Kaffeeherstellung)
    - Vorher ca. 5 Jahre Berufserfahrung in Beratung
  - Interviewtes Unternehmen (Geschäftsbereich in Fokus des Interviews):
    - Geschäftsbereich Kaffeeherstellung und Vertrieb
    - Insgesamt ca. 400 Mio. EUR Umsatz in diesem Bereich
    - Weiterer Fokus Interview auf Relation Hersteller-Lebensmittelhandel
    - Nicht in Fokus des Interviews: Belieferung Gaststätten und andere Geschäftsbereiche wie beispielsweise Automatenservice (sind bezüglich logistischer Entscheidungen unabhängig)
    - Produktion gesamt: ca. 50.000 t Kaffee pro Jahr
    - Ca. 15 relevante Artikel
    - Hauptsächlich Herstellung von Markenartikel
    - Abfüllung "No Name" Marken für Discounter unwesentlich (nur wenn zwei Kriterien erfüllt sind: Vorteil in Kundenbeziehung und rentabel)

- **Gedanken zur Modellierung des Handels**
  - Argument gegen (verhaltens) homogene Gruppen von Akteuren auf Wirtschaftsrelation: Unternehmen differenzieren sich durch Logistik -> bei ähnlichem/gleichem logistischem Verhalten wäre diese Differenzierung nicht möglich
  - Handel extrem dynamisch, es wird viel experimentiert – bei vielem ist die Vorteilhaftigkeit/Nutzen noch nicht belegt

- **Nachfragestruktur/Aktionen**
  - Nachfrage schwankt bezüglich Einzelkunden (Handelskette) sehr stark, Gesamtabnahme schwankt weniger (einzelne Peaks z.B. Ostern)
  - Aktionen
    - Schwankungen bei Einzelkunde durch Aktionen
    - Bei Filterkaffee wird ca. 80% des Umsatzes über Aktionen erzielt
    - Weitere Beispiele für Artikel, die stark Aktions-getrieben sind: Schweineschnitzel, Waschpulver, Nutella
    - Daraus folgt wichtigste Frage bei Belieferung nicht Optimierung der Losgröße, sondern Frage des "uplift"-Faktors, d.h. wie viel mehr wird durch Aktion abgesetzt (z.B. Faktor 8 oder 15) und wie kann dafür die Verfügbarkeit sichergestellt werden
    - Beispiel Discounter macht ca. 8-9 Aktionen mit einzelner Kaffeemarke pro Jahr
    - Beispiel LIDL (siehe GFK Statistik),
  - Hoher Umsatz bei Kaffee - wichtigste "Fast Moving Consumer Goods" (FMCG) im deutschen Lebensmittelhandel: 1. Coca Cola Literflasche, 2. Kaffeemarke 1, 3. Kaffeemarke 2
  - Beispiel Nachfragevolumen Discounter je Zentrallager: ca. 300t pro Jahr (entspricht ca. 10 vollen LKW Lieferungen bei 8-9 Aktionen pro Jahr)

- **Transportmittel/-verantwortung**
  - LKW Transporte über Dienstleister (keine eigenen Fahrzeuge in Geschäftsbereich)
  - Meist Voll- Teilladungen, teilweise Stückgut und Paketsendungen (insb. für Nebensortiment)
  - Organisation Transport Hersteller-Zentrallager Handel durch Kaffeehersteller
  - Einzelne Ausnahmen:
    - Dienstleiser von Handelskette übernimmt Transporte in Kooperation mit eigenem Dienstleister
    - Metro: Kosten wurden offen gelegt, Übernahme Transporte durch METRO abgelehnt da momentan sehr kostengünstig

ERGEBNISSE INTERVIEW KAFFEE HERSTELLER (2/3)

- **Werks-/Distributionsstruktur**
  - Entscheidung Werkstruktur
    - Werkstruktur historisch gewachsen:
      - Stammhaus/-werk
      - Produktionsstätte in Berlin – Berlinförderung währen DDR Zeit – viele Zigaretten und Lebensmittelhersteller bauten Produktionsstätten auf
      - Zukäufe (Gelegenheiten)
    - Zusammenlegung von kleinen Werken heute nicht gewollt, da Gefahr von Schaden für Markenidentität (auch an Ort und Betrieb gebunden)
  - Werksstruktur
    - Ein Hauptwerk in Berlin, dort werden nur 500g Vakuumverpackung produziert (ca. 70-80% der Gesamtmenge, 35.000 t)
    - Weitere 4 Werke über ganz Deutschland verteilt, in denen zwischen 1.000 t und 9.000t produziert werden
      - 2 Werke für Produkte für Gaststättenvertrieb
      - Ein Werk für Produkt mit speziellen Anforderungen
      - Stammwerk, in dem alles produziert werden kann
  - Entscheidung Distributionsstruktur
    - Distributionszentrum an Werk mit größtem Volumen
    - Überschlägige Rechnung (keine detaillierte Analyse vorgenommen) für Distribution in LMH aus kleinen Werken ergibt: es ist sinnvoller Produkte nach Berlin zu fahren und alles von dort zu distributieren
    - Eigene Distribution in LMH von anderen Werken macht nur bei entsprechenden Mengen Sinn (bei kleinen Mengen Vorteile durch Bündelung der Distribution)
    - Transporte ex. Berlin sind wesentlich preisgünstiger als von anderen Standorten
    - Kundenauftrag verlangt Ware in 36h in 2h Zeitfenster – Koordination verschiedener Sendungen wäre zu komplex
  - Distributionsstruktur
    - Distributionszentrum für Lebensmittelhandel in Deutschland in Berlin, d.h. Artikel werden dort gebündelt und aus drei Werken nach Berlin transportiert
    - Weiteres Distributionszentrum gemeinsam mit anderem Konsumgüterhersteller in Berlin (über diese Struktur werden alle Sendungen unter 5 Paletten versendet)
    - Distribution an Gaststätten aus eigenen Werken (eigene Marke und eigene Produktion)
    - Stammwerk
      - Früher wurde für Lebensmittelhandel in Region alles von Stammwerk distributiert, d.h. Optimierung Transportstrecke (heute nicht mehr s.o.)
      - Heute Distribution ins Ausland, Nebenware an Lebensmittelhandel und Kaffee an andere Geschäftsbereiche
    - Teilweise Distribution "Produkt mit speziellen Anforderungen" direkt ab Werk

- **Bestände**
  - Bestände bei Handelsketten sehr unterschiedlich:
    - Beispiel Discounter: hält ca. einen Monat Bestand, Bestände werden erst nach Aktion aufgefüllt
    - Beispiel Handelskette (Schwerpunkt große Supermärkte):
      - 5-10 Tage Reichweite
      - Lieferungen bei Aktion:
        - Handelslager-Filiale: Filiale erhält vor Aktion 1x Ware, während Aktion 3x Ware
        - Hersteller-Handelslager: wahrscheinlich eine Lieferung vor Aktion und eine während Aktion
  - Bestände bei Kaffeehersteller
    - Bestand kaum erfasst, da Kaffee schnell drehend
    - In Berlin durchschnittlich ca. 3 Wochen Bestand (schwankt zwischen 1-4 Wochen Bestand von Fertigwaren)

Figure C.15: Interview results with coffee producer (1/3) and (2/3)

ERGEBNISSE INTERVIEW KAFFEE HERSTELLER (3/3)

- **Entscheidung Strecke/Lager**
  - Anteil der Streckenlieferanten in den letzten zehn Jahren dramatisch zurückgegangen (bei fast allen FMCG Lieferanten)
  - Heute meist Lieferung an Zentrallager
  - Ausnahme Rand oder Sondersortimente, die in Zentrallager nicht geführt werden – dann bedarf es Streckenfreigabe durch Handelskette (Filiale bestellt über Handelskette mit Ordersatz, geliefert wird aber durch Hersteller)
  - Bei Streckenlieferungsfreigabe werden nur diese Artikel über Strecke geliefert, anderen Artikel weiterhin über Handelskette geliefert
  - Argumente bei Entscheidung
    - Lieferung nur über Zentrallager führt zu einer Sortimentsverarmung (deswegen Streckenfreigabe)
    - Nachteil für Hersteller: Streckenlieferung sehr viel teurer
    - Vorteil für Hersteller: Möglichkeit eigene Pflege der Regale, dadurch:
      - Kein Out of stock
      - Geordnetes Auftreten
      - Konzepte wie Continuous Replenishment (CRP)
    - Beispiele Produkte mit Streckenbelieferung
      - Dekorativer Kosmetik
      - Fritolay (Kartoffelchips) - gehört zu PepsiCo
      - Tchibo
  - Bei Interviewtem Kaffeehersteller:
    - Bevorzugt niedrige Distributionskosten
    - Dazu unregelmäßige Besuche bei Filialen durch Außendienst zur Qualitätskontrolle
    - Früher wurden teilweise alle Artikel auf Strecke geliefert (zum Beispiel bei EDEKA, Dole (heute an REWE angeschlossen), METRO)
    - Heute weniger als 4% des Gesamtvolumens:
      - Nebenprodukte, die nicht über Zentrallager laufen aber für Strecke freigegeben sind (z.B. bei EDEKA und REWE)
      - EDEKA C&C - geschätzt 300t
      - Als Paketsendungen bzw. Stückgut versendet
    - METRO C&C heute über Crossdocking 2-stufig (1-stufig: Aufträge für Märkte vorkommissioniert, 2-stufig: sortenreine Lieferung)

- **Losgrößen**
  - Wichtigste Frage nicht Optimierung der Losgröße, sondern Sicherstellung der Verfügbarkeit bei Aktionen
  - Wichtigste Größe für Losgrößenbestimmung ist Nachfragestruktur über Zeit
  - Hauptsächlich Teil und Volladungen, kaum Stückgut (wegen Nachfragestruktur)
  - Ca. 50% " Volladungen" (d.h. min. eine Lage mit 12t bis zu 2 Lagen mit 24t)
  - Mengen unter fünf Palette (ca. 1500 kg) werden über separates DZ gemeinsam mit weiterem Konsumgüterhersteller vertrieben
  - Belieferung unterschiedlich, teilweise ist Handel auch an einige Paletten "gewöhnt"
  - Konditionssystem
    - Konditionssystem versucht Handel zu incentivieren
    - Konditionen von Kunde zu Kunde unterschiedlich: teilweise Rabatte ab 1 Palette, 5 Paletten, 10 Paletten teilw. Mindestbestellmenge 10 Paletten
    - Es werden keine Einzelheiten über System angegeben (Preisnachlass nicht nach Umsatz da hochwertiges Produkt)
    - Einführung Konditionssystem nur als Preisnachlass für Handel möglich
    - Vielfältige Komponenten Preisverhandlung bei Handel:
      - Nettopreis
      - Möglichkeit zum Abruf Anbruchpaletten oder einzelner Paletten
      - Zahlungsziel (in der Regel erst ein Monat nach Verkauf in Filiale)
      - Beteiligung Hersteller an Kosten (z.B. Werbungskosten, Servicekosten in Filiale)

Figure C.16: Interview results with coffee producer (3/3)

ERGEBNISSE INTERVIEW HERSTELLER FRISCHEPRODUKTE (1/2)

- **Wirtschaftszweig:** Herstellung Lebensmittel
- **Anzahl Mitarbeiter:** ca. 3000
- **Umsatz:** ca. 2 Mrd. EUR (davon ca. 25% in Ausland)
- **Kategorisierung Kunden:** Nach Nationalitäten, in D: Weiterverarbeitende Industrie, Lebensmittelhandelsketten, Großverbraucher (Cash und Carry)
- **Produktkategorien:**
  - Zuteilung Lager: 2 Kategorien kühlpflichtige Produkte
  - Transportanforderungen: Gekühlte/ungekühlte Produkte
  - Kundenanforderungen: Industrieprodukte, Produkte für Lebensmittelhandel
  - Marke: Eigenmarke, Handelsmarke
- **Geschätzte Anzahl Produkte:** ca. 30
- **Geschätzte Anzahl Artikel:** ca. 500
- **Anzahl Produktionsstandorte:** ca. 15 (produzierte Anzahl Produkte zwischen 1 und 10 – teilweise werden Produkte an mehreren Standorten produziert)
- **Lagerstandorte/Lagerregime :**
  - Lager an allen Produktionsstandorten für Produkte des jeweiligen Standortes
  - 2 Zentrallager für kühlpflichtige Produkte (eines je Kategorie)
  - Auslieferungslager auch bei Speditionen (bei Teilpartien)
  - Entfernung zwischen Produktionsstandorten und Zentrallagern: 20-400 km
- **Geschätzte Wertedichte pro Tonne:** ca. 500 EUR – 10.000 EUR
- **Max. Entfernung zu Kunden in Deutschland:** ca. 800 km
- **Genutzte Verkehrsmittel:** LKW (kein eigener Fuhrpark mehr), sehr wenig Bahn (nur im internationalen intermodalen Verkehr mit Industrieprodukten)
- **Verkehr Zentrallager 1:** ca. 70 LKW/Tag (ca. 10 Anlieferung, ca. 60 Auslieferung)
- **Interviewpartner:**
  - Leiter Logistik, 23 Jahre Berufserfahrung
  - Verantwortlicher Frachten, 6 Jahre Berufserfahrung bei interviewtem Unternehmen

ERGEBNISSE INTERVIEW HERSTELLER FRISCHEPRODUKTE (2/2)

Rahmenbedingungen/ Voraussetzungen
- Hoher Preisdruck in Markt (dadurch z.B. Einführung von Logistikrabatten bei Handelsmarken schwierig)
- IT System ordnet Logistikkosten ex post den Kunden zu (inkl. Lager, Transport, keine Kapitalkosten, kein Bruch)
- Unternehmen ist produktionsorientiert (Rohstoffe müssen verarbeitet werden)
- Preise Produkte nach Entfernung differenziert (Ausnahme: Rahmenvertrag mit Handelskette)
- Kooperation mit Lebensmittelketten nur beschränkt möglich , Ketten versuchen ihre System zu optimieren (z.B. Crossdocking)
- Große Discounter verlangen Möglichkeit zur täglichen Belieferung in Rahmenvertrag
- Ca. 65% der Produkte werden gekühlt transportiert
- Verspätungen durch Verkehrssystem unerheblich (d.h. werden nicht bei Planung berücksichtigt)

Entscheidung Lagerstruktur:
- Als Zentrallager für kühlpflichtige Produkte wurden Standorte mit größtem Aufkommen in jeweiliger Produktkategorie gewählt

Entscheidung Lieferfrequenz/Losgröße:
- Entscheidung durch Kunden (festgelegt in Rahmenvertrag)
- Verkäufer sollte Logistikkosten in Preiskalkulation einbeziehen (wird nach Deckungsbeitrag bewertet, fragt teilw. Logistikkosten an)
- Offene Kommunikation Logistikkosten
- Einbezogene Kosten bei Anfragen: Lagerkosten, Transportkosten (hier keine Kapitalbindungskosten)

Entscheidungen Transportplanung

Selbstabholung
- Große Losgrößen deswegen Selbstabholung nicht effizienter
- Problem Planbarkeit (Viele Kunden würden dann gerne zwischen 10 und 14 Uhr laden)

Faktoren Auflösung Fuhrpark:
- Niedrigere Kosten bei DL
- Bessere Möglichkeit Dienstleister zu beauftragen (da inkl. attraktiver Grundlast)

Faktoren Nutzung Bahn:
- Langer Vorlauf (inflexibel)
- Systembruch
- Produktschäden
- Preis erst ab 800-1000km vorteilhaft
- Unzuverlässig

Lager, Belieferung aus Lagern
- Sendungen über 5-6 Paletten werden direkt von Produktionsstandorten versendet (andere wenn möglich gebündelt über Zentrallager)
- Teilweise auch Auslieferungslager bei Speditionen/ Systemdienstleistern (bei kl. Mengen)
- Beispiel Sicherheitsbestände Frischeprodukte: 4-5 Tage (teilweise Quarantäne für Tests)

Lieferfrequenzen (Losgrößen)
- Ganzladungen, Teilladungen und Stückgut
- Artikelbeispiel: Anteil Volladungen bei ungekühltem Artikel (hoher Verbrauch, niedrige Wertedichte, lange Haltbarkeit) >80%
- Losgröße vor allem abhängig von Verbrauch (Distanz und Wertedichte nachgeordnet)
- Gründe Teilladung/Stückgut:
  - begrenzte Lagerkapazität Kunde
  - Risiko Verfall
- Bündelung unterschiedlicher Produkte bei Transporten
- Direktbelieferung nur bei gr. Abnahme (z.B. Cash und Carry Märkte)
- Bei Handelsketten wird meist an deren Zentrallager geliefert
- Versuch Vermeidung kleine Lieferung (teilw. schwierig wg. Marktdruck)
- Transportkosten momentan noch nicht entscheidend bei Kunden (könnte sich über Kostenanstieg und Umweltimage ändern)

Transportplanung
- Wenig Selbstabholung bei interviewtem Unternehmen (wenn dann vor allem internationale Kunden)
- Tendenz Lebensmittelhandel zur Selbstabholung zur Optimierung seiner Touren
- Früher eigener Fuhrpark (ca. 30% selber gefahren, vor allem Grundlast), heute durch DL
- Bahntransport: nur ungekühlte Produkte zur Weiterverarbeitung nach Italien (kombinierter Verkehr)

Figure C.17: Interview results with diary producer

ERGEBNISSE INTERVIEW BRAUEREIGRUPPE (1/4)

- **Interviewte Person / Unternehmen**
  - Interviewpartner:
    - In Bereich Logistik (Verantwortlicher SCM) seit 7 Jahren
    - Vorher Bierbrauer
    - Berufsbegleitendes Studium Betriebswirtschaft/Logistik
  - Unternehmen:
    - Brauereigruppe: ca. 1.000 Mitarbeiter, Produktion von mehr als 8 Mio. hl Bier
    - Internationale/nationale sowie regionale Biermarken
    - Aussagen in Interview können als exemplarisch für die 10 großen Brauereien in Deutschland gesehen werden (anderes Verhalten bei kleinen Brauereien)
    - Insgesamt ca. 350 Bierartikel und 4.000 Werbemittel (z.B. Kugelschreiber, Pferdedecke, Kühlschränke, Theke…)
    - Einteilung der Artikel durch klassische ABC Analyse (z.B. Mixgetränke mit Bier oft B bzw. C Artikel)
    - Betrachteter Standort (Stammhaus): ca. 80 LKW (Outbound) pro Tag

- **Kundenstruktur/Belieferungsart**
  - Kunden können in Feld (Gastronomie) und Key Accounts/organisierter Handel aufgeteilt werden
  - Feld (Großteil Fässer)
    - Getränkefachgroßhändlern sind Kunden zugeteilt (ca. 40.000 belieferte Gastronomieobjekte)
    - Kundenschutz kein Gebietsschutz
    - Durch diese werden Abnahmemengen gebündelt und Transport organisiert (Abnahme ab Rampe)
    - Kleine Abnehmer müssen entweder bei Zwischenhändlern kaufen (bedeutet Aufpreis) oder können sich zu Einkaufs-/Transportgemeinschaften zusammenschließen
  - Key Accounts/organisierter Handel (Großteil Flaschen)
    - Bei Handelsketten mit Vollsortiment übernehmen die Belieferung der Filialen meist separate Getränkefachgroßhändler, Transporte werden durch Getränkefachgroßhändler organisiert
    - Beispiel Trinks (macht Kommissionierung bei Metro): ca. 16 Zwischenlager, beliefert z.B. Metro C&C, holt einen LKW pro Tag mit verschiedenen Artikeln (in dieser Kategorie gibt es weitere zwei bis drei Getränkefachgroßhändler)
    - Discounter werden mit Volladungen über beauftragte Getränkespedition in Zentrallager beliefert (keine Pfandflaschen)
    - Tankstellen werden über Leckerland beliefert (Key Account), werden aber zusätzlich auch von Feldorganisationen betreut
  - Unterschied bei kleine Brauereien: lokale Kunden, liefern selten in Lebensmittelhandel (Außnahme Händler mit regionalen Artikeln wie EDEKA)

ERGEBNISSE INTERVIEW BRAUEREIGRUPPE (2/4)

- **Fakten zum Ablauf der Abholung in interviewtem Betrieb**
  - Bestellung werden meist mit Abholung aufgegeben
  - Keine Vorbestellung notwendig (auch keine Incentivierung dafür) – Bestellung an Werkseinfahrt, über Fax, EDI oder Telefon möglich
  - Verladezeit ca. 15 min, Verweilzeit ca. 45 min, wenn sortenrein und ohne Leergut reichen 20 min
  - 12 Verladespuren, 3 Exportverladespuren, 70 Gabelstaplerfahrer, 3 Schicht Betrieb
  - Bezahlung über Bankeinzug, i.d.R. wenn Ware Rampe verlässt
  - Verladen werden Bierartikel und Bier affine Werbemittel (z.B. Gläser, Kühlschränke, Theken)
  - Es können an jedem Brauereistandort auch die wichtigsten Biermarken der Gruppe gekauft werden

- **Zusammenarbeit mit Kunden**
  - Nur beschränkte Kooperation mit Lebensmittelhandel/Kunden
    - POS Daten aus dem Handel (müssen bezahlt werden)
    - Gemeinsame Kostenoptimierung findet nicht statt, man tauscht sich aber viel aus
  - Versuche:
    - Vorgelagerte Rampe (Kooperation mit Getränkefachhändlern): Probleme bei Verzollung und bei Qualität
    - Heute nur noch Außenlager an eigenen Standorten (anderen Brauereien der Gruppe)

- **Nachfrageschwankungen/Absatzplanung**
  - Schwankung führen zu bis zu 50% zusätzlichem Umsatz
  - Wichtigste Faktoren:
    - Wetter (erst wenige Tage vorher absehbar)
    - Aktionen (Termin absehbar, Stärke Effekt schwirig prognostizierbar)
    - Veranstaltungen/Events wie z.B. Fußballspiele
  - Wirkung/Gesamteffekt durch einzelne oder Kombination von Faktoren schwierig prognostizierbar
  - Prognosen durch verschiedene Gremien:
    - Zweiwöchentlich (operativ durch Vertrieb, Produktion, Logistik)
    - ¼ jährig
    - Jahresplanung (mit Saisonverteilung)
  - Planung schwierig da Unsicherheit/Änderungen der Rahmenbedingungen
  - IT Systeme nur beschränkt einsetzbar (Versuche mit verschiedenen Beratungen/Universitäten gescheitert)
  - Prognose großteils manuell auf Basis Vergangenheitsdaten (Vertrieb gibt Jahresplanung vor, Planung wird manuell auf Artikelebene disaggregiert)

Figure C.18: Interview results with brewery (1/4) and (2/4)

ERGEBNISSE INTERVIEW BRAUEREIGRUPPE (3/4)

- **Bestände/Produktion/Out of stock Situationen**
  - Brauerei arbeitet produktionsorientiert, jedoch mit wenig Lagerkapazität (d.h. Rückwirkung auf Produktionslose)
  - Planungsvorlauf Produktion ca. 4-6 Wochen
  - Probleme der Produktion bei Nachfrageschwankungen:
    - Kurzfristige Anpassung der Produktion bei B/C Artikeln teilweise schwieriger, z.B. bei Mixgetränke längerê Umstellzeit notwendig, deswegen 1-2 Woche Vorlauf
    - Es kommt Mangel an Leergut vor, da Kunden Leergut nur bringen, wenn sie neue Lieferung abholen können
  - Bestände
    - Brauerei:
      - A-Artikel 3-4 Tage,
      - B Artikel 4-8 Tage,
      - C Artikel teilweise bis zu 2 Monaten
    - Großhändler min. 1-2 Tage
    - Lebensmittelhandel min. 1-2 Tage
  - Bestände der gesamten Gruppe können eingesehen werden, Transportkoordination zwischen Standorten mit Blick für Bestände

- **Transportdurchführung**
  - Interviewte Brauerei hat keinen eigenen Fuhrpark mehr
  - Bei großen Brauereien hat nur Oettinger eigenen Fuhrpark
    - Kunden werden alle direkt beliefert (Mindestbestellmenge 1 Palette)
    - Geschäftsmodell Oettinger basiert auf Kostenminimierung: aufgekaufte alte Brauereien, keine Werbung, nur Rücknahme eigener Pfandflaschen (dadurch keinen Sortieraufwand)
  - Erfahrungen Nutzung Bahn:
    - Nachtsprung zu Lager für Absatzregion (8 Wagen pro Tag):
      - Lager der DB Cargo in Absatzregion regelte Absatz
      - Transportkosten und zusätzliche Kosten Bahnbetrieb (Anschlussgleis, werkseigene Bahn) von Brauerei übernommen (Maßnahme zur Marktgewinnung)
      - Vorteile/Zielsetzung: Erhaltung/Nutzung Bahn(anschluss), Einsparung Lagerplatz
    - Heute Nachtsprung bei Bahn nicht mehr möglich

ERGEBNISSE INTERVIEW BRAUEREIGRUPPE (4/4)

- **Losgrössen**
  - Zielsetzung Brauer:
    - Volladungen
    - Artikelreinheit, wichtige Grenze hierbei: 4 Paletten (da in 4er Gruppen ver-/ bzw. entladen wird) bzw. 1 Palette
  - Zielsetzung Kunde/Handel:
    - Kleine Losgrößen (z.B. ¼ Paletten), vorkommissionierte Abnahme
  - Argumentation Brauerei
    - Vermeidung Mehrkosten bei Verladung und Inhouse Logistik durch gemischte Ladungen (Mehrkosten: zusätzliche Stapler, Personalkosten, Rüstzeiten (Stillstandszeiten))
    - Sortenreinheit wichtig für niedrige Lagerbestände bei Brauer (B/C Artikel werden wöchentlich an bestimmtem Tag abgeholt, synchron mit Produktion)
  - Argumentation Kunde: Kostenvorteile durch kleinere Losgrößen/Sortenmischung:
    - Bestand
    - Einsparung Kommissionierung (kann evtl. direkt distributieren)
  - Gesamtkosten wären evtl. bei gemischter Ladung idealer, aber technische Einrichtung (Produktion und Lager) müssten umgestellt werden (gleiche Problematik bei allen Brauereien)
  - Risikokosten werden nicht beachtet, da Systeme nicht so fein arbeiten
  - Vorgehen: Ketten werden incentiviert gr. Mengen abzunehmen (bei Brauerei nicht über direkte Logistikrabatte, aber z.B. über Verkaufspreise für Selbstabholer)
  - Hoher Anteil Volladungen (z.B. 1. Oktober 2007: 21 t pro LKW im Schnitt)
  - Anderes Verhalten bei kleinen Brauereien (hier können auch 5 Kästen abholt werden)
  - Beispiele Frequenzen von Kunden
    - Großhändler einer Lebensmittelkette: 1 mal pro Tag
    - Großhändler: 3-4 mal pro Tag
  - Früher mehr sortenreine LKW (heute Braugruppe mit mehr Artikeln, volle LKW durch Kombination von verschiedenen Artikeln, Sortenreinheit schwierig zu argumentieren)

Figure C.19: Interview results with brewery (3/4) and (4/4)

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