Contributions to Management Science

Thorben Seiler

Operative Transportation Planning

Solutions in Consumer Goods Supply Chains

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Acknowledgement

> The beginning of every act of knowing, and therefore the starting point of every science, must be in our own personal experience [...] They form the forts and most real hook on which we fasten the thought chain of science (Planck 1932)

This research has been motivated by numerous real-life experiences in the application of transportation management. It has been the foremost objective to academically assess and improve the tools and methods for transportation management against the dynamic background of the consumer goods industry. This would not have been possible without the support of many people to whom I would like to express my gratitude.

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Finally, I thank my parents for their confidence in me – they have encouraged the curiosity and stamina that are both required to tackle such research. Last but not least, I want to thank Lisa, who has supported me in every possible way.

Thorben Seiler

Abbreviations

.csv	Comma Separate Values (File Format)
.txt	Textfile (File Format)
.xls	Excel File (File Format)
.xml	Extensible Markup Language (File Format)
3PL	Third Party Logistics Provider
4PL	Fourth Party Logistics Provider
a.m.	ante meridiem
AMS	the Americas
ADSp	Allgemeine Deutsche Spediteursbedingungen
AMB	Ambient
approx.	Approximately
APS	Advanced Planning System
ATP	Available to Promise
Benelux	Belgium, Netherlands and Luxemburg
bn.	Billion
BOM	Bill of Materials
CEP	Courier, Express Parcel
CH	Switzerland
CHD	Chilled
CMR	Convention relative au contrat de transport international de Marchandises par Route
CO_2	Carbon Dioxide
COE	Cab over Engine
CPFR	Collaborative Planning, Forecasting and Replenishment
CPU	Central Processing Unit
DARP	Dial-a-Ride Problem
DC	Distribution Center
DDP	Delivered Duty Paid
DDU	Delivered Duty Unpaid
e.g.	exempli gratia
EC	European Community

ECR	Efficient Consumer Response
ERP	Enterprise Resource Planning
et al.	et alii
etc.	et cetera
EU	European Union
EUR	EURO
EXW	Ex Works
FCA	Free Carrier
FCL	Full Container Load
FI/CO	Finance and Controlling
FMCG	Fast Moving Consumer Goods
FTL	Full Truckload
FY	Fiscal Year
GBP	Pound Sterling
GFT	Güterferntarif
GHz	Gigahertz
GIS	Geographical Information Service
GUI	Graphical User Interface
GVE	Güterverkehrsentgelte
i.e.	id est
ID	Identification
INC.	Incorporated
IT	Information Technology
JIS	Just-in-Sequence
JIT	Just-in-Time
JP	Japan
kg	Kilogram
km	Kilometer
KPI	Key Performance Indicator
Lacs	Lac of Rupees (=100,000 Rupees)
LCL	Less than Container Load
LLP	Lead Logistics Provider
LSP	Logistics Service Provider
LTL	Less than Truckload
MAPE	Mean Average Percentage Error
MCND	Multi Commodity Capacitated Network Design
MCNFP	Multi Commodity Network Flow Problem
mn.	Million
MILP	Mixed Integer Linear Programming
MIP	Mixed Integer Programming
MIS	Merchandise Information System
MRP	Material Requirement Planning
MS	Microsoft
N/A	Not Available

N.N.	Nomen Nescio
NAFTA	North American Free Trade Agreement
OR	Operations Research
OVE	Overall Vehicle Effectiveness
p.a.	per annum
p.m.	post meridiem
PDP	Pickup and Delivery Problem
PLC	Public Limited Company
PMCND	Path Based Multi Commodity Capacitated Network Design
POS	Point of Sale
PP	Production Planning
RAM	Random Access Memory
resp.	respectively
RFID	Radio Frequency Identification
RFQ	Request for Quotation
RKT	Reichskraftwagentarif
S.A.	Société Anonyme
SCM	Supply Chain Management
SKU	Stock Keeping Unit
SQL	Structured Query Language
TEM	Temperature Controlled
thsd.	thousand
TMS	Transportation Management System
TP	Transportation Planning
UK	United Kingdom
UNSPSC	The United Nations Standard Products and Services Code
US$	U.S. Dollar
VMI	Vendor Managed Inventory
VRP	Vehicle Routing Problem
vs.	versus
WM	Warehouse Management System

Contents

Chapter 1
Introduction

The consumer goods supply chain is characterized by high demand volatility due to seasonal variations, a high number of promotions, shortening product lifecycles and an increasing number of product innovations pushed into the markets. At the same time providing a high on-shelf availability has proven to be an essential means of establishing and retaining a loyal customer base. Along these lines retailers are demanding faster replenishment and shortened cycle times as well as smaller order quantities and higher shipping frequencies to reduce their inventory, thereby stressing the importance of flexible and reliable transportation and production planning processes.

The major trends toward a global sourcing and operations footprint as well as the penetration of new markets will add to the importance of transportation services all the more. Expanding transportation distances have already heightened the awareness of transportation costs in many enterprises. Rising crude oil prices, road taxes and the impact of transportation on CO_2 emissions accompanied by possible environmental taxes have added further relevance to transportation issues. Nonetheless, road transportation has been favored in previous years due to increasing pressure for fast and flexible delivery and the possibility of direct access to the customer despite increasing traffic congestion and uncontrollable emissions (Vannieuwenhuyse et al. 2003).

This research is inspired by a case study from the European consumer goods industry. Therefore, most of the investigations take place upstream the supply chain where the consumer goods are produced and stored before they are passed on to the retail channels. Although the underlying case study is located in Europe, most findings are applicable to industrialized regions of similar population, especially to North America.

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1.1 Introduction to the Field of Research

In today's consumer goods industry a major section of the transportation services is outsourced to external carriers (Lütke Entrup 2005). The key factor driving the outsourcing decision is a transition toward more flexible cost structures that promise lower total transportation expenses for the consumer goods manufacturers. The availability of less-than-truckload (LTL) services is of significant importance for small shipments, since the shipper only pays a price according to the proportion of the truck capacity utilized by the shipment (Lapierre et al. 2004). In contrast to that, for full-truckload (FTL) shipments there is a fixed cost per load for a given capacity (truck capacity). Even very small loads are charged the price of the full load, if the service is contracted for an FTL (Rieksts and Ventura 2008).

Transportation services can be categorized according to their major cost drivers: transportation quantity, transportation distance and service level (transportation speed). Transportation quantity ranges from very small shipment sizes usually covered by parcel services to extra-large shipments served by special shippers (e.g., construction equipment). A special case is constituted for the transportation of raw materials and chemicals where bulk transportation is very common (Blauwens et al. 2008). As for load sizes, this research concentrates on general cargo with a minimum shipment size of one euro-pallet and a maximum shipment size covering a full truckload. These sizes are usually shipped using LTL and FTL modes. Transportation distances in this study range from local distances comprising only very few miles to transcontinental distances often involving sea transportation. Since the underlying case study is based in Europe, transportation distances are within this continental range and are covered using road transportation mode. For FTL services, the required service level is on a continental scope usually limited by the trucking speeds. Long distances may be covered with an additional driver (to attain the maximum driving hours); for LTL services, transit times between origin and destination are usually longer than for FTL services due to handling operations at several hubs (Rieck 2009; Caputo et al. 2005; McLaughlin et al. 2003).

The commercial software suites employed to manage an enterprise's transportation operations are originally designed to meet the needs of standardized and efficient carrier communication. They are generally referred to as "transportation management systems" (TMS). However, these systems are intended to manage the manufacturers' interfaces to the logistics service providers and are therefore mainly transaction based (Caputo et al. 2003). In today's implementations, TMS lack true optimization features. Complex business rules are used to consolidate orders aimed at a reduction of shipping costs (for example, if shipment size is less than one ton, the shipment is transported via a hub) (Fleischmann 2008a).

This research was inspired by a transportation planning problem at a consumer goods manufacturer with suppliers, plants and customers distributed all over Europe. After initially gaining a coherent overview of transportation activities from a continental perspective, an integrated strategy on transportation management was pursued. This strategy included the implementation of transportation management software and the exploration of cost saving opportunities within the operational transportation management processes.

The major contribution of this research is the development of a comprehensive approach for operative transportation planning based on transportation network conditions and freight rate structures that are typical of the European consumer goods industry. In this regard, this research goes beyond the many operations research (OR) inspired approaches that do not sufficiently meet the requirements of transportation management in practice.

1.2 Research Objectives

Inspired by the practical challenges of operational transportation planning in the consumer goods industry, this research is laid out to answer three research questions that have been derived from the implementation requirements of an operational planning process, and are intended to guide the development of a systematic and academically founded planning process.

Research Question 1.
Which requirements must industrial transportation management in the consumer goods sector meet in order to fulfill its supply chain value proposition?

Any supply chain planning activity is in practice subject to numerous restrictions as well as multiple objectives. Since this also accounts for any transportation management task a detailed assessment of the consumer goods supply chain constitutes the foundation for any process design. In order to determine the requirements, the transportation process is approached from three different perspectives: First, the transportation side is thoroughly assessed. The process is integrated into the broader field of logistics and supply chain management. Second, transportation processes are examined from a consumer goods perspective. It goes beyond a mere process analysis to include structural components arranged in the network. Third, external factors are determined that influence transportation management rather indirectly, by ways of the market participants. The implications are deducted from social and political requirements. Within these three areas of analysis multiple requirements and objectives are assessed and discussed. The presented analyses and approaches in this research therefore have to be regarded within the described industrial environment.

Research Question 2.
Which incentives does transportation pricing in outsourced transportation networks induce in order to increase a shippers' transportation efficiency?

While it is easily understood that increasing transportation efficiency will result in a competitive cost base of one's own fleet, outsourced transportation processes may follow different schemes. Therefore, transportation markets are analyzed thoroughly in order to assess the according context of outsourced shipping processes. The prevailing models for freight costs in an outsourced transportation environment are freight rates, the contractual agreement between shipper and carrier on prices and charges for a transportation service. Since the outsourcing decision is a make-or-buy decision for the shipper, the analysis is based on a review of prime costs for transportation services. A general freight rate analysis together with a detailed assessment of the development of transportation markets is performed in order to gain a systematic understanding of cost drivers in outsourced transportation. Different transportation modes are regarded in the analyses. The assessment of rates is derived from real life data.

Apart from analyzing freight costs and freight rates the above research question implies that efficiency gains are possible and worthwhile for the shipper. A detailed assessment of transportation efficiency with special focus on European road transportation will evaluate the former thesis. Summarizing the above, approaches in the dimensions of processes, IT and organization are analyzed toward the extent of actively addressing incentives for efficiency increase. Sources range from academic contributions to business process documentations and IT system specifications giving a broad overview of state-of-the art transportation management.

The findings serve as a guideline for assessing measures to further increase efficiency from a shipper's point of view. They will be used in the course of this text to identify behavioral blueprints and serve as decision support for shippers managing a number of carriers in an attempt to fulfill their transportation demand.

Research Question 3.
Which measures can increase transportation efficiency in outsourced transportation networks? How can these measures be implemented systematically into a transportation management environment?

With the foundation of a sound representation of freight costs in an outsourced transportation network, different measures increasing transportation efficiency are assessed. They adhere to the specifics of transportation management in the consumer goods industry. However, a mere mathematical representation of measures is considered insufficient within this research. By directly addressing the framework of processes, IT and organization, general implementation guidelines are specified with regard to the underlying case study. In addition, efficiency benefits need to be quantified and held against potential implementation obstacles in order to evaluate the prospects of real-life application.

1.3 Outline

In this text transportation management is described as the integration among business requirements defined by transportation demanders and suppliers. An overview of the structure is shown in Fig. 1.1.

This chapter is followed by an introduction to transportation services in consumer goods supply chains. Transportation is identified as one of the key supply

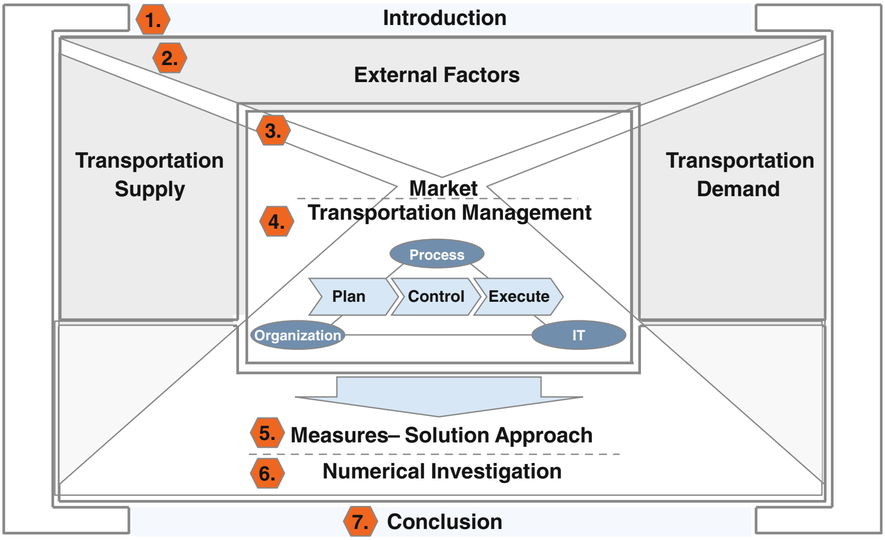

Fig. 1.1 Structure and focus of the sections within this text

chain processes. It is categorized according to service aspects and the associated planning tasks are briefly described. Furthermore, a profile of the consumer goods supply chain is presented and its requirements toward supply chain processes in general and transportation processes in particular are assessed. In addition, the organizational structures are described and the IT landscape is assessed. Finally, external factors and trends are analyzed according to their impact on consumer goods supply chains.

The third chapter focuses on the analysis of transportation costs in consumer goods networks. The specific situation in the consumer goods industry is reflected by specifically assessing freight rates in outsourced networks. The findings are reviewed using practical freight rate examples. The underlying case study is also presented in this section.

In Chap. 4, state-of-the art transportation management functions are described in the context of the three dimensions processes, IT and organization. Current transportation planning problems and the according solution methods are presented in the process description. The general process is then mapped against key functions of currently available TMS. Certain releases from different vendors are assessed according to functionality. Finally, an overview on supply chain and transportation management responsibilities in a modern industrial organization is given.

Chapter 5 focuses on a solution approach to reduce transportation costs in consumer goods transportation networks. The proposed approach consists of two major steps. In the first step, a systematic procedure for consolidating individual transportation orders is applied. This step is implemented in a data base environment including a specific processing phase in which cost savings for combined transportation orders are identified based on realistic freight rate structures. In the second step, alternatively a binary optimization model and a greedy heuristic are applied to select the best order combinations.

In Chap. 6, the general approach is specified and extended and then its process implementation is discussed. Numerical results are assessed using a specified testing environment. The overall findings are compared to real life results. Finally, in Chap. 7, an overall conclusion is drawn and fields of further research are identified.

Chapter 2
Transportation Services in the Consumer Goods Industry

Transportation has been a major component enabling trade for centuries. The physical movement of goods has historically been the basis for economic wealth and political power for states as well as for private enterprises. Consumer goods have always had a great share of total transportation demand. Fruit, coffee, tea, cocoa, tobacco or rice are distributed from their growing areas all across the globe and have gained high acceptance in areas where they are not native, due to efficient transportation (Garnett 2003). Still, never before have consumer goods moved across such long distances and in such vast quantities from their origins to their destinations as they do today. Trade and transportation have been closely linked all throughout the history of both sectors. Some of the biggest European consumer goods manufacturers have evolved from a trading background.

Today, efficient transportation is accepted as a prerequisite for specialization. Furthermore, it allows production and consumption of goods to occur in different locations. Managing the material flows from raw materials and across different and geographically distributed production stages to the customer is the key task of supply chain management, of which transportation is one key process (Chen and Paulraj 2004).

This chapter delivers an overview of the transportation and consumer goods markets in a supply chain management context. It is therefore structured as follows: First, an overview of transportation processes is presented that will position transportation in the context of supply chain management and logistics. Afterwards, an introduction to transportation concepts as well as a short overview on transportation planning follows. In the second subsection the focus is put on supply chain processes in the consumer goods industry. Third, external influences on transportation and consumer goods markets are analyzed toward their impact on the underlying study scope.

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2.1 Transportation Services

Transportation processes are a significant contributor to every supply chain, and in many industrial sectors they are held responsible for the majority of the supply chain costs (Ballou 2007). Yet, in an industrial environment transportation is often regarded as a necessary evil. Transportation is perceived as a non-value-adding process (Simons et al. 2004). Since transportation effort is best to be eliminated completely, this view may have contributed to the increasing popularity of outsourcing decisions among supply chain managers in industry and retail in recent years.

As the title of this subsection indicates, transportation is to be regarded as a service and is, in contrast to goods, not "storable" (Blauwens et al. 2008). This implies the necessity of demand for transportation to be synchronized with the capacity thereof. Unused transportation capacity of one period cannot be stored for deployment in a future period. It could be compared to the supply of electricity that shows a similar service behavior. And, as with electricity, trading of transportation services is easiest if these services are standardized according to certain parameters.

In this subsection transportation services are characterized as a key process within supply chain management and logistics. Furthermore, different types of transportation services are described and the markets for outsourced transportation services are specified. In addition, a short introduction to transportation planning tasks within the environment of supply chain planning activities is given.

2.1.1 Transportation in a Supply Chain Context

In order to understand the significance of transportation in consumer goods supply chains, a general definition and differentiation of the terms "transportation," "supply chain management" and "logistics" is given. The term "management" as used in "transportation management" is understood to encompass the tasks of planning, control and execution.

Supply Chain Management

Supply chain management (SCM) has in past years evolved to be a competition relevant competence for many companies. The concept comprises a large number of areas such as production planning, inventory management, material control and many more. The Council of Supply Chain Management Professionals defines SCM as follows (Ballou 2007):

> Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all Logistics Management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, Supply Chain Management integrates supply and demand management within and across companies.

The integrative aspect of supply chain management is highlighted in many contributions by focusing on decision making processes that include conflicting objectives. Examples are the trade-off between transportation costs and inventory costs and the optimization of transportation frequencies (Ballou 2007), or the trade-off between material costs and transportation costs, often referred to as total costs of ownerships and in retail closely linked to the term "factory gate pricing" (Thonemann et al. 2005; McKinnon and Ge 2006).

From an academic perspective supply chain management comprises disciplines such as management, industrial engineering, logistics, operations research and business computing (Günther 2005). This integrated aspect is stressed by Stadtler (2008b) defining supply chain management "as the task of integrating organizational units along a supply chain and coordinating material, information and financial flows in order to fulfill (ultimate) customer demands with the aim of improving competitiveness of a supply chain as a whole."

While the integrative aspect of supply chain management is widely accepted, the growing complexity of the approach has resulted in two strong trends:

- *Standardization:* In order to control the growing complexity accompanied by the integration efforts, process standardization has been identified as a key concept to reduce process lead times and guarantee high process quality (Mayer 2007).
- *Extensive deployment of IT:* IT systems can relieve the process stakeholders and especially the decision takers from repetitive tasks in information gathering through immediate access to large amounts of relevant data, thereby increasing transparency and in turn decision quality (Stadtler 2008b; Thonemann et al. 2004).

In accordance with the above mentioned definitions Fleischmann (2008a) states that it is "the integrated view of transport, production and inventory holding processes [that] is characteristic of the modern SCM concept." This statement already hints at the strong influence of logistics within supply chain management. And it admits transportation to be a key component alongside production and warehousing. This view is supported by Ballou (2007) claiming transportation to be responsible for the major share of logistics costs, and according to Rider (2003) amounting to 3–7% of total sales.

The preceding paragraphs have shown the integration aspects of supply chain management on the one hand and the measures that are taken to control the resulting complexity on the other hand. The management of a supply chain requires the balancing between complexity and simplification by standardization. This may be eased by focusing on the key components of supply chain management.

Logistics

Of the many aspects to logistics processes, the two commonly mentioned elements are transportation and storage. While transportation can be characterized as a function for bridging in the dimensions of space, storage can be understood as a function for bridging time (Fleischmann 2008b). These two functions may be viewed as the core processes that are surrounded by many supporting processes and activities that usually find consideration in the term logistics.

According to Ballou (2007), the Council of Supply Chain Management Professionals defines logistics management as "part of SCM that plans, implements, and controls the efficient forward and reverse flow and storage of goods, services, and related information between the point of origin and point of consumption in order to meet customer requirements."

Tempelmeier (2008) states the approach connected with the term "supply chain management" is as integrated as the generally acknowledged term of logistics. In this text a position following Großpietsch (2003) is taken, maintaining that whereas logistics constitutes a central part of supply chain management, it is, however, not a synonym thereof (see also Fig. 2.1).

Transportation

According to Chopra and Meindl (2007) transportation can be defined as follows: "Transportation refers to the movement of a product from one location to another as it makes its way from the beginning of a supply chain to the customer's hands." Fleischmann (2008b) puts it directly into a logistical context and states transportation to be the means of bridging the dimensions for objects. These so-called objects may be people, information or physical products—the last of which shall be referred to in the rest of this text.

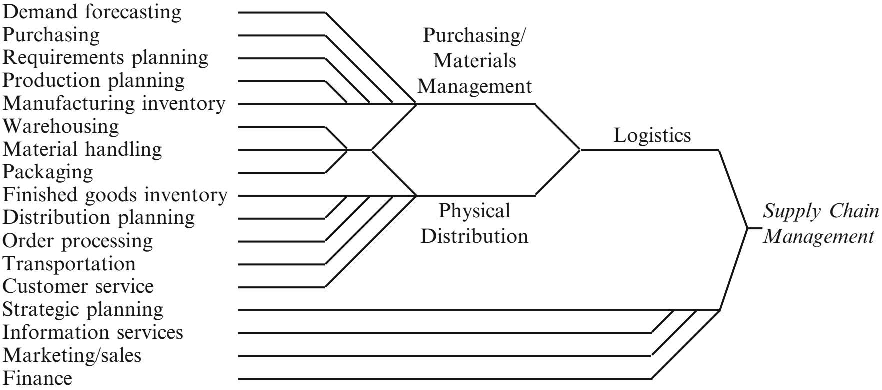

Fig. 2.1 Evolution of supply chain management (Ballou 2007)

While Simons et al. (2004) argue that even though transportation could, by means of the activity definitions, be classified as waste, it is indeed a value adding activity. The whole supply chain should be viewed as one common value adding stream. Transportation should therefore not be viewed in an isolated fashion but as part of a greater picture (Simons et al. 2004).

Efficient transportation is therefore important at an economic, social and environmental level as well as for company profitability (Crainic 2003). As Stank and Goldsby (2000) put it, "benefits accruing from world class operations at the points of supply, production, and customer locations are pointless without the accompaniment of excellent transportation planning and execution."

2.1.2 Categorization of Transportation Services and Transportation Markets

The choice of the "right" type of transportation service is the key decision with regard to transportation planning and network design. Due to the presence of highly standardized transportation services they can be categorized according to three dimensions as depicted in Fig. 2.2; namely, load sizes, transportation distance and transportation speed.

With regard to the first dimension, Fleischmann (2008a) states that the "appropriate structure of a transport system mainly depends on the size of the single shipments." Standardized shipment sizes start with letter and parcel consignments. They are usually covered by so-called CEP (courier, express, parcel) service providers that often evolved from postal service providers (Carbone and Stone 2005). Large global players in this section are DHL (Deutsche Post), UPS or FedEx. The big providers will cover almost any distance using different transportation modes and offering different service levels (transportation speeds). They usually rely on their own network of hubs and large fleets of transportation vehicles, including standard trucks, delivery trucks and airplanes. Due to the high investment

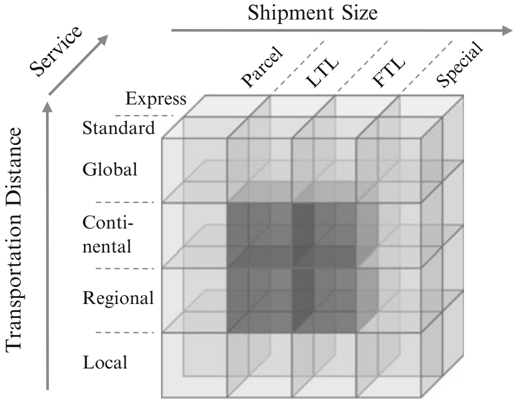

Fig. 2.2 Structure of transportation services

into network infrastructure and fleet, the companies dominating the CEP market are usually of considerable size with a global annual turnover exceeding EUR20 billion (Klaus et al. 2009). This also constitutes a serious barrier for market entries resulting in competition only among the big players. Remote markets are often served in collaboration with partner organizations (Carbone and Stone 2005). Shipment sizes of up to a few hundred kilograms may be shipped economically using CEP providers (Arcelus and Rowcroft 1993).

Larger shipment sizes that will not completely fill a truck or sea container are usually served by specialized logistics service providers. For truck transportation, these are usually referred to as LTL carriers, such as Schenker, Danzas, Ryder. The equivalent for sea transportation is sometimes referred to as LCL (less than container load) carriers. These service providers are specialized in consolidating shipments from different shippers within their own network structure consisting of a number of hub locations as well as their own fleet of vehicles. However, in comparison to CEP providers, these networks are nowhere near as tight and often the area served by a single company is considerably smaller. Therefore, collaboration among several carriers is even more common as is forwarding of transportation orders to partner carriers or subcontractors (Rieck 2009; Krajewska and Kopfer 2006). Since carriers are by far smaller, super regionally operating ones feature an annual turnover of between EUR1 and 10 billion annually and competition is usually much stronger (Klaus et al. 2009).

When shipment sizes get large enough so that a whole truck or container can efficiently be deployed to serve the complete shipment, the mode is often referred to as FTL (full truckload) in case of truck transportation or FCL (full container load) in the case of containerized sea transportation. Apart from the vehicles, no further equipment is necessary to serve these shipments; therefore, the number of competing carriers is very large compared to the market for smaller load sizes. Operations are usually performed on a door-to-door basis; that is, the truck goes directly from the dispatching location to the receiving location and the load is not handled at intermediate locations. This usually results in shorter transportation times for FTL shipments in comparison to LTL shipments (Crainic 2000). In the FTL market segment, collaboration is also very common and small carriers are regularly contracted by larger service providers to fulfill their transportation orders (Rieck 2009; Krajewska and Kopfer 2006).

Load sizes that exceed truck and container capacity are referred to as special loads. For these large load sizes, a differentiation between bulk cargo (for example, crops and liquids such as oil or chemicals) and piece cargo needs to take place. Bulk cargo could easily be split into multiple smaller loads; however, the transportation of large amounts within a single shipment is more efficient. Piece cargo, in contrast, cannot be split into smaller loads; it is therefore necessary to ship it as a whole. Carriers fulfill these transportation demands often using specialized equipment and the market is clustered according to different commodities.

While load sizes have so far been referred to in a very abstract way, it should be clear that they may be measured in many different dimensions. The classical dimensions are weight and volume. An additional factor usually influencing vehicle utilization is the stackability of the transported goods (super-stackable, under-stackable).

Transportation distance is the second dimension under which transportation services may be categorized. For very small distances on a local and regional level, carriers may deploy drivers and equipment that are permanently located within the region. Often they are assigned to a depot location from where operations start and end. Therefore this market is dominated in every region by a number of local carriers. The most commonly used transportation mode for covering local and regional distances is the road. For longer distances truck transportation increasingly competes with rail transportation. However, even for distances covering several hundred kilometers, the truck is still the most commonly used means of transportation. The majority of overseas volume is transported by ship.

As for transportation speed, usually referred to as the service level, it is often roughly differentiated into standard delivery and express delivery. Express services may be offered using different transportation modes (e.g., air instead of sea) or using different equipment (e.g., using a small truck instead of a 40-ton truck).

The three dimensions are by no means independent of one another, as a parcel delivery in the U.S. may illustrate: While FedEx primarily concentrates on express shipments relying heavily on air transportation, UPS uses a combination of road and air transportation to offer slower, yet cheaper services to the customers. While the FedEx pricing system will charge packages mainly on size (weight and dimensions), UPS also has a stronger distance component (Chopra and Meindl 2007).

The described categorization of transportation services is sometimes extended toward the integration of transportation modes. Chopra and Meindl (2007) differentiate among air, parcel carriers, truck, rail, water, pipeline and intermodal. Considering that the above mentioned three dimensions usually determine the mode choice, a further dimension is of no additional value. Furthermore, the differentiation is by no means exclusive: for example, parcel carriers may use trucks in order to transport the shipments between origin and destination. The mentioned segmentation according to transportation mode is therefore well suited to outline different transportation markets that usually feature different service providers.

The multitude of different services clustered in different service segments makes transportation mode choice a key component in transportation planning (Vannieuwenhuyse et al. 2003). For a detailed analysis regarding the different transportation modes the works of Sahin et al. (2009) and Vannieuwenhuyse et al. (2003) provide a thorough insight into mode choice criteria. The relevant transportation service segments with regard to this research are highlighted in the center of Fig. 2.2.

2.1.3 Outsourcing of Logistics Services

Transportation and storage, as mentioned before, are often regarded as a non-value creating process and therefore may be considered as waste (Simons et al. 2004).

Therefore many industrial corporations have attempted to shift these processes out of their core focus business areas. In fact, in the last several years, logistics has experienced an unmatched trend toward outsourcing (Selviaridis and Spring 2007; KPMG 2000; Langley et al. 2007). Some of the reasons, including the terms and conditions, coverage and trends of outsourcing of logistics in general and of transportation services in particular, will be described in the next few paragraphs.

The reasons for outsourcing logistics services are manifold and often it is a combination of different reasons that drive outsourcing decisions. In general, every outsourcing decision is a make-or-buy decision in favor of the buy side (Baker and Hubbard 2003). In order to better understand outsourcing decisions for logistics services, the reasons for outsourcing are categorized according to their impact horizon—strategic, tactical and operational. Strategic reasons for outsourcing include the following:

- Concentration on core competences (KPMG 2000; Wilding and Juriado 2004),
- Lack of internal know-how (Selviaridis and Spring 2007),
- Lack of willingness to invest and build up one's own assets (Thonemann et al. 2005), and
- Higher asset utilization due to shared assets (Baker and Hubbard 2003).

Tactical reasons that drive an outsourcing decision are usually of mid-term impact and often include the following:

- Lack of one's own resources; that is, over-proportional growth in past years (Selviaridis and Spring 2007),
- Increasing flexibility during transition periods or for future growth (KPMG 2000; Sheffi 1990; Wilding and Juriado 2004), and
- Short-term access to a better infrastructure (Thonemann et al. 2005).

As for operational reasons in favor of an outsourcing decision, the following are usually mentioned:

- Higher operational efficiency due to better resource utilization (Fleischmann 2008a),
- Better operational service (KPMG 2000), and
- Lower costs of operations due to more competitive cost structures, especially for personnel with low qualification profile (Engardio et al. 2006).

Economic issues are usually stressed when specifying the outsourcing decisions of physical transportation services. Outsourcing transportation to a service provider is considered to be very beneficial in the case of a shipment structure consisting of many small orders, since these shipments can be combined with shipments from many other senders (Fleischmann 2008a). Outsourcing of transportation services seems beneficial also for unidirectional traffic. Using a dedicated fleet for these services would result in poor overall utilization, since one trip would take place with empty equipment. However, outsourcing these trips to an independent transportation service provider may open up the opportunity to combine these trips with transports from different demanders (Baker and Hubbard 2003).

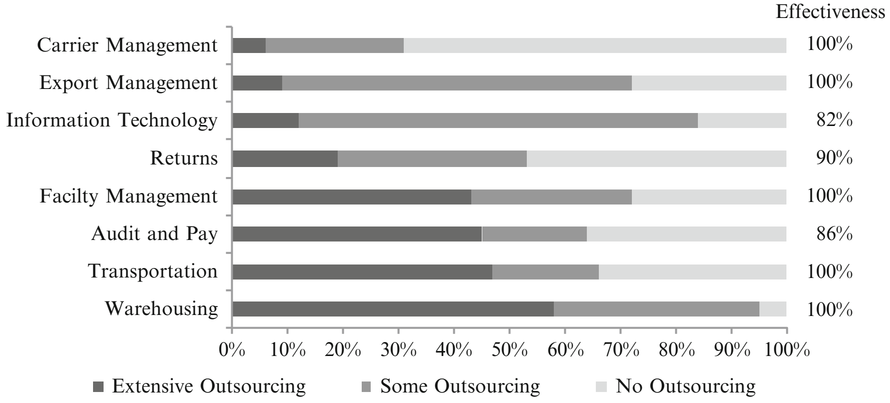

Fig. 2.3 Outsourcing trends and effectiveness in CGI (Grocery Manufacturers Association 2008b)

In general, any logistics process may be subject to outsourcing, but it is by no means limited to logistics. However, in common practice, some processes have been subject to more intensive outsourcing than others. As early as 1990, Sheffi states that transportation and warehousing, the two key logistics processes, are subject to considerable outsourcing activities. And the broad continuation of this trend has not excluded the consumer goods supply chain, as shown in Fig. 2.3. The depicted analysis is based on consumer goods manufacturing companies as well as retailers. For the consumer goods industry alone, outsourcing shares for physical transportation are reported to be considerably higher (Langley et al. 2007). Outsourcing of the two physical processes – transportation and warehousing – not only enjoy great popularity but are also characterized by high effectiveness. With regard to logistics processes, however, it is the physical tasks that are more likely to be subject to outsourcing than the administrative ones. While transportation itself is largely outsourced, carrier management is seldom handed over to outside companies (Wilding and Juriado 2004).

The trend toward the outsourcing of logistics services is still very strong. However, since a large share of logistics activities is outsourced by now, growth rates for operational processes are diminishing (Langley et al. 2007). However, outsourcing of logistics services that exceed the boundaries of the merely physical operation is gaining significance. KPMG (2000) distinguishes the status quo as well as the trend with regard to outsourcing within the three levels of operational, tactical and strategic processes:

- *Operational:* Transportation 85%; Warehousing 50%; Trend: Growing, but not at high speed.
- *Tactical:* 20–25%; Trend: Toward mode selection, inventory management, freight payment. Growth up to 50% until 2005.
- *Strategic:* 5–18%; Trend: Virtual warehousing, inventory ownership, network optimization.

Generally, a transportation process involves two key players: the sender and the receiver and either may be responsible for transportation. The contracts that determine the terms and conditions for the traded goods usually contain clauses regarding responsibility for transportation. *Incoterms*, or international commerce terms, are the standardized and internationally common terms used in these transactions. They not only specify transportation cost responsibility but also transportation risk responsibility and responsibility to cover customs and duties. There are contractual settings that specify the selling side in charge of these actions (free incoterms: for example, delivered duty paid, DDP, or delivered duty unpaid, DDU), and there are incoterms that specify the responsibility at the buying side (not free incoterms: for example, free carrier, FCA, or ex works, EXW). The responsible party for transportation along a particular segment of the journey will subsequently be referred to as the *shipper* (Chopra and Meindl 2007) throughout the rest of this research.

After the first two parties have been introduced — the sending or usually selling party and the receiving or usually buying party, the transportation may very well be carried out by none of these parties but by a *carrier*, an independent transportation service provider. They are often referred to as a *third party logistics [service provider]* — the 3PL (Wilding and Juriado 2004) or just *logistics service provider* — LSP (Selviaridis and Spring 2007). These terms will be used as synonyms throughout this text and although they are usually associated with the offering of multiple services rather than being limited to transportation, the latter will be the service of most relevance within this context. However, the terms 3PL and LSP do not only refer to transportation service providers but to logistics service providers in general.

The increase in outsourcing activities on a tactical and strategic level has led to the development of an additional type of logistics service providers referred to as the fourth party logistics service provider, in short 4PL (KPMG 2000; Skjøtt-Larsen 2000). Due to a high number of 3PLs operating in large transportation networks, the 4PL or LLP (lead logistics provider) has been devised as the additional, independent instance with the task of controlling the deployment of 3PL services (Schmitt 2006). Even though this concept was introduced in 1996, the practical application of these concepts is not prevailing, nor has it in many cases left the status of an implementation pilot (Selviaridis and Spring 2007). In the progress of this work, referring to outsourcing of transportation will relate to the outsourcing of transportation operations. Tactical or strategic processes are not assumed to be outsourced but are covered in-house. For most of the administrative activities it is of no relevance for the processes, tasks and decisions whether they are covered in-house or from an external player. For the physical processes of transportation, however, there are some differences that are discussed in the following paragraphs.

2.1.4 Introduction to Transportation Planning in a Supply Chain Planning Context

Transportation planning must in general be put into the context of general supply chain planning and logistics planning. As pointed out in Sect. 2.1.1 the interdependence of numerous processes and process steps has helped with the acceptance of the supply chain management concept. In an advanced planning systems (APS) context, transportation planning is linked to other planning tasks in the supply chain context; namely, to strategic network design, master planning, demand planning and production scheduling (Fleischmann 2008a).

Industrial supply chain planning generally deals with decisions on how to deploy a company's assets and resources in order to source, convert and distribute its products and services. The high complexity of the planning task is reduced by splitting the planning process into different sections according to the temporal planning impact (i.e., long-term planning vs. short-term planning). Such a differentiation is shown in Fig. 2.4. In addition to a temporal fragmentation, segmentation according to the planning object is very common.

Another important strategic issue is the make-or-buy decision with specific regard to logistics services already mentioned in Sect. 2.1.3. When making

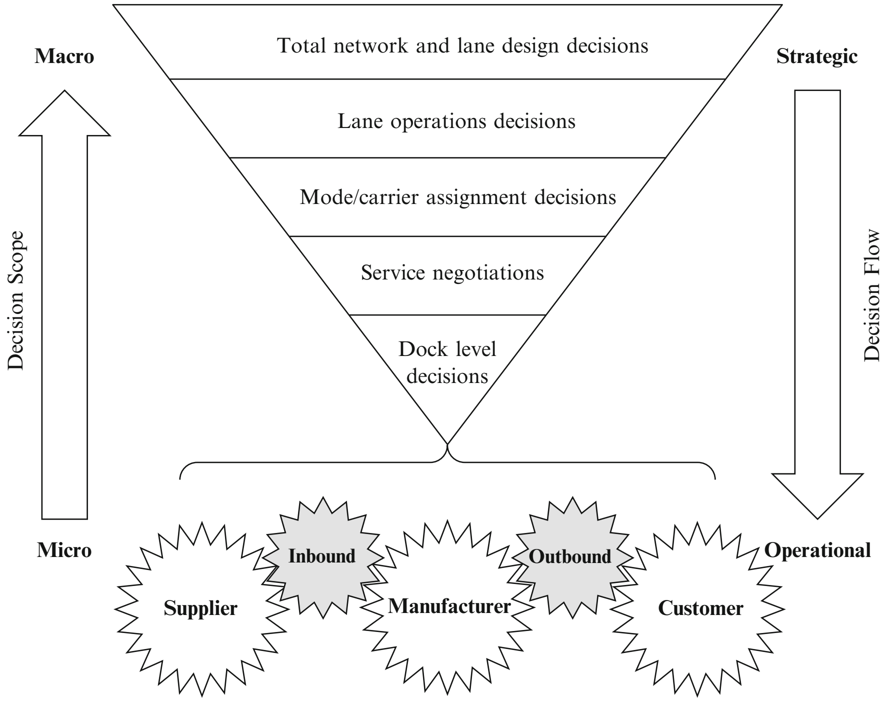

Fig. 2.4 Transportation decision making in an integrated supply chain (Stank and Goldsby 2000)

transportation decisions, a distinction must be made as to whether they are taken from a shipper's point of view with transportation being outsourced, or from a fleet provider's or carrier's perspective:

- The carrier as a fleet operator makes long-term investment decisions toward vehicles and operating decisions promising the maximum return on these assets (Chopra and Meindl 2007).
- The shipper will try to minimize total costs (transportation, inventory, information and facility) at the appropriate service level (Chopra and Meindl 2007).

Fleischmann (2008a) puts the essence of transportation planning for outsourcing transportation in an APS environment as follows:

> An LSP may consolidate the transport flows of several shippers, operating in separate supply chains, in his own network. Then he is responsible for planning how the transports are executed, i.e., by which vehicles along which routes. However, the decisions on the transport orders, i.e. the quantity, source and destination of every shipment, remain a task of the APS of the shipper. Usually, it is not practicable to include the flows of all other shippers of an LSP into the APS. However, the additional flows have an impact on the transport costs and should be taken into account implicitly by appropriate cost functions.

Within the shorter planning horizons of tactical and operational transportation planning, complexity with regard to the interdependence of many different parties is largely reduced. Therefore, the integrative perspective of supply chain management falls behind and operational problems dominate the real life planning environments (Mayer 2007). These vary largely in different supply chain segments and business sectors. With regard to the consumer goods supply chain the different operational problems are subject to a more detailed analysis in Sect. 2.2.4.

The combinations of relevant network arcs and nodes are often regarded as network processes and are referred to — depending on the perspective — as supply or distribution processes. Since these processes are usually installed for a long-term period, the planning task must be regarded as a strategic one. Different processes may be applied within the same network structure. This is best described by a simple example from the consumer goods industry. A product is distributed from a plant to many customers via a distribution center, where the product is stored. One of those customers requires special packaging. Packing may in one process alternative take place at the plant, directly after production. In another process alternative the product is re-packed at the distribution center just before dispatching the ordered quantities to the according customer. The described process alternatives are based on the same network architecture. The procedure for network process planning is characterized by a two-stage procedure. First, it must be decided which processes are generally admitted within the network. In the second stage, the products and material flows are assigned to these processes. The data required for decisions in the first stage is usually highly aggregated (e.g., product groups and time) while the data used in the second stage is often more detailed concerning the product information. Some well-established network processes are just-in-time (JIT) and just-in-sequence (JIS) concepts (Grocery Manufacturers Association and Booz Allen Hamilton 2006). Network process planning is of high relevance for total landed cost or factory gate pricing concepts (Garnett 2003; McKinnon and Ge 2006). These have gained increasing popularity over the past few years, usually driven by integrated purchasing and logistics organizations for inbound material flows (Ghodsypour and O'Brien 2001).

The term supply chain planning integrates many different, yet interdependent planning tasks with a large impact on transportation processes within a supply chain. However, their degree of interdependence relates to the characteristics of the actual planning problem. A more detailed view on the consumer goods' specific planning problems is therefore provided in Sect. 2.2.3. Transportation planning in practice largely depends on the availability of information. In the past, this has been the key obstacle to achieving high quality transportation planning (Stank and Goldsby 2000). In particular when transportation is outsourced and planning responsibilities are shared among different organizational units, information availability is usually poor.

2.2 Consumer Goods

Defining the term *consumer goods*, the Industrial Marketing Committee Review Board determines that they are "goods destined for use by the individual ultimate consumer and in such form that they can be used by him without further commercial processing [. . .]" (Industrial Marketing Committee Review Board 1954). In order to receive a wider definition a market perspective on consumer goods is taken. Webster (1978) differentiates marketing activities in consumer goods from those of industrial goods in four dimensions:

- *Functional Interdependence:* On consumer goods markets, marketing is neither as integrated nor as dependent on other business functions as industrial goods.
- *Product Complexity:* On consumer goods markets, products are usually less complex than on industrial goods markets.
- *Buyer-Seller Interdependence:* This dimension can be observed in substantial negotiation processes on industrial goods markets.
- *Buying Process Complexity:* In consumer goods markets, buying decisions are usually analyzed in terms of different types; for example, routine purchase. In contrast, industrial goods buying decisions are taken against a complex organizational background.

Although this differentiation seems straightforward, Fern and Brown (1984) give some counterexamples. This becomes evident when considering that the consumer goods industry will supply retail organizations who are selling the goods to the final customer. In this case, the relationship between the consumer goods industry and the retailers will in many cases resemble the relationships in industrial goods markets. Furthermore, any services offered by a consumer goods manufacturer for the retail organizations (shelf-ready packaging, transportation etc.) are surely to be defined as industrial services. In the context of this research, the term “consumer goods” is therefore also tackled from the sales side. From a product perspective, consumer goods in this study are mainly contained in UNSPSC Segments 49 (food, beverage and tobacco products) and partly 53 (home and personal care) (United Nations Development Programme 2001). They can be characterized by the following:

- Low degree of product differentiation (Meyr and Stadtler 2008),
- High availability requirements (Mars 2008),
- Expected long product lifecycles (Meyr and Stadtler 2008),
- Physical existence (Industrial Marketing Committee Review Board 1954),
- Retail traded (Meyr and Stadtler 2008).

In accordance to Großpietsch (2003), this text concentrates on product categories with a high turn rate — so called *fast moving consumer goods*. They are often abbreviated as FMCG.

2.2.1 Profile of the Consumer Goods Supply Chain

Consumer goods are not only a major part of the world’s economy, with an annual retail volume of US$11,480 billion. Food, beverages and tobacco also account for 17% of total consumer expenditure worldwide (The Economist Intelligence Unit 2005). Thonemann et al. (2005) assess the relevant consumer goods retail volume — supermarkets, department stores, discounters and drugstores — in Europe at EUR1,100 billion for 2004. In Germany the food processing industry turns over approximately EUR100 billion, of which approximately 50% is generated by fresh food (Lütke Entrup 2005). The food market in Britain has a total volume of GBP103.8 billion (Garnett 2003).

The biggest market for consumer goods is the United States with US$4,310 billion followed by Western Europe (US$2,380 billion) and Japan (US$1,240 billion). Overall growth in this sector has been a steady 3–4% p.a. over the past years with the strongest growth rates observed in Eastern Europe, Asia, the Middle East and Africa (The Economist Intelligence Unit 2005). The largest corporations in the consumer goods industry are listed in Table 1.1.

Apart from the high trade volume that consumer goods markets steadily generate, there is also high demand volatility. On the one hand, this volatility is consumer induced, due to seasonal consumption behavior of many food products (e.g., ice cream in warm seasons). On the other hand, the behavior is also induced by industry and retail. A high number of promotions (Michael et al. 2002) together with pricing incentives often lead to sales peaks reaching a multiple of regular sales, as shown in Fig. 2.5. The management of these peaks imposes a great challenge on the entire supply chain.

The consumer goods market can be divided into two sections along the consumer goods supply chain (Großpietsch 2003). In the first section consumer goods are produced. Further upstream the supply chain markets are referred to as raw

Table 1.1 Top ten consumer goods manufacturers according to definition (Deloitte 2009)

Company	FY 07 net sales (mn. US$)	Country	Sector
Nestle S.A.	89,724	CH	Food, drink, tobacco
The Procter & Gamble Company	83,503	US	Personal and household
Altria Group, Inc.	73,801	US	Food, drink, tobacco
Japan Tobacco Inc.	56,277	JP	Food, drink, tobacco
Unilever	55,086	UK	Personal and household
PepsiCo, Inc.	39,474	US	Food, drink, tobacco
Kraft Foods, Inc.	37,241	US	Food, drink, tobacco
The Coca-Cola Company	28,857	US	Food, drink, tobacco
Tyson Foods, Inc.	26,900	US	Food, drink, tobacco
Imperial Tobacco Group PLC	24,308	UK	Food, drink, tobacco

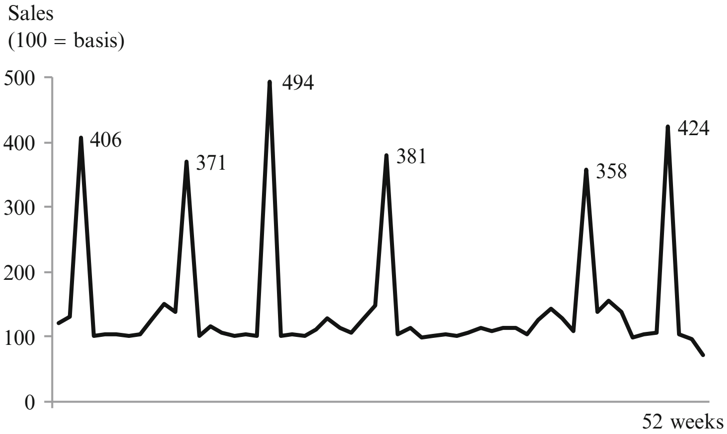

Fig. 2.5 Demand volatility (Großpietsch 2003)

material markets. The goods traded in these markets do not meet all of the above mentioned requirements of consumer goods. After the production stage the goods are moved toward the customer and the influence of retail organizations. This is considered the second stage of the consumer goods supply chain. In most consumer goods markets, the industry and retail tasks are taken on by different, legally independent organizations. The greater focus of the following work is dedicated toward supply chain processes in general and transportation processes in particular in the sphere of the consumer goods industry. It is important to distinguish between an industry and a retail section of the consumer goods supply chain since their key players usually feature different legal entities. However, the two sections can face common challenges, such as demand volatility. Yet in contrast to the retail markets that are characterized by high concentration (Ernst and Young 2007; Michael et al. 2002; Caputo and Mininno 1998), the consumer goods markets appear less concentrated at first. Still, when considering certain commodities, such as coffee, a substantially higher degree of concentration can be observed for the consumer

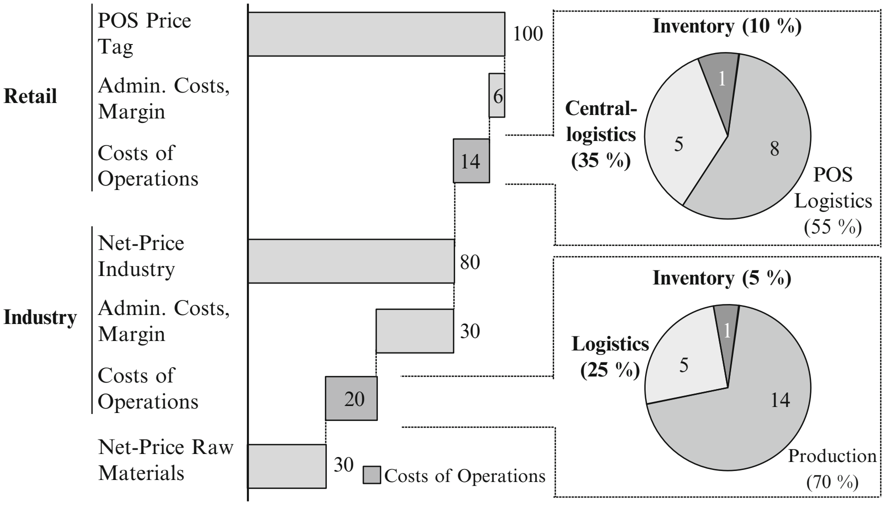

Fig. 2.6 Cost structure in consumer goods (Thonemann et al. 2004)

industry as well (Cap Gemini Ernst and Young 2002; Lütke Entrup 2005). With regard to value creation, the consumer goods industry has the largest share along the consumer goods supply chain. As shown in Fig. 2.6, half of the value of a product is generated within the industry section of the supply chain.

According to Thonemann et al. (2004), raw materials account for approximately 30% of the total sales price of consumer goods. Since raw materials are highly standardized goods, they are subject to just as standardized trading processes. On international commodity exchanges, goods as well as derivatives are traded to guarantee the long-term demand and supply of raw materials. Since many raw materials are subject to seasonal availability variation, raw material storage is very common and often requires a large raw material inventory to be stocked over considerable time (Caputo and Mininno 1998).

Production costs account for approximately 14% of the total sales price of a consumer good (see Fig. 2.6). In contrast to the production of many industrial goods, consumer goods production is hardly continuous but more often batch-oriented, similar to production processes in the chemical industry (Meyr and Stadtler 2008). It is often associated with the term *Make-and-Pack* Production (Neuhaus et al. 2003; Méndez and Cerdá 2002). Batch production is characterized by non-continuous material flows into a production system (usually at the beginning of a production batch, all required material must be ready in full quantity), and also non-continuous completion (again, usually when a batch is ready, the complete production amount is ready at once or within very short time). As a result, consumer goods production systems are very push-oriented requiring high inventory levels (Fleischmann 2008a). The processing of food products as well as products of personal and home care usually prompts sequence dependent setup operations (Meyr and Stadtler 2008; Lütke Entrup 2005) making production planning tasks very complex. In addition, high quality requirements make continuous quality monitoring along with frequent quality checks and quality gateway processes a core component of every production system.

Since a full demand synchronization of production is by no means possible and sensible, finished goods are usually stored after leaving production. However, the storage does not necessarily take place on the production site but may be shifted toward the distribution center (Fleischmann 2008a). The goods are usually transferred from there to the retailers and, depending on the distribution structure, may again be stored or directly shipped on to the stores.

2.2.2 Logistics Responsibilities, Costs and Performance along the Consumer Goods Supply Chain

In Fig. 2.7, the three-stage distribution process of consumer goods is shown (Meyr and Stadtler 2008). Within consumer goods distribution, warehouses and distribution centers (DC) serve as decoupling points between demand and supply (Meyr and Stadtler 2008). The distribution structure of the consumer goods industry is usually regionally determined. The warehouses feature the complete assortment of the manufacturer and allow a short reaction time toward retail customers (Caputo and Mininno 1998).

The retail distribution structure also has a strong regional component featuring central and regional DCs. However, along the two-stage distribution, the stocked

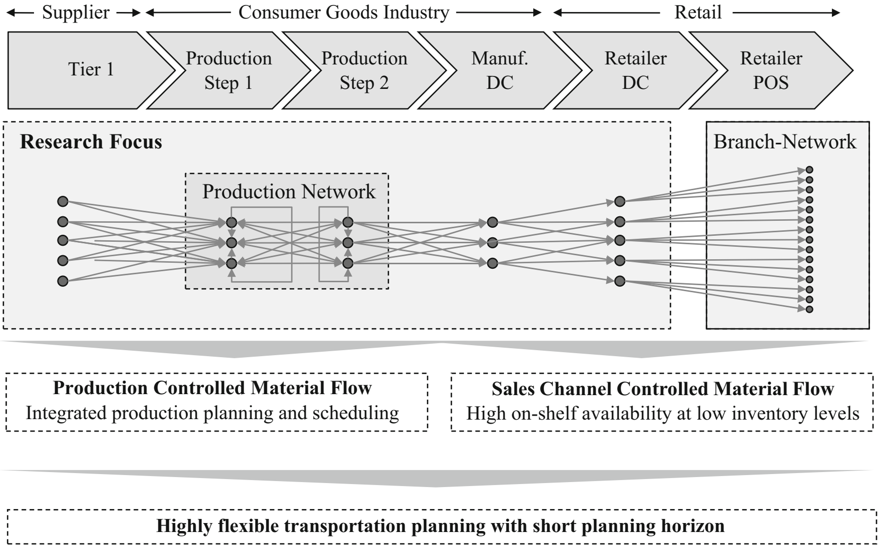

Fig. 2.7 The consumer goods supply chain

assortment may vary. Slow-moving products may be stored within a central warehouse while faster moving articles are typically stored within regional distribution centers (Thonemann et al. 2005). The slow movers are usually picked to order within the central DC and moved via the regional DCs into the retail markets. This way, safety stock levels for slow-moving goods may be lower since the stock is centralized.

All consumer goods supply chain processes aim at delivering the goods to the shelf, so the consumer can purchase them. Therefore on-shelf availability is a key aspect when assessing supply chain performance. Thonemann et al. (2005) show that on-shelf availability varies between 90% and 99% and in the event of unavailability of a product, the consumer will in 50% of the cases try and purchase the article at another retailer or not buy the article at all. Further upstream the supply chain, the average service level supplying the retail organization is therefore usually very high, reaching 97.5% for Germany, and the delivery time amounts to an average of 3.5 days (Thonemann et al. 2004). The finished goods inventory range in retail warehouses averages 30.6 days for German retail (Thonemann et al. 2004). This KPI overview already suggests the high relevance of logistics performance supplying the retail organizations.

Figure 2.7 demonstrates the numerous locations and transportation relations utilized in the sourcing, production and distribution processes of consumer goods. Even though it is the driving force behind the supply chain, the consumer purchase is possible only at the very right in Fig. 2.7, while the inventory levels are distributed across the different stages in order to attain the required service level. Since order cycles between the retail and the manufacturer DCs are relatively short, the retailer DCs do not contribute toward the supply chain's safety stock significantly but rather serve to consolidate and buffer the requirements of the assigned single retail points. Some retail processes (e.g., cross-docking) use this stage as an inventory-free handling location (Thonemann et al. 2005). The largest share of the finished goods safety stock is therefore concentrated at the manufacturer's central warehouses. The operation of the warehouses and distribution centers is also usually outsourced to specialized service providers (Michael et al. 2002).

The determination of the optimal number and locations of central warehouses is a problem typical of strategic network design. On the one hand, many central warehouses reduce transportation time and distance to the customers while on the other hand fewer warehouses result in better inventory concentration and lower inventory levels. The challenges of inventory management are especially obvious for fresh food with short shelf life. These products require frequent transportation in order to keep shelf life balanced throughout the network. This in turn is necessary in order to obtain a high availability while at the same time reducing the risk of obsolescence due to expired shelf life (Silver 1989; Nahmias 1982).

Due to trade promotions or seasonal specials, the products are often repacked into special displays (often also limited to a certain distribution channel) (Mars 2008). This task is usually outsourced either to the warehousing service providers (on-site) or to specialized, so-called "co-packers" off-site. After re-packing, the goods are stocked back in the distribution center ready to be forwarded into the retail channels. Although it may seem disadvantageous to pack the goods several times, the process will help to minimize overall inventory levels. And since forecasts, especially those for sales promotions, are highly error-prone, availability is best maintained if the product is stored in its standard packaging and proliferation takes place as late as possible (Großpietsch 2003). Transportation in this case is usually performed by service providers as well. Due to an increasing number of trade promotions, consumer goods manufacturers are facing an increasing share of transportation at this section of the network (Mars 2008).

Further up the consumer goods supply chain, hardly any finished goods inventory is stored. Since the production facilities have undergone a strong concentration process in the past years, all inventory is bound to leave the plant after quality clearance. In many locations, buffer space is limited to an extent that makes pickup scheduling crucial for seamless production operation.

High logistics cost and performance awareness are typical of the consumer goods supply chain (Grocery Manufacturers Association 2008b). In Germany, logistics costs account for approximately 5.0% of a retailer's turnover (Thonemann et al. 2004). The highest share of logistics costs for consumer manufacturers is caused by transportation (see Fig. 2.8) and this share is expected to further increase in the future (Thonemann et al. 2005). They amount to approximately two-thirds of the total logistics costs and are split between intra-company transportation and outbound customer transportation. A quarter of logistics costs are caused by warehousing activities in the distribution centers and the rest is similarly distributed between packaging (especially co-packing, see above) and overhead costs.

And while supply chain responsibility is split between retail and consumer goods manufacturers, additional parties are involved when it comes to fulfill customer demand. Apart from raw material and packaging suppliers, the production process is by no means solely in the hands of a consumer goods manufacturer — defined here as the brand owner (Großpietsch 2003). Today, a considerable share of production is outsourced to so-called co-manufacturers (Ferrer and Karlberg 2006). They are independent producers of consumer goods and do not appear as producers in the perception of consumers and may not have their own brand but solely produce on

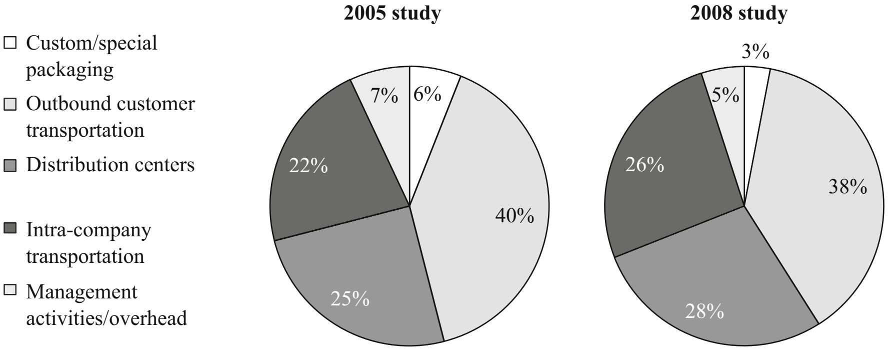

Fig. 2.8 Logistics costs in consumer goods (Grocery Manufacturers Association 2008b)

the account of the consumer goods industry owning the brands (Cap Gemini Ernst and Young 2002).

Transportation from the manufacturer DC to the retailer DC or cross dock is usually organized by the consumer goods manufacturer (see Fig. 2.9). However, the trend toward a stronger supply chain control by the retailers has been identified by Thonemann et al. (2004) and Mars Deutschland (Mars 2008). Transportation responsibility to the stores is mostly in the hands of the retailers. Compared to the consumer goods manufacturers' facilities, the operations of the retail DCs and cross docks are not subject to such strong outsourcing activities as they are often still operated by the retailers themselves (Cap Gemini Ernst and Young 2002; Michael et al. 2002; Wilding and Juriado 2004). In addition, the vehicle fleets used to distribute the goods to the stores are very often, at least partly, retailer operated.

Much integration effort has been put into the harmonization of information and material flow between consumer goods manufacturers and retailers. Collaborative planning, forecasting and replenishment (CPFR) is one initiative to standardize the cross-organizational interfaces and to streamline the order-to delivery process on a shared information basis (Großpietsch 2003; Esper and Williams 2003). However, the high expectations have not been met and in many cases the practical implementations have not exceeded piloting stages (Thonemann et al. 2005). Efficient consumer response (ECR) is another initiative to implement standardized processes; for example, for continuous replenishment and vendor managed inventory (VMI) (Meyr and Stadtler 2008). Thonemann et al. (2005) explicitly mention

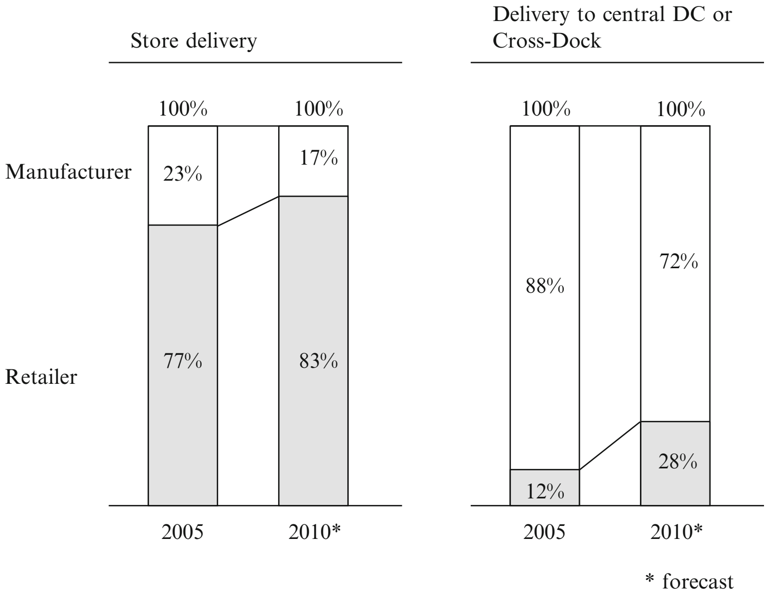

Fig. 2.9 Transportation responsibility along the consumer goods supply chain (Thonemann et al. 2005)

the limited success of these initiatives and provide some reasons for their lack of acceptance. They furthermore show some promising examples for successful collaboration between manufacturers and retail; among them the concept of shelf ready packaging. This is provided by the consumer goods manufacturers (at a possibly higher price than ordinary packaging) and is designed to ease on-shelf presentation in the stores, thereby reducing in-store handling and waste at the advantage of the retail organization.

2.2.3 Supply Chain Planning Processes in Consumer Goods Supply Chains

The supply chain planning processes encompass the planning cycle of general APS planning task from strategic network design, demand planning, supply network planning, production planning, procurement to transportation planning (Günther 2005). However, with respect to the work share between retail and manufacturers, the retailers usually do not have to plan any production activities, yet they still need to manage their resources in the distribution centers and in the stores to guarantee an efficient material flow and high on-shelf availability.

Strategic Network Design

As already stated above, the strategic planning horizon usually covers several years and involves investments of considerable volume (Chopra and Meindl 2007). In the retail sections of consumer goods supply chains, decisions are mostly based on a number of given and known markets. The planning tasks usually focus on the processes that are employed to supply the markets. This includes the number and location of retail distribution centers as well as the employment of inventory-free supply processes such as cross-docking (Thonemann et al. 2005). Another question of strategic relevance is tackled with the assignment of assortment types to physical warehousing locations. Specific assortment requirements, especially refrigeration at different temperature levels, may result in major investment. As a result, only some of the regional distribution centers may be capable of handling frozen goods. Strategic network planning tasks in retail will furthermore include the opening and closure of warehousing locations in changing market environments (e.g., frequent openings of new warehouses by discount channel retailers during the expansion).

The warehousing location decision is usually of secondary importance for consumer goods manufacturers. The central DC policy makes sure that the number of DCs required is generally only determined by long-term factors such as infrastructure and demographic development. Yet, since brands and product lines are subject to be traded between the global players in the consumer goods industry, their integration into existing networks regularly imposes a serious challenge for supply chain executives (Ballou 2001). More frequently, the planning involving the production locations is subject to decision within a strategic network scope. The past few years have shown a greater concentration of production volume in a few facilities serving several national markets (Meyr and Stadtler 2008). Economies of scale in production and coalescing markets (EU, NAFTA) have favored this development. The decision regarding the locations where a product is made not only influences the necessary investment into production technology at the relevant locations, it also influences the transportation and warehousing effort for the temporal range of the decision (Meyr and Stadtler 2008).

Demand Planning

The result of demand planning is usually a volume forecast and the process rarely results in directly recommended actions. It is designed to supply input data for several other planning processes, especially replenishment and replenishment planning. Still, the importance of demand planning cannot be underestimated. Since it delivers input values for successive planning stages, the quality of all results largely depends on the quality of demand planning (Thonemann et al. 2004). Research on the accuracy of demand forecasts varies widely. While the Grocery Manufacturers Association (2008b) state an average mean absolute percentage error (MAPE) of 31% for a month's planning horizon and 45% for a week's planning horizon, Thonemann et al. (2004) show that better results are possible.

Replenishment Planning

Data from demand planning is required to initialize the replenishment planning process. Results of this process are replenishment strategies (Gudehus 2006). In addition, replenishment frequencies and rhythms are specified. The process therefore determines the inventory and the service level within the network and may differ between the retail section and the manufacturing section of the supply chain. The Grocery Manufacturers Association (2008b) mention an average inventory range of 45 days for U.S. consumer goods manufacturers while Thonemann et al. (2004) indicate a value of 30.6 days for central European manufacturers; for the latter region this results in a 97.5% service level with a delivery time averaging 3.5 days.

Distribution Planning

Distribution planning combines the results of network planning and replenishment planning (Thonemann et al. 2005). Within distribution process design, different order types are determined (e.g., stock order, rush order) that may be employed by the replenishment process. In addition, parameters determining the source of supply are applied using numerous and often complex sets of rules. Order size, replenishment lead time, demand forecasts, safety stock and inventory levels determine from which DC an order is completely or partially fulfilled.

Production Planning

Production planning is one of the key planning processes that are currently receiving wide attention in academic literature as well as in practice. The recent development to concentrate production capacities of one product for large markets within one facility has increased efficiency expectations from the conversion process. Furthermore, consumer goods often face a multi-stage production process, which can be characterized as make-and-pack production process, combining batch production and continuous production (Fündeling and Trautmann 2005). In addition, the high quality requirements of consumer goods will impose considerable set-up and cleaning operations reducing the effective production time—very often with sequence dependent set-up times (Günther and Tempelmeier 2009). As a result, lot-sizing and sequencing decisions have to be made simultaneously (Meyr 1999). A great deal of research has been published in past years tackling the specific requirements in the consumer goods industry. For a general overview, see Fündeling and Trautmann (2005). For fresh food specific production plans regarding shelf life, Lütke Entrup et al. (2005) have provided a set of models worth considering. Very promising results have been achieved in this area using "natural sequences" in color or taste (bright → dark; mild → strong) forming a production block (Günther et al. 2006). Production planning and scheduling is usually performed with a planning horizon of 1 week (Lütke Entrup 2005).

Transportation Planning

Along the consumer goods supply chain, structured transportation planning approaches across different horizons are only partly in place. According to the overview on transportation planning in Sect. 2.1.4, transportation planning ranges from network design to operative vehicle scheduling. As for network design, its effects on consumer goods supply chains have already been discussed within this section. Strategic transportation planning focuses on the size and specification of the vehicle fleet or on the form of contract for external transportation service providers (Baker and Hubbard 2003). Due to the high outsourcing share of their transportation activities the planning scope for consumer goods manufacturers is rather limited toward the latter. Decisions on the general forms of contract as well as on some transportation modes must be made since they result in lead time parameters for the replenishment process. Tactical transportation planning will, along the consumer goods supply chain, be determined within the replenishment process. In order to receive high quality results regarding the efficiency of the transportation processes, a thorough planning approach that includes costs, restrictions and requirements of the transportation processes is necessary. The extraordinarily good data quality and IT coverage at consumer goods manufacturers partly allows the implementation of replenishment processes in favor of efficient transportation processes. However, along the retail section of the consumer goods supply chain, the data quality and therefore the accuracy of planning results are reasonably lower (Ferrer and Karlberg 2006).

Only some aspects of tactical transportation planning are applied along consumer goods supply chains. As for the supply of the retail stores, tour planning is usually perceived as the key planning tasks within retail — due to management of the retail stores' own fleet this results in a vehicle scheduling task. On the manufacturers' side, the task is limited to a mere service provider management process without any planning characteristics. Operative transportation planning tasks are limited to a very short planning horizon along every segment of the consumer goods supply chain. This is due to the very short-term generation of material orders (Günther 2005). Retail markets may finalize their orders only a few hours prior to delivery and stock orders for the retailers DCs show an average lead time of 3.5 days (Thonemann et al. 2004), resulting in a planning horizon for transportation planning of a few days. This also accounts for operative transportation planning within the manufacturer section of the consumer goods supply chain. Since production planning for a 1-week planning horizon is performed for 3–4 days in advance (Lütke Entrup 2005), the resulting planning horizon for operative transportation planning is limited to the material flows from the production plan.

2.2.4 *Transportation Requirements in Consumer Goods Supply Chains*

McKinnon et al. (2004) classify transportation activities along the consumer goods distribution chain into three categories:

- A primary level focusing on transportation from a production location to a primary consolidation center and onward to a regional distribution center,
- A secondary level covering transportation between a regional distribution center and a local warehouse or retail outlet,
- A tertiary level regarding the transfer from local warehouse to independent wholesalers and multiple retail outlets.

The scope of this research largely concentrates on transportation processes controlled by the producers of consumer goods. Within this scope two subsections of the consumer goods supply chain can be distinguished. The first subsection covers the manufacturing facilities as well as the supplier locations. Processes here largely include batch production requiring simultaneous production planning and scheduling. Taking into account that storage space at plant level is very limited, time windows for pick-up and delivery operations have to be considered. In the second subsection all distribution related activities are covered (distribution centers and some related co-packing activities). They are dominated by the objective of sustaining high product availability at low inventory levels. Flexible and reliable processes are necessary to cover these requirements; therefore time windows are usually applied to transportation orders specifying departure and arrival times of goods at the associated locations (Crainic and Laporte 1997).

The transportation requirements in consumer goods supply chains are directly deductible from the consumer goods supply chain profile. In order to reach and maintain a competitive market position, transportation services must be provided in an efficient way regarding costs and performance. The objective of high on-shelf availability at low inventory levels defines the requirements for all involved supply chain process steps (Bilgen and Günther 2010). For transportation processes this will result in high reliability together with short order lead times. The resulting short planning lead times and planning horizons have already been identified in Sect. 2.2.3. The case of serving the retail stores with a retailer owned fleet imposes considerable requirements for the transportation planning process (see above). As for the outsourced transport relations, the restrictions may be more severe—within a very short time the best service provider needs to be identified and contracted (Stank and Goldsby 2000).

Transportation Time/Reliability

During transportation the goods transported are non-accessible inventory (Blauwens et al. 2008). Inventory carrying costs, that is, imputed costs, are incurred by the owner of the inventory (according to incoterms) during transit time. However, in-transit inventory carrying costs are in practice much lower than the transportation costs, and the inventory impact of transportation speed is only relevant for very expensive goods. Transportation reliability and punctuality, however, have a major influence on availability directly influencing inventory levels at warehouses and stores and thereby affecting on-shelf availability.

Time Windows

Time windows for transportation processes are very common all along the consumer goods supply chain. Make-and-pack production, together with high quality requirements, imposes a fixed finishing timestamp on every production step. First, all packaging and raw materials need to be available at the plant at the beginning of the production batch. This determines the latest delivery time for the material flow to the plant. Once quality control has approved the product, the complete production batch is cleared. This point in time is usually the earliest timestamp from which the production volume may be picked up for transportation. Due to very limited storage capacity at the plants, the goods' maximum retention time at the plant is limited by a latest pickup time for onward transportation. In cases when consecutive production or packaging steps are performed in batch mode, the batch starting time at the successive site determines the latest delivery time for the intermediate products in question. Time window length at production sites may be as little as 2–4 h. Warehouse operations are usually less strict in their time window employment. Still, the inbound and outbound material flows are usually leveled in order to achieve a balanced workload within the receiving and dispatching areas. Time window length is therefore usually about 4–8 h. The strictest time windows are usually found supplying the retail stores. Since many stores have very limited storage space, the majority of the material coming into the store is directly stocked onto the shelves (Thonemann et al. 2005). This is usually done by a non-permanent assistant workforce that is scheduled for the shipment arrival times. Early arrival therefore may result in either waiting time for truck and driver or inappropriate storage (e.g., not refrigerated) until the scheduled workforce is ready. Late arrival in contrast will result in idle time for the scheduled workforce thereby wasting resources. Time windows may be as short as few minutes for store deliveries (Mars 2008). In order to provide a reliable basis for workforce scheduling, goods arrivals are subject to rhythmic patterns according to assortment type (e.g., fruit arrives daily at 7:00 a.m., beverages arrive Monday, Wednesday and Friday at 13:00 p.m.).

Transportation Temperature

The goods that are shipped along the consumer goods supply chain may impose strict temperature regulations on transportation processes due to quality requirements (Lütke Entrup 2005). Further upstream the supply chain, along the section that is under control of the consumer goods manufacturers, temperature requirements are usually met using designated reefer equipment. The following four temperature zones are typical of the consumer goods industry, ambient (no refrigeration), temperature controlled, chilled (0–5°C; 32–41°F) and frozen (−18°C; 0°F) (Stringer and Dennis 2000). Within the retail controlled section of the consumer goods supply chain, different goods requiring different transportation temperatures are usually mixed on the trip. This may be achieved by using either multi-temperature zone vehicles with dedicated compartments or insulated loading devices.

Transportation Equipment

Transportation equipment is largely determined by the transportation mode choice. However, especially when transporting raw materials, special transportation equipment requirements may apply. Milk and other bulk material may require transportation in specifically designed silo vehicles. Apart from raw materials the majority of consumer goods today are prepared for transportation on standardized loading devices such as the euro-palette. Standardized transportation containers facilitate the handling at the plants, warehouses and retail stores and help to maximize vehicle utilization. Furthermore, they have enabled the standardization of transportation services according to commonly accepted rules. Consequently, this has made prices for transportation services easily comparable and enabled their tradability on market places.

Effects on Transportation Mode Choice

Transportation requirements lead to a distinct mode choice along the consumer goods supply chain. As for the supply of the retail markets, road transportation is the generally accepted norm (Vannieuwenhuyse et al. 2003) due to a lack of access alternatives at the destinations. In particular, since many retail stores are located in residential areas for customer convenience and proximity. Access for heavy goods vehicles may therefore be limited due to structural constraints (e.g., narrow roads), traffic or noise restrictions for defined periods. Supplying the DCs heavily relies on road transportation today (Department for Transport 2006), and the existence of rail services between central DCs and regional DCs are still an exception (e.g., COOP, Switzerland) (Perren 2009). Further upstream the supply chain the greatest share of transportation takes place on the road, the exception being raw material supply, which is subject to multiple transportation modes depending on their respective origins. In the case of intercontinental supply relations containerized sea transportation is the predominant mode (Blauwens et al. 2008).

2.2.5 The Consumer Goods Supply Chain's IT-Landscape

The evolution of business applications for supply chain processes has undergone various stages in the past 40 years. The MRP I (Material Requirement Planning) concept was developed and deployed in the 1960s and 1970s. Its functionality focuses on the calculation of net demands by taking into consideration a primary (customer) demand, a product structure or bill of materials (BOM) as well as stock balances (Stadtler 2008a). Based on net material requirements the production orders may be issued and assigned to specific resources (Lütke Entrup 2005). The next evolutionary level was constituted by MRP II. These systems are based on the MRP I concept, but the functionality was extended. Key areas of improvement are primary demand forecasting and the consideration of capacity for production (Lütke Entrup 2005; Shehab et al. 2004). Within the following evolutionary step, ERP systems have been subject to immense popularity resulting in ERP software vendors becoming the largest software enterprises (Chopra and Meindl 2007). These systems have become the IT backbone for numerous business functions such as sales, finance, accounting, human resources, manufacturing, logistics and many more (Lütke Entrup 2005). The final evolution process is advanced planning systems (APS). Actively shaping the supply chain by deploying mathematical models and algorithms is the key application area of these systems (Günther 2005). However, as APS are decision support tools rather than transaction systems, they rely heavily on the data and information quality in the underlying ERP systems (Lütke Entrup 2005).

The supply chain processes for consumer goods described in Sect. 2.2.2 require extensive IT support. The efficient management of large material flows through a complex network of production sites, warehouses and stores requires a large number of decisions to be made frequently. However, only a fraction of these decisions are of a true planning nature as described in Sect. 2.2.3. The greater share is dominated by operational scheduling, control and execution decisions (Thomas 2008). For example, thousands of decisions are made in a warehouse every day determining which article is picked next, from which place, by whom, and which dispatching zone will be used for shipment preparation and so forth. Not all of these decisions are made by people; in fact, they are made by designated IT systems that follow a pre-determined decision making process. Decision rules and parameters are designed to secure a resource efficient material flow and sustain high on-shelf availability for the customer (Günther 2005).

The system landscape along the consumer goods supply chain can be viewed from different perspectives, revealing several key systems or modules. Within the following paragraphs the focus lies on systems architecture more than on systems functionality or on supported processes. Since organizational limits usually also impose systems' limits, the two sections of the supply chain, manufacturing and retail, are subject to separate investigation (see Fig. 2.10).

Planning processes are covered by dedicated planning tools. These planning tools do not necessarily encompass the scope of advanced planning systems. They comprise a number of different little tools and their level of integration usually

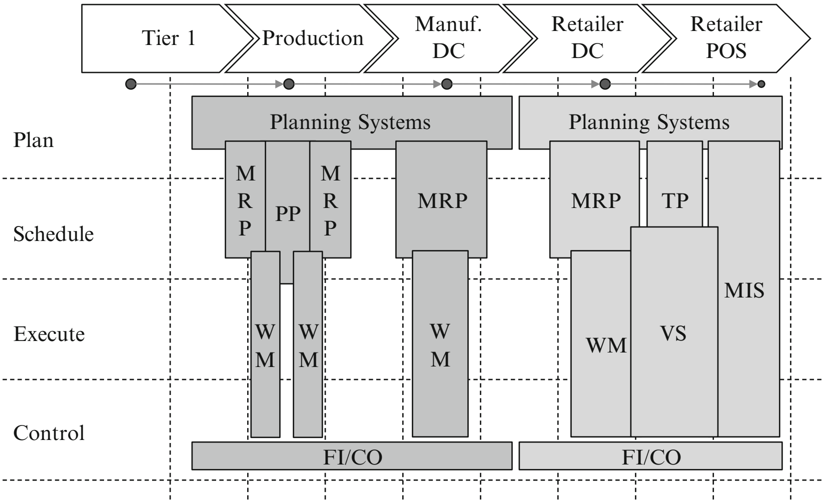

Fig. 2.10 Module landscape along the consumer goods supply chain

varies widely. Their focus is best described using the term *strategic network design* and, in real life, a great deal of the planning tasks is done by simple spreadsheet and database programs comparing different scenarios according to their cost and performance impact.

After the network's structure has been determined by network planning, material flows are planned and scheduled using MRP functionality, thereby converting gross demand into net demand (Stadtler 2008a). Even though MRP functionality is usually covered by ERP systems, it is normally an independent, yet well-integrated system component (Günther 2005). As a result, the ERP systems directly control the level of inventory along the supply chain and thus determine the product availability (Thonemann et al. 2004). Most of the ERP systems also contain a forecasting module in order to generate "demand elements" if necessary. Most forecasting data, however, is supplied by specialized forecasting systems deployed in retail (Thonemann et al. 2005). As for the in-store software, most functionality including MRP and Warehouse Management (WM) is directly integrated into the Merchandise Information System (MIS) (Hertel 1999).

The production stage within the manufacturers' section of the consumer goods supply chain constitutes the area where production planning and scheduling systems are in use. Production volumes and schedules are determined according to the net demands from the MRP run, taking into account the available resources and production material in the planning horizon (Meyr and Stadtler 2008).

Transportation planning tasks other than those covered in strategic network design are tour planning and vehicle scheduling with dedicated system support and integration. They are almost solely deployed in the retail section of the consumer goods supply chain (Mars 2008; Michael et al. 2002). As mentioned in Sect. 2.2.2 the transport relation supplying the retail markets are those with a considerable share of distributor operated vehicles (Mars 2008). While tour planning usually determines only the route and stops of a dedicated tour, vehicle scheduling assigns vehicles and drivers to these tours and is therefore located at the execution end of the process. At the location sites, material flow execution is dominated by warehouse management systems, which control the stock locations and initiate material movements by assigning relocation orders to resources (Thomas 2008).

An entire organization's section of the consumer goods supply chain is spanned by the finance and controlling (FI/CO) modules. Key tasks include accounting, budget-spent alignment, invoicing and the management of receivables and liabilities (Shehab et al. 2004). Although these modules have received little attention in operations management and operations research literature, the financial capabilities of integrated IT systems such as ERP systems have contributed greatly toward their wide propagation (Mandal and Gunasekaran 2003).

Figure 2.10 illustrates that IT system support for the tactical planning, scheduling and control of transportation processes is non-prevailing along the manufacturers' section of today's consumer goods supply chain. Possible ways of closing this gap are discussed in detail in Sect. 4.2.

2.2.6 Responsibilities Along the Consumer Goods Supply Chain

Organizational concepts applicable to consumer goods manufacturers and retailers may be structured using several dimensions, such as sales region, commodity, brand, sales channel and so on. Some supply chain processes may stretch across all these organizational dimensions while others may be subject to dedicated organizational units; more often than not different and widely independent organizational units are involved in the operation of a company's supply chain (Meyr and Stadtler 2008).

Large retail organizations often feature multi-national market presence (Michael et al. 2002). They serve these markets using several sales channels such as department stores and discount markets (Axel Springer 2009). The SCM organization in retail is therefore usually integrated into the purchasing organizational unit or split between purchasing, sales and category management (Thonemann et al. 2005). The supply chain strategy is often centralized, whereas its implementation and interpretation may be subject to every sales channel in every region. Still, responsibility for single process steps such as warehousing or transportation may again be centralized (Thonemann et al. 2005).

Today's organizational structures of consumer goods manufacturers are fragmented in three main dimensions. Figure 2.11 shows an organizational chart of one of the biggest consumer goods manufacturers, Nestlé S.A., and the three dimensions are described as follows:

Region: On the first organizational level, multinational consumer goods manufacturers usually differentiate organizational structures into large-scale regional clusters (e.g., continents). These regional organizations usually enjoy a great degree of freedom regarding their business development and are controlled by the global board, largely with regard to financing and reporting (see Nestlé 2009a, b; Unilever 2009; Deloitte 2009). Their key responsibilities are the financing of mergers and acquisitions and the appropriation of profits, in particular when the companies are publically listed. All further decisions, including key strategic issues regarding business development, for example, are taken within the regional/continental organizations. On the second level, country organizations usually have a sales focus and are generally responsible for supply chain processes that ensure customer (i.e., retail) satisfaction. Their area of responsibility on the consumer goods supply chain usually begins at the incoming dock of the distribution centers and ends at the goods receiving area of the retail customers.

Category/product: Category and product responsibility is also usually distributed over several levels and may be extended by brand liability (Armstrong et al. 1996). Commodity representatives are often part of the executive board. On the second and third level the duties are differentiated according to product groups and brands. The main focus within this dimension is on marketing, which makes the involvement in supply chain management decisions of minor importance. Still, product and quality requirements substantially influence supply chain requirements (Armstrong et al. 1996). In addition, commodity responsibilities are concentrated in

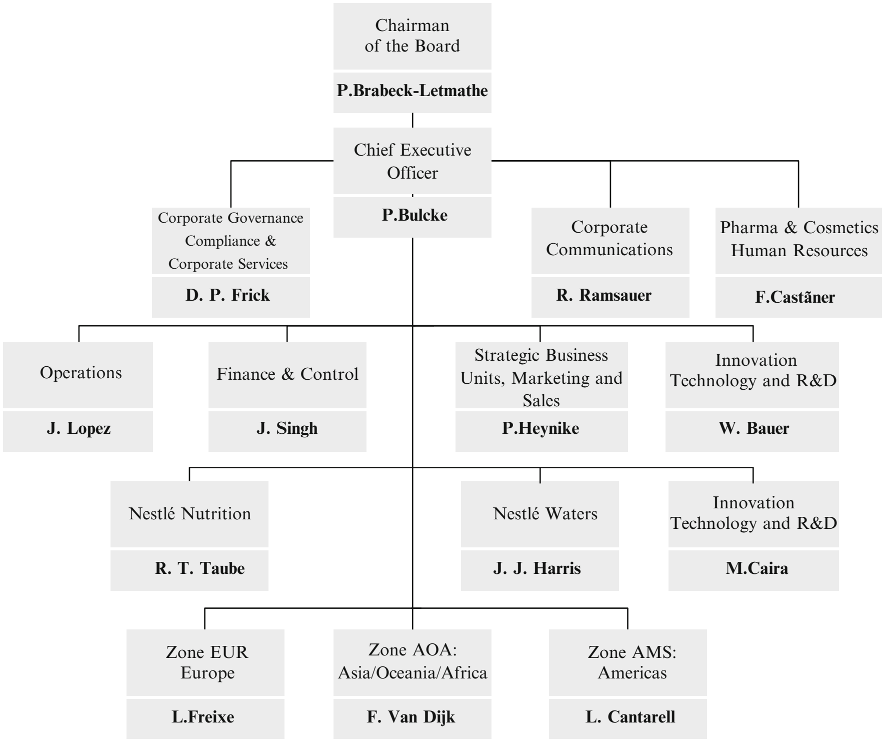

Fig. 2.11 General organization of Nestlé S.A. (2009a)

cross-regional teams. Important players in the sales organization are key account managers (teams) assigned to the large retail customers (Armstrong et al. 1996). Besides pricing they are also responsible for supply chain processes on the interface between manufacturer and retail.

Function: As in many other industries responsibilities are also shared along a functional dimension including finance, strategy, research and development, production and many more (Großpietsch 2003; Armstrong et al. 1996). While purchasing and production currently feature strong centralization, sales units are usually broken up into different sub units featuring a country or are region specific (i.e., Benelux — Belgium, the Netherlands, Luxemburg) sales organizations. Decisions with high relevance for the supply chain are made within production and operations functions.

In every subsection of every dimension, supply chain management decisions are made across the planning horizon from the operational to the strategic. It is, however, not the objective of this research to identify the specific responsibilities and resulting multitudinous areas of conflict. The strong fragmentation of responsibilities, however, shows that the term centralization for any supply chain management activity does not describe binary conditions as either central or de-central. The current trend toward centralization of supply chain management responsibilities (N.N. 2008a) may therefore affect only fractions of the overall organization.

This description of organizational structures along the consumer goods supply chains shows a very limited consideration of a holistic SCM approach (Thonemann et al. 2005). This restricts the integration effect of SCM as described in Sect. 2.1.1. The size of markets, the extent of organizational responsibilities and the independence of purchasing, production and sales generally allow for centralization only within very limited functional areas. Nowadays, it is very common to find organizational units that concentrate accountability for shared functions for the entire macro region (e.g., continent) (N.N. 2008a; Armstrong et al. 1996).

Organizations along the consumer goods supply chain feature a wide distribution of tasks and responsibilities. The downside of this may be found in a lack of organizational integration and therefore obstacles when striving for a comprehensive and optimal supply chain configuration. Thonemann et al. (2004) describe three conflicting areas in classic consumer goods organizations (see Fig. 2.12):

- *Sales vs. Production:* As one of the classic areas of conflict, production is in favor of stable and long-term schedules and plans, while sales, aligning to customer requirements, seek high flexibility in order to meet every customer demand (Mars 2008). In consumer goods organizations this often leads to production claiming that disadvantageous cost structures result from short-notice schedule adjustment while sales may blame an inflexible production organization for falling short of inventory targets and poor service level.

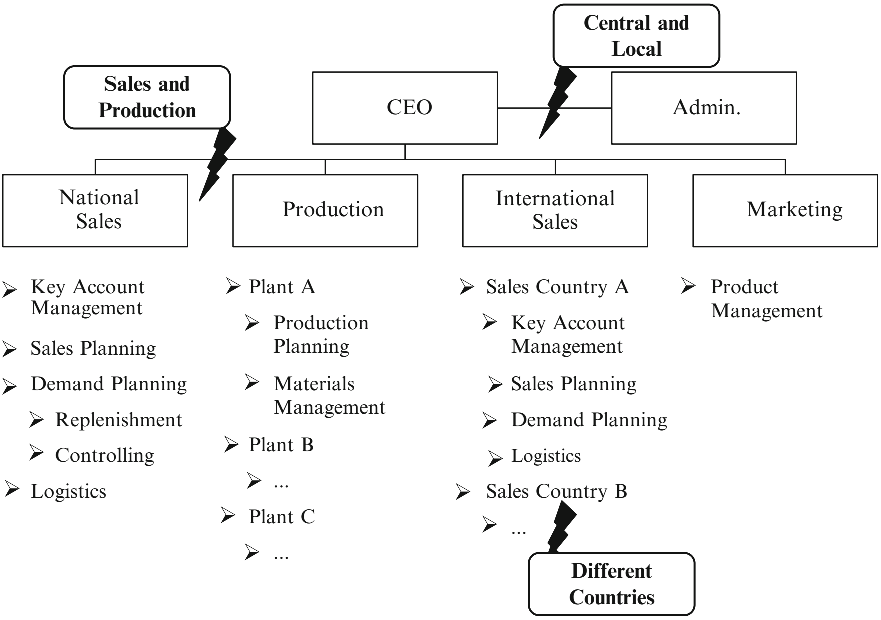

Fig. 2.12 Organization in consumer goods industries (Thonemann et al. 2004)

- *Inter-Regional:* Sales organizations from different countries share the same production capacity in international consumer goods corporations. This organizational structure carries much conflict potential, especially in transitional stages where production and supply will already take place on an international level, whereas sales and distribution remain in the hands of regional or national organizational units.
- *Central vs. Decentralization*: While decentralized organizational units will want to make their decisions as autonomously as possible, they will have to align with company strategy. A central supply chain organization may be better at identifying and striving toward a supply chain optimum; however, this may come at a high price in the regional organizations prompting a potential loss in motivation.

2.3 Trends and Future Developments along the Consumer Goods Supply Chain

Many reasons for dynamic business development have been appointed to trends. Within the key focus area of this work — transportation along consumer goods supply chains — development directions are multiple. In this subsection, major drivers and trends are identified and evaluated according to their expected influence. Trends are of special interest when they determine long-term strategic decisions. However, in order to identify the choice associated with decisions and their impact, causes and effects need to be assessed beforehand.

2.3.1 Relevant Trends

The scarcity of all resources, but particularly the finite availability of exhaustible raw materials, has been subject to intense academic discussion and is the foundation for many economic models regarding the influence on prices and in turn on demand (Hartwick 1989; Hotelling 1929). Due to the naturally diminishing supply of fossil fuels, ever-rising prices are generally expected (Grocery Manufacturers Association 2008b; Mars 2008). By no means a new finding, public awareness of these factors has steadily risen, influencing consumer behavior in terms of awareness toward the origin of goods (deducting resource consumption required for transportation—Rieck 2009). The sustainable use of renewable resources as well as fossil fuels has therefore received increasing interest.

Pollution is another environmental factor that has received growing public attention in recent years. For example, greenhouse gas emissions from cattle breeding add to the emission footprint of the consumer goods supply chain as well as transportation. Food transportation already accounts for 3.5% of the

U.K.'s total CO_2 emissions (Garnett 2003). These factors have moved to the center of public awareness regarding environmental pollution in conjunction with the farming and production of food. In contrast to these relatively new developments the contaminating effects of the production and the use of chemical products (such as washing liquids and detergents) have been countered using a greater share of biodegradable components (Banerjee and Solomon 2003).

The increasing public awareness of environmental aspects has not been without influence on consumer behavior (Garnett 2003). Alongside the growing popularity of a healthy diet these trends have not only increased bio-labeled products' turnover but has led to a re-evaluation of fresh products over strict convenience aspects (Nielsen 2009; Michael et al. 2002). This has prompted the introduction of a completely new commodity type, referred to as ultra-fresh processed foods. Products that fall into this commodity type are characterized by a shelf-life considerably lower than fresh foods (such as yogurt or other dairy products). Examples are freshly made juices (the so-called "smoothies"), cut-and-washed lettuce and salad dressings (Mars 2008). Increasing quality awareness has by no means led to a decreasing pricing awareness. On the contrary, the discount retail channels are still growing despite an already strong market share (Thonemann et al. 2005). It should be further noted that consumer activation — for example, trade promotions — is facing growing difficulties due to sensory overload (Mars 2008).

Demographic changes are an additional driver for altered business requirements, especially in consumer goods markets (Breithor et al. 2001). Increasing customer individuality shows in changing consumption behavior (Axel Springer 2009). Consumers are therefore subdivided in patterns that feature a number of demographic elements such as age or household size (Nielsen 2009; Ernst and Young 2007; Breithor et al. 2001). Addressing these customer groups with specific products invariably leads to a growing number of new products or product innovations flooding the markets (Michael et al. 2002). Product differentiation has thus become a competitive instrument for consumer goods manufacturers (Garnett 2003). Approximately 30,000 new articles enter German retail shelves annually — not taking into account the growing number of fresh food products (Mars 2008). In this context, a distinction between true product innovations and product variations seems necessary (Grocery Manufacturers Association and Booz Allen Hamilton 2006). While true product innovations are aimed directly at the consumer's desires, product variations (e.g., different packaging sizes) are often pushed into the markets by manufacturers in order to increase shelf space coverage of the own product, thereby diminishing competitors' shelf space (Thonemann et al. 2004). Demographic development, however, not only affects consumption behavior (Breithor et al. 2001); for example, with more people moving from rural into urban areas (Mars 2008) traffic congestion in densely populated regions seemingly increases (Vannieuwenhuyse et al. 2003).

Driving forces behind demographic changes as well as individual consumer behavior are often of an economic nature. The past decades have seen politically enforced liberalization resulting in the formation of free trade zones (e.g., NAFTA, EC), and even further toward the merging of several national markets into one domestic market (EU). In other parts of the world, liberalization has boosted economic development (e.g., South Korea, China), which has led to an enormous increase in international trade volumes; today usually referred to as globalization. The opportunity of transferring goods in international markets without customs restrictions or time-consuming border crossing procedures has shifted the manufacturing footprint of many industries toward regions where labor costs are comparably low (Ernst and Young 2007; Garnett 2003). But these markets are not only the destination of production relocation activities. Due to their growth rates they often feature an increasing share of the population that, according to their income, qualifies as potential consumers (The Economist Intelligence Unit 2005). Growth rates of consumer goods sales in these countries exceed those in the saturated consumer markets (N.N. 2008b).

As a result of the dynamic development of markets, some companies' reactions have substantiated trends. The trend toward outsourcing, higher flexibility and shorter lead and cycle times are developments that account for many industries today (Grocery Manufacturers Association 2008b; Rider 2003).

2.3.2 Political Influence and Actors

With political developments having been identified as driving forces behind the expansion of domestic markets, counter movements are not far away. Subsidies for agricultural raw materials, for instance, influence their pricing and have a strong influence on the consumer goods supply chain (Grocery Manufacturers Association 2008b). The enforcement of customs on raw materials is meant to serve as a protection of national domestic markets.

Service markets, in comparison to goods markets, have not been subject to liberalization to such an extent. The European cabotage regulation limits the operations in central Europe of carriers from Eastern European member states (European Commission 2007). Even stricter rules apply to services within the NAFTA region (Beilock and Prentice 2007). Apart from that, transportation infrastructure is often state owned, controlled and even operated. This also accounts for the road network. The state is responsible for vehicle taxes, road charges and petroleum tax. The operation of rail networks, their infrastructure and equipment in Europe is largely controlled by state-owned companies

2.3.3 Implications for the Consumer Goods Supply Chain

The growing customization of products together with product innovations will increase the number of articles or stock keeping units (SKU) (Grocery Manufacturers Association and Booz Allen Hamilton 2006; Michael et al. 2002) throughout the consumer goods supply chain. With shelf space in the retail stores remaining constant this will inevitably lead to less shelf space per SKU and therefore to less on-shelf and in-store inventory (Meyr and Stadtler 2008; Rider 2003). In order to retain on-shelf availability, either supply frequency must increase while supply lot-sizes decrease or a reduction of replenishment lead time may reduce safety stock levels and diminish total inventory requirement (Rieck 2009; Günther and Tempelmeier 2009). More SKUs will also prompt lower sales per SKU and are likely to increase relative demand volatility, which in turn is likely to raise inventory levels rather than make a substantial decline of safety stock levels possible (Gudehus 2005). In the past, diminishing sales have been avoided by a substantial growth in emerging markets, such as Europe and Latin America (Deloitte 2009; The Economist Intelligence Unit 2005). Taking into account that production is concentrated in very few locations, transportation distances have increased. This in turns opposes the trend toward shorter replenishment cycles (Grocery Manufacturers Association 2008b).

Economies of scale, growth rates in emerging markets and the development of high volume discount sales channels have increased concentration on retail markets (Ernst and Young 2007; The Economist Intelligence Unit 2005; Caputo and Mininno 1998). In the European retail markets, the market share of the top five companies has increased 15–20% points since 1990 (Thonemann et al. 2005), with the effect that consumer goods manufacturers are becoming more dependent on a few retail customers (Ernst and Young 2007; Garnett 2003), which in turn is met by a growing concentration on the manufacturing site (Thonemann et al. 2005). In addition, retailers are challenging the manufacturers' sovereignty by introducing retail brands (Ernst and Young 2007). Furthermore, they are tightening their control on supply chain processes at the interface between manufacturing and retail (Ernst and Young 2007) and taking over transportation from the manufacturer into the warehouse. This trend is part of a supply chain transparency initiative in retail, often referred to as factory gate pricing (McKinnon and Ge 2006). It resembles a total landed cost approach dividing a product's price into conversion cost (= price at the factory gate) and logistics costs (= transportation, warehousing, dedicated packaging) — thus each of the pricing components is subject to separate negotiation. Furthermore, the retailers may calculate whether it is less expensive to collect the goods at the manufacturer or to have it delivered to their own warehouses (or even into the stores, for example, using VMI concepts) (Thonemann et al. 2005).

A growing number of SKUs, lower in-store inventory levels and shorter replenishment cycles all add to the complexity of planning tasks along the consumer goods supply chain (Grocery Manufacturers Association and Booz Allen Hamilton 2006). It also imposes additional restrictions that are likely to result in rising supply chain costs (Mars 2008). However, the dynamic development may also be regarded as offering new opportunities by delivering customized services such as pre-allocated cross docking or shelf-ready packaging (Thonemann et al. 2005). Logistics activities may thereby contribute toward the long expected "revenue generation strategy for the supply chain" (Ballou 2007).

2.3.4 Implications for Transportation Markets

Political, social, and economic developments have an impact on service demand, supply and prices of transportation markets. As a result of a heightened environmental awareness, vehicle taxes, fuel taxes and road taxes have been subject to an over- proportionate increase in recent years (ECR Europe 2000). Road and vehicle taxation have been modified according to the specific emission of a vehicle. Additional measures penalizing vehicle emissions are being discussed. Reporting schemes regarding the carbon footprint are also applicable to transport emissions (Garnett 2003). But it is not only the environmental factors that are subject to political and social discourse. Even though the acceptance of alternative transportation modes (as opposed to the road) features environmental aspects, it is the deregulation and accessibility of rail services that will decide upon their acceptance and intermodal transportation. Hidden and open subsidies for publicly owned railway companies have led to a market situation lacking transparency. Road regulations have also been subject to discussion recently (e.g., in Germany). Plans to increase the permitted gross vehicle weight and extend truck dimensions have recently been abolished.

Mars (2008) states that as a result of several governmental regulations within the transportation sector, transportation costs are constantly increasing at rates above inflation. Decreasing transportation lot sizes and high product proliferation complete the picture of the rising complexity of transportation management for both consumer goods manufacturers and retailers in the near future.

Chapter 3

Assessment of Transportation Cost Saving Opportunities in 3PL Operated Consumer Goods Industry Networks

Chapter 2 discussed how transportation costs contribute substantially toward total supply chain costs in the consumer goods supply chain. Furthermore, it was pointed out that the consumer goods supply chain may be segmented into two sections; namely, a manufacturer controlled section and a retailer controlled one. While a larger part of the retailer controlled transportation activities is covered by the retailer operated fleets, outsourcing of transportation services is most common along the manufacturers' section of the consumer goods supply chain. Since the following chapters are based on an outsourced transportation network environment, the manufacturers' section of the supply chain will be subject to closer investigation. And since road is still the prevailing transportation mode, this research primarily focuses on truck transportation.

In order to determine the prices for outsourced road transportation, it proves helpful to look at the development of freight rates in the past. While today's markets for road transportation services are subject to intense competition, thus affecting pricing, trucking markets in the past were subject to regulation in many parts of the world. In the U.S., deregulation of the *motor carrier industry* took place in 1980 (Mentzer 1986). Previously, the Interstate Commerce Commission controlled the number of carriers serving a particular shipper, the rates carriers charged for certain routes, as well as the routes they were allowed to serve (Krapfel and Mentzer 1982). The situation was similar in Europe, for example in Germany. Prices for road transportation were defined in the *Reichskraftwagentarif* (RKT) up until 1989 and in the *Güterferntarif* (GFT) tables until 1994 (Kopfer 1984). The deregulation of the European transportation markets took place between 1990 and 1993 (Blauwens et al. 2008; Skjøtt-Larsen et al. 2008) and led to transportation price reductions of approximately 20% (Zimmermann 2004). The regulation of transportation services served several purposes: one of the most prominent being the competition among transportation modes (Krapfel and Mentzer 1982). With rail services usually provided by state-owned companies, privately offered road transportation was regulated by imposing higher prices, which was a means to shift the goods flows toward rail, thereby increasing profitability of the public enterprises (Zobel 1988). In Germany, inter-company transportation was widely excluded from regulation as

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long as it was provided by the companies' own vehicle fleets (Zobel 1988). This led to consumer goods manufacturers being among the largest fleet owners in Europe in the 1980s (Sheffi 1990).

While the assessment of transportation costs and the benchmarking of transportation efficiency were comparably easy during times of regulation, it has become more complex after deregulation. Prices for transportation are subject to individual contracts between shipper and carrier and are therefore subject to freedom of contract (Krapfel and Mentzer 1982). They can, and will take numerous forms, which makes it difficult to compare different pricing schemes. The benchmarking study "KPIs for the food supply chain" (McKinnon 1999) claims to be "the first major study of its kind in the world" and was repeated in 2002 (Department for Transport 2006; McKinnon et al. 2004). These surveys were incorporated as a key constituent of the U.K. Government's *sustainable distribution* policy (Simons et al. 2004). They provide us with some background knowledge on the cost savings opportunities in today's transportation networks, no matter whether they are 3PL operated or industry operated. The analysis of freight rates in this research will largely take place based on an adjusted GFT from Germany since the data is easily available and still features many aspects that find their way into today's contracts between shipper and carrier (for details see Appendix I).

The remainder of this chapter is structured as follows: First, freight rates are subject to a thorough analysis regarding cost drivers and prime costs — always with regard to the types of services required in the consumer goods industry's transportation networks. The second subsection features a case study from the consumer goods industry that serves for the development of a transportation planning approach aimed at a reduction of transportation costs by utilizing freight rate effects.

3.1 Freight Rate Analysis

While it is generally acknowledged that efficient utilization of transportation capacities is a key to effective freight management, a structural understanding of price building mechanisms on transportation markets may result in further saving opportunities. This section will therefore briefly address the most basic pricing rules on these markets and develop approaches for further saving prospects.

Outsourcing, the use of LTL services and one-way rates supports a variable transportation cost structure (Chopra and Meindl 2007). In contrast to the operation of an own fleet, transportation costs only occur for actual shipments, which are charged according to freight rates that in turn depend on the contractual agreements between shippers and carriers (KPMG 2000). It can be observed that the freight rate structure partly resembles the cost structure of the fleet provider; that is the carrier (Sahin et al. 2009). Therefore, improving transportation efficiency will constitute a means of reducing freight costs, even if transportation services are outsourced (Caputo et al. 2005; Moore et al. 1991; Stank and Goldsby 2000).

3.1.1 Freight Cost Focus in Consumer Goods Industry Networks

The terms freight costs and transportation costs will be used synonymously throughout this research. As Sect. 2.2.2 illustrated, logistics costs do account for a substantial share of total costs for the consumer goods manufacturers (see Fig. 7, p. 23). Transportation in turn is responsible for approximately two-thirds of logistics costs in the consumer goods industry (see Fig. 9, p. 26). Figure 9 also shows that a perspective of total transportation effort in the consumer goods industry is one that is seldom shared. Inbound and outbound transportation costs are considered separately, which is typical of a strict organizational division of transportation responsibilities. A common planning approach will be needed to overcome some organizational boundaries. In addition, outbound transportation is subject to further division in terms of organizational responsibility. While transportation from the plant into the DC is usually in the hands of a central organizational unit, often in close proximity to the production organization, distribution is a key responsibility of national sales organizations. As a result, awareness of freight costs is rather low, since transportation costs are usually only a fraction of an organizational unit's responsibility.

In effect, the organizations' priority to optimize their operations will focus on areas other than transportation expenses, even more so when facing conflicting objectives such as availability and inventory requirements that impose strong additional constraints (Lebensmittel Zeitung and PwC 2002).

3.1.2 Prime Costs of Transportation Services

One way of determining the costs of transportation is the analysis of prime costs for transportation services. As discussed in Sect. 2.1.3, in-house provision of transportation services may in many cases constitute a serious alternative to outsourcing — at least for road transportation where investment into vehicles is minor compared to other modes of transport. Therefore, a natural price limit for outsourced road transportation is constituted by the prime costs of these services that occur for the make option when considering a make-or-buy decision.

Sahin et al. (2009) define a number of factors influencing a carrier's cost structure:

- *Capital:* Capital costs reflect investment and interest for the vehicle as well as for the infrastructure (road, rail, waterways, and airports). The latter will in most cases be operationalized by the provider of the infrastructure (e.g., tolls and road pricing, lock and harbor fees) and may only be subject to long-term carrier investment decisions for terminals or hubs (Chopra and Meindl 2007). Sahin et al. (2009) assess depreciation on vehicles to be time dependent. Carriers, however, will often depreciate their vehicles over a lifetime-distance (Blauwens et al. 2008). Yet, even this is only the case when vehicles are subject to book depreciation. More often they are leased or rented and therefore not subject to book depreciation. In general, the investment into any assets necessary to offer transportation services must be incorporated in a costing model. Temporal factors as much as risk aspects have a strong influence on investment decisions and may affect transportation pricing far beyond the context described in this text. Chopra and Meindl (2007) assess these vehicle- related costs as being fixed for short-term decisions but variable for long-term decisions.

- *Fuel and Lubricants:* Fuel and lubricant costs are usually distance dependent and are not necessarily influenced by the amount shipped. Fuel costs may be influenced by the vehicle type and do largely depend on the prices of energy and on the efficiency of energy conversion technology. For an overview on fuel consumption and energy intensity, see Department for Transport (2006).
- *Operational and Maintenance Costs:* Operational costs include the driver of the vehicles as well as insurance costs, taxes, road pricing, tolls and general maintenance activities such as the replacement of wear and tear parts. Although some costs are time dependent (e.g., driver), they — as time is often considered a function of distance — may be regarded indirectly as distance dependent (Blauwens et al. 2008). Other costs are directly distance dependent (maintenance, road pricing), while again others largely depend on the choice or route (e.g., tolls or ferry charges). Route choice is an important operational decision for transportation, usually balancing between transportation time and distance, aimed at the minimization of total journey costs (Schweikl 2007).

This segmentation examines costs and prices of input factors when providing transportation services. Chopra and Meindl (2007) suggest a different segmentation of transportation prime costs aimed at the underlying cost drivers:

- *Vehicle-Related Costs:* These are costs that are incurred by purchasing or leasing the fleet of vehicles. They are fixed for short-term decisions but variable for medium to long-term decisions.
- *Fixed Operating Costs:* These are costs that are incurred by the operation of facilities such as hubs or terminals. As for the vehicle-related costs, they are fixed for short-term decision making and are variable in medium and long-term decision processes.
- *Trip-Related Costs:* These are costs that include the price of labor, fuel (and tear and wear parts of the vehicle) for each trip. These costs are independent of the quantity shipped but depend on the length and the duration of a trip.
- *Quantity-Related Costs:* These are costs that contain loading and unloading as well as the portion of the fuel costs that is actually dependent on the transportation quantity.
- *Overhead Costs:* These are costs necessary to plan and schedule a transportation network including those incurred from necessary investment (such as IT).

The concepts described in academic literature mostly cover prime costs for transportation services. However, they lack relative quantification of their cost contribution. Figure 3.1 shows that fuel and driver and vehicle costs contribute approximately three-fourths of total transportation costs.

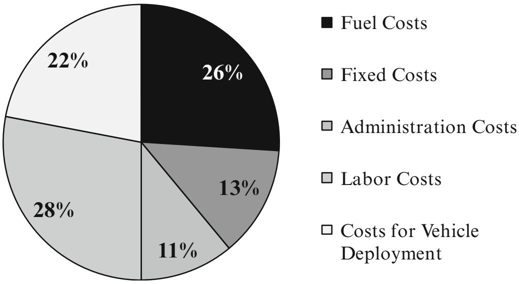


Fig. 3.1 Distribution of prime costs for long-distance road transportation services (Heintze 2008 according to BGA)

3.1.3 Transportation Efficiency

The importance of transportation costs in consumer goods transportation networks has been stressed repeatedly in the previous sections. An efficient provision of transportation services is therefore necessary for a sustainable business model of all actors along the consumer goods supply chain. Transportation efficiency is thus determined with the objective of supplying transportation services at minimum costs. Transportation efficiency has been subject to extensive research in the past and while most approaches to transportation planning aim at increasing the efficiency by minimizing costs in different ways, the theoretical foundation is often lacking a quantitative statistical background. An overview of some figures by the Department for Transport (2006) and by Simons et al. (2004) should provide a deeper understanding of means for increasing transportation efficiency and their practical application.

In general, there are two ways of increasing transportation efficiency for a given service:

(a) Decreasing the factor input for a fixed amount of goods on a given transport relation.
(b) Increasing the number of goods that can be transported with the same factor input on a transport relation.

Technical progress in terms of engineering has in the past significantly improved the fuel efficiency of trucks (Warren et al. 2005). However, this has been overcompensated by an increase in the cost of fuel due to rising crude oil prices (Mars Deutschland 2008). Further technical advancements have been pursued in terms of increasing truck payload. Since most dimensions are subject to country or state regulation, only minor improvements are possible without legislative changes. In Germany, a petition for such a legislative change has recently been pursued and is closely connected to the term *gigaliner* (Friedrich et al. 2007). The vehicle has an increased loading space of approximately 50% resulting in a significant reduction of per-unit fuel consumption and emissions. Due to road safety issues as well as concerns for the road surface stability these propositions stand little chance of short- or medium-term implementation. Different regulatory requirements in the U.S. vs. the EU result in a very obvious visual difference of towing units: Since trailer length (from fifth wheel kingpin to axle) is often the tightest restriction, in U.S. towing units the driver sits behind the engine that is covered by a long hood and towing units are usually very long. In the EU, the cab over engine (COE) construction is preferred since the total vehicle length is restricted. By fitting a short towing unit the cargo floor length can be maximized — the reason why European towing units are usually significantly shorter but higher than American ones.

Increasing the trucks' capacity will only lead to a reduction of transportation costs if the additional capacity can be fully utilized. A survey by the Department for Transport (2006) has shown that in Great Britain the average vehicle fill is only 69% in floor space, 52% in cube space and 53% in weight capacity (see Fig. 3.2). Up to 26.5% of the trucking distance is performed with the truck being completely empty in Great Britain's consumer goods industry (McKinnon et al. 2004; Department for Transport 2006). Measures to increase the vehicle fill can be of an operational process as well as of a technical nature. The latter point aims at increasing space and weight utilization by way of better packaging (e.g., stackability of containers) or adjustments to the vehicles (e.g., double-deck trailers). Operational measures aim at the adjustment of shipping lot-sizes in order to utilize the vehicle capacity. The simultaneous consideration of multiple shipment attributes may contribute to significant savings when heterogeneous articles can be transported together. For example, in FTL contexts, the right combination of heavy and voluminous shipments may reduce the number of trucks needed compared to the utilization of a truck only by weight, leaving space unused (heavy articles). The same applies to the utilization of the entire space but only a fraction of the weight capacity (voluminous articles) (Department for Transport 2006). In LTL contexts, voluminous shipments are often penalized with extra rates according to their "dimensional weight" (Chan et al. 2002a). Improving vehicle utilization has for some time now been a field examined in operations research by formulating and solving instances of the bin packing problem (see, for example, Attanasio et al. 2007). Despite this problem receiving much attention, the propagation of these approaches and use in transportation software is very limited.

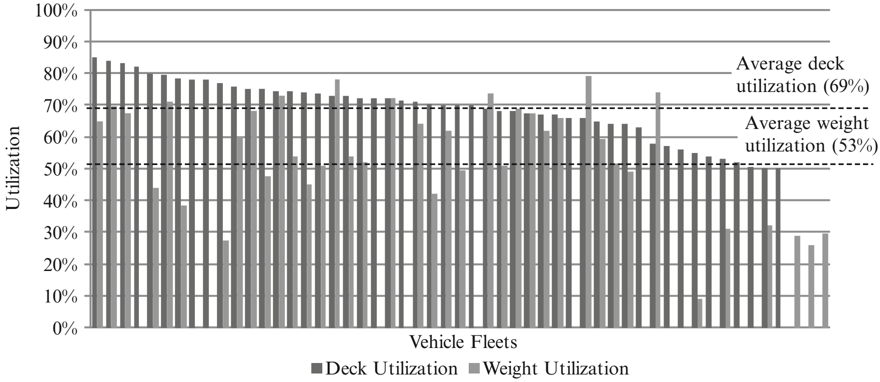


Fig. 3.2 Vehicle utilization across 53 fleets (Ranked by Deck Utilization) (Department for Transport 2006)

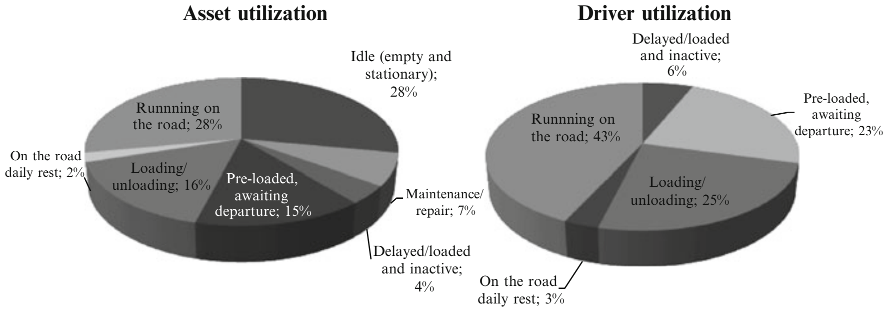


Fig. 3.3 Utilization by time (Department for Transport 2006)

While the input factors driver and vehicle are usually enhanced when increasing vehicle capacity utilization for a moving vehicle, idleness of the vehicle still results in poor factor utilization. However, a differentiation between planned and unplanned idleness has to be made. The vehicle can theoretically be operated with major breaks only for maintenance and repair. Legislation, however, is usually very strict regarding working and rest periods for truck drivers. Therefore, time utilization is usually differentiated between asset utilization and driver utilization (Department for Transport 2006).

Figure 3.3 shows that 35% of the time assets are used for loading or unloading operations while the time on the road accounts for only 28% of the total time. Improving warehouse operations will increase asset utilization. Utilization is slightly increased to 43% when focusing on the driver. It is obvious that major delays result from loading and unloading operations. Unplanned delays lead to major deviations from the transportation schedule, with 29% of journeys recorded to have unscheduled delays (Department for Transport 2006). These are often incorporated into planning processes using slack. As a result, fleets are too large and *scheduled idle time* is added on top of unscheduled delays.

A case study by Simons et al. (2004) shows an overall vehicle effectiveness of 54% vs. a target of 70% that is assessed to be possible in a short implementation horizon (see Fig. 3.4). However, the study does not assess to what extent efficiency gains may result in cost reductions.

3.1.4 Costs and Pricing for Outsourced Transportation Services

The prime costs for transportation represent the costs of the carrier or fleet operator. The outsourcing of transportation services implies that the shipper and the carrier are two legally independent entities. The shipper has his transportation demand fulfilled by a carrier, based on one or numerous contracts. Today, in most transportation markets these agreements are subject to freedom of contract and are manifold in their structure defining prices and services. Prices for transportation are often

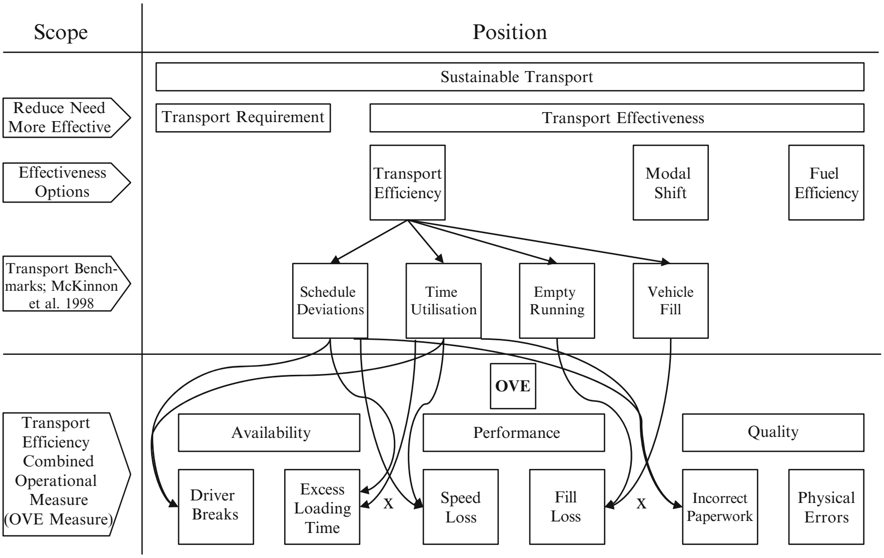


Fig. 3.4 Overall vehicle effectiveness—scope and position (Simons et al. 2004)

referred to as rates or tariffs and may include the basic transportation services as well as handling (at hubs and terminals) and paperwork. This section will pick up the market segmentation from Sect. 2.1.2 and focus on road transportation of medium load size and transportation distances ranging from regional to continental.

For the load sizes covered in this study the differentiation between transportation charges for FTL and LTL services is necessary. For a given transport relation (defined origin and destination) an FTL rate will be charged at a fixed price for a defined capacity of one truck regardless of the actual load size. Services dispatched in FTL mode are usually operated from door-to-door making additional stops for handling unnecessary. LTL rates for a given transport relation in contrast usually depend on the actual load size. These rates are often given in freight rate tables differentiating between shipment sizes in load bands, for example, 1,000 and 2,000 kg. For smaller shipment sizes prices are usually considerably lower compared to FTL services since the carrier can consolidate different shipments from different shippers on the same vehicle. From an operational point of view long-distance LTL services are often provided through a hub-and-spoke structure: First, the loads are gathered from many shippers of one region and are brought to a hub — this relation is referred to as the pre-carriage. There, the different goods are distributed onto trunk-line services that operate between the hubs. From a hub in the region of a shipment’s destination, the distribution to the final receiving location is provided. The difference in operation leads to generally longer transit times for LTL shipments compared to FTL services due to handling and waiting times for suitable subsequent services.

Having identified the cost drivers of transportation services in Sect. 3.1.2 it is obvious that transportation distance as an important cost driver also has significant impact on transportation pricing in an outsourced transportation environment. Apart from specific vehicle requirements distance is the key cost driver for FTL services. For LTL services there is an additional pricing component referring to the load size. The dimensional bands for pricing are common in the dimensions of weight, cube space and floor space.

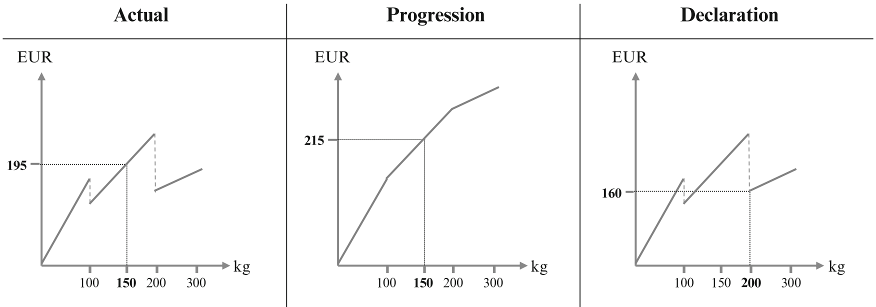
However, although the two cost drivers — distance and load — account for a great share of transportation costs (Meixell and Norbis 2008), freight rates can take very complex structures (Crainic and Laporte 1997). So far, prices for transportation services have been largely deducible from the demanded service in question. However, in many geographical regions we can find large market imbalances causing impacts on pricing (Garnett 2003; Mentzer 1986; McKinnon and Ge 2006). In Europe, an example is the goods flow between the U.K. and continental Europe. Transports into the U.K. are considerably more expensive than those out of the U.K. The same applies on an intercontinental scope to overseas containerized transportation, for example between China and Europe. Transports from China to Europe are significantly more expensive than vice versa (Barletta et al. 2008). In most contracts, however, transportation prices are subject to a transport relation in one direction at the carrier's risk, as they need to find additional transport orders that will get the vehicle and the driver back to the depot. Substantial reductions are usually granted for so-called round-trip or backhaul orders that include the return journey (Moore et al. 1991; Mentzer 1986). In case the destination region of a shipment is disadvantageous for a carrier, so-called repositioning costs are taken into account. These cover the effort of moving the equipment into more advantageous areas for the carrier and are usually not transparent to the shipper.

Additional pricing components are often directly cross charged by the carrier to the shipper. In particular, in long-term contracts that are valid for a large number of different lanes as can be found in many industrial corporations, selected pricing components are taken out of the individual contracts and are bundled in framework contracts. One of these components features changes in fuel prices that are often subject to *diesel price floater* adjustments. Diesel surcharges are covered by a set of indices that monitor the fuel price development. The benefit of such a floater is argued to be better hedging capabilities by large corporations with direct access to finance markets and lower value at risk vs. specialized road carriers whose profitability may otherwise heavily depend on fuel prices. Road pricing and ferry charges are also often subject to broader contractual agreements, however, usually for transparency reasons.

In cases when the transport relation in question covers large distances, the standard charge often covers the deployment of a single driver and the transit time includes the rest hours. Shorter transit times can be implemented using additional driving personnel at additional charges.

While the most common influences on transportation prices have been assessed, the manner in which they are integrated in the contractual agreements between shipper and carriers are manifold. Many LTL rates are given in one dimension only, for example, weight. However, shipments that use a lot of space, but are very light, are often penalized with a *dimensional weight,* which is a conversion of volume into

Relation A→B	
0-100 kg	1.50 EUR/kg
100-200 kg	1.30 EUR/kg
200-300kg	0.80 EUR/kg



P_{ship}= 150kg·1.30EUR/kg = **195 EUR**

P_{ship}= 100kg·1.50 EUR/kg 50kg ·1.30 EUR/kg = **215 EUR**

P_{ship}=MIN (150kg·1.30 EUR/kg; 200kg·0.80 EUR/kg) = **160 EUR**

Fig. 3.5 Common application schemes for LTL freight rates for a shipment of 150 kg

weight. The real weight is then compared to the dimensional weight and the higher value is applicable for freight cost calculation.

Even if given within the same dimension, LTL rates find different application. Fig. 3.5 shows a simple LTL rate example that can be applied in different ways. Here a shipment of 150 kg is rated, and according to the *Actual* scheme, the real weight is applicable for a freight cost calculation; in this case, costs of EUR195 apply to the 150 kg shipment. As for the calculation scheme *Progression,* the first 100 kg shipment weight is rated in the according band of 0–100 kg at EUR1.50/kg while the remaining 50 kg are rated in the next band at EUR1.30/kg summing up to total shipment costs of EUR215. The third calculation scheme referred to as *Declaration* does not use the actual shipment weight for freight cost calculation but allows the shipper to declare a larger sized shipment and be billed accordingly. Only very few shipments are actually weighed on a scale, and in most cases the shipment weight is calculated based on the shipment contents' master data net weight plus a packaging supplement.

The pricing components for diesel, road taxes and further planned surcharges as mentioned above find their way into the contracts just as penalties for unplanned eventualities do, the most common ones being demurrage charges. Another integral part of transportation contracts is insurance coverage that may differ in case transportation goods are handled during between different legs. Insurance terms and conditions are highly standardized (e.g., ADSp, CMR) and are in most networks covered using a total network approach (Cardeneo 2008). Finally, rebates and volume guarantees are part of many transportation contracts: Rebates are usually applied according to total transportation expenditure with each carrier, and lane volume guarantees state that a single carrier is awarded a minimum share of the volume moved along a transport relation.

The above enumeration of contractual pricing components is by no means complete but merely an overview of some commonly used pricing schemes and their application. It shows that freight rates are complex contractual constructs with limitless modification possibilities due to the underlying freedom of contract. In fact, freight rates in real life often reach a complexity that imposes high requirements on the modeling of universal freight rate cost functions for usage in transportation planning and optimization. The maintenance of this data for a transportation network covering all of Europe and including several hundred carriers on several thousand lanes is a major task (McLaughlin et al. 2003). It is therefore a key functionality of a TMS.

3.1.5 An Introduction to Freight Rate Degression

Freight transportation services have for the underlying case study been divided into two categories according to shipment size: (1) LTL shipments and (2) FTL shipments. Lapierre et al. (2004) determine the optimal rates depending on the shipment size by means of an optimization model. The resulting function clearly resembles a concave curve and will here be referred to as load degression (Fleischmann 2008a; Chan et al. 2002a).

Since fuel, labor and vehicles determine the main costs of transport providers, travel distance has a major impact on freight costs (Simons et al. 2004; Hall 2003). It can be observed that for long distances the travel costs per mile tend to be lower than for short distances. Fixed costs per order such as order processing fees, transit to the pick-up location and transit from the delivery location, as well as idle time for loading and unloading, are usually constant per shipment regardless of the travelling distance. This results in diminishing costs per mile, which will be referred to as distance degression (Moore et al. 1991; Rider 2003).

It is widely argued that outsourcing transportation services increases truck utilization, since the carrier not only can combine several shipments from different shippers but can also provide a one-way shipment with a backhaul shipment reducing the total distance of empty runs (Mentzer 1986). The carrier's chance of finding an adjacent order to a one-way trip is an influencing factor on the carrier's price calculation (McKinnon et al. 2004; Department for Transport 2006).

Based on a set of benchmarking freight rates that are derived from the German GFT, the *Güterfernverkehrstarif,* a detailed analysis of freight rates in continental road transportation is performed (for further details, see Appendix I). Having identified the major transportation cost drivers — distance and load size — these do not necessarily correlate linearly with transportation costs. Reality shows that in many cases we can find diminishing transportation costs with increasing load and distance (see Fig. 3.6). This follows the concept of economies of scale (Stolletz and

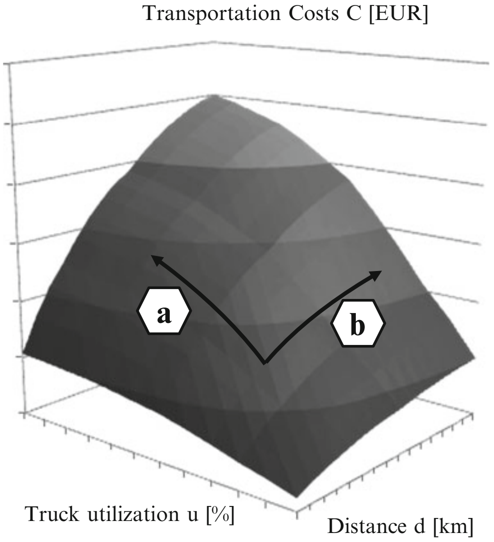


Fig. 3.6 Freight rate degression

Stolletz 2008; Blauwens et al. 2008). The following paragraphs provide an overview of the extent and some potential reasons.

Load Degression

Load degression can be defined as diminishing transportation costs with increasing transportation load resulting in lower transportation costs per piece. This can be observed exemplarily in the benchmarking reference: shipping 9 m^3 over a distance of 600 km will incur costs of EUR309.92 while transportation of 90 m^3 will result in costs of EUR801.72 for the same distance. The per m rate for 90 m^3 with EUR 8.91/m^3 is therefore 74% lower than the rate for 9 m^3 with EUR34.44/m^3. There are different reasons for load degression in real life freight rates:

- *Fixed Cost Allocation:* There is a set of fixed cost components for every transportation order, which are usually not allocated to the single cost drivers and are generally considered to be included (see above subsection). Only cargo mileage is usually billed; the empty ride to the dispatching location when considering an FTL shipment (or poorly utilized ride in LTL mode), as well as the empty transit after the transportation order has been fulfilled at the receiving location, is not billed separately. Even more so, as the empty rides are insignificant of the load size. Waiting times at the dispatching and receiving locations (waiting for shipping documents, waiting for free loading/unloading docks and additional idle time) are also incorporated. A maximum waiting time, which is included in the transportation rate, is usually fixed in the contract. Consequently, only the time exceeding the contractually agreed on period is subject to demurrage charges. Order processing at the carrier usually does not depend on the shipment size either. These processes include order acceptance, load assignment and invoicing.

- *Alternative Means of Transportation:* By offering an LTL service via a hub and spoke network, a carrier may, for small loads, compete with small carriers that could potentially offer the same service as an FTL service using smaller vehicles. However, these vehicles will only have a fraction of the capacity; still they produce higher costs per capacity unit (Blauwens et al. 2008). The resulting function resembles the described LTL cost function in shape. The LTL network carrier will need to offer the services at lower costs than these in order to remain competitive with regard to the in-sourcing option of a shipper.
- *Risk Allocation*: In the case of LTL shipments, one load is usually combined with loads from other shippers in order to utilize the truck fully. However, there are several reasons why these costs are not distributed evenly according to load sizes: Larger shipments will cover a base load for the equipment; very few of these shipments may be sufficient to operate a trunk line in a hub and spoke network efficiently, therefore the utilization risk is rather small. However, small shipments will only utilize a small fraction of the equipment and it is necessary to combine them on a trunkline with other shipments in order to transport these shipments efficiently. The utilization risk for carriers is therefore much higher for smaller shipments.

In practice, the extent of load degression also depends on the shipping distance. The per m^3 and km costs for small distances is more than ten times higher compared to larger ones for the same load. For distances longer than 600 km, this multiple remains at approximately 3.8. Reasons for the distance component in load degression are likely to be different transportation concepts. Long distances can be covered using a hub and spoke network architecture resulting in high trunkline utilization, whereas short distances are served without handling, resulting in a possibly poor utilization.

Distance Degression

Distance degression can be defined as diminishing transportation costs for a given load at increasing distance, resulting in decreasing transportation costs per mile (Domschke 1997). This can be observed exemplarily in the benchmarking reference for FTL rates: While costs for a 200 km trip amount to EUR354.28, costs for twice the distance sum up to EUR623.41, which represents a reduction in per kilometer prices by 12% from EUR1.77/km to EUR1.56/km. There are different reasons for load degression in real life freight rates:

- *Fixed Cost Allocation:* There is a set of fixed cost components for every transportation order, which are usually not allocated according to the cost drivers but are generally considered to be included. As already mentioned above, when only cargo mileage is billed, the empty drive to the dispatching location, as well as the empty transit after accomplishment of the transportation, is not billed separately; even more so, as it does not depend on the cargo mileage. It has also been mentioned before that order processing at the carrier is usually not dependent on the cargo mileage either. Cargo insurance is in many cases independent from the travelling distance (within the study focus of continental road transportation). The insurance that is provided by the carriers is therefore often also allocated at fixed costs.

- *Risk Allocation:* It is the carrier's risk to utilize the assets (trucks, trailers etc.) in order to operate the fleet efficiently. An average annual mileage between 120,000 and 150,000 km is suggested (NN 2009; Blauwens et al. 2008). Longer cargo mileage will reduce the carrier's risk to utilize its assets.

The per km costs for small shipments are approximately 4.8 times higher for short distances compared to longer ones. For bigger shipments this multiple is reduced to approximately 1.75. As mentioned above, load degression will decrease with increasing distances and distance degression decreases with increasing load. An explanation for this behavior may be found in the above mentioned fix cost allocation. It is evident that when offering LTL services for very short distances, costs for approaching, loading, unloading, and continuation will dominate total transportation costs.

3.2 Introduction to a Consumer Goods Case Study

Transportation planning in an outsourced network environment aims at the deployment of the above mentioned degression effects. Since transportation costs closely resemble the carrier's cost structure, it may be assumed that transportation cost savings for a given service are largely obtainable by efficiency gains. A popular means to achieve load degression is the adjustment of shipping lot sizes toward perfect utilization of a truck. With regard to the organizational units concerned with transportation this has historically proven to be difficult in practice. Since shipment sizes are usually determined by material order lot size, their determination is subject to planning tasks covered by other MRP processes. As they may very well feature transportation costs data as a vital part of their decision models, for the remainder of this text, it may be assumed that transportation lot sizes are not subject to alteration.

Within this setting, transportation orders specify the demand for transportation service. Once shipment information is available in the form of a transportation order, a process must be defined as to how these orders can be altered, combined or manipulated so that fulfillment of the transportation orders by an external carrier may be achieved at minimum costs. The baseline cost is defined by the existing orders rating each order as if shipped individually. Transportation costs amount to the sum of all orders transported individually. Any manipulation of the transportation orders will need to comply with restrictions concerning time windows, temperature and truck capacity.

Operative transportation planning is conducted based on given transportation orders for a determined planning horizon that is ideally congruent with the planning horizon for production planning and replenishment. In practice, this planning horizon usually spans one calendar week (Thonemann et al. 2004) from Sunday to Saturday (see also Lütke Entrup 2005). Production planning and replenishment processes are usually performed by the Thursday of the previous week. After these processes are completed, demand volumes and times are known for all locations in the network, and transportation orders are generated from this data. They form the basic data input for the operative transportation planning process. Carriers need a few days of advance notice before they can carry out a shipment, which is why operative transportation planning should be completed by Friday noon.

In the described process and network environment a static and deterministic planning problem with multiple origins and destinations is examined. Physical transportation is outsourced to a multitude of different carriers. All transportation orders are “open”; that is, after fulfilling a transport order there is no need for the equipment to return to the dispatching location (from the shipper’s perspective). Different temperature levels and equipment types have to be considered. However, the amount of trucks available for shipping is practically unlimited (due to outsourcing).

3.2.1 Transportation Activities Covered by the Case Study

The underlying case study for this research is based on transportation processes along the consumer goods supply chain. Since the planning focus within the underlying research has been laid onto transportation management in environments where physical transportation services are outsourced, transportation management analyses are performed with a focus on the consumer goods industry’s section of the supply chain. As supplying the retail outlets is a core competence of the retail organization and is often performed using a retailer owned fleet, this aspect will be excluded from the research scope. The average shipment size in this study is therefore expected to be rather large compared to smaller shipments serving the retail markets (Chan et al. 2002b). The case study is furthermore centered on continental road transportation; the applied methods of transportation planning, however, can be extended to meet the requirements of additional transportation modes.

In contrast to the retail controlled transportation processes that supply the stores in the manufacturer controlled section of the consumer goods supply chain, transportation is outsourced to transportation service providers. Transportation services are subject to a contractual agreement between consumer goods manufacturer and carrier. Every transportation requirement that occurs in the sourcing, production and distribution processes of the consumer goods manufacturer issues a transportation order. The appropriate carrier is mandated to fulfill the transportation order and is paid the contractually agreed amount. It is therefore of no relevance for the manufacturer which vehicle is used to fulfill the transport order as long as it meets the specified requirements. It is furthermore not relevant which order by which customer has been served before by the very vehicle or driver, nor is it necessary to have any knowledge about successive transport orders of vehicles or drivers. Transportation management for the shipper no longer includes vehicle or driver scheduling. These tasks are covered by the transportation service provider.

The case study will cover inbound material flows from suppliers to consumer goods manufacturing facilities. These transports are covered as far as the incoterm for the according supply relation for goods determines transportation to be the responsibility of the consumer goods manufacturer; that is, e.g., an FCA or EXW incoterm has been agreed upon. This is often the case for commoditized transportation processes that allow the use of standard transportation equipment. In cases where special transportation equipment is required (e.g., for milk, grain) transportation is often the responsibility of the supplier.

Transportation between production facilities is completely the responsibility of the consumer goods manufacturers. However, production has been concentrated in recent years to an extent that material flows between two production stages mostly take place within the same facility and do not require road transportation. A very common exception is the supply of flavor or fragrance essences, which are usually supplied to many different production facilities from few chemical production facilities. Therefore, material flows between production facilities are of minor significance to the transportation network.

The finished goods are usually moved from the production facilities to central warehouses and distribution centers where a substantial level of inventory is kept in order to be able to meet demand on short notice. The warehouses are usually operated on behalf of the consumer goods manufacturers and transportation also falls under their responsibility. Special packaging for sales promotions, as well as re-packing activities, is usually outsourced to co-packers. Transportation of packaging material to the co-packers and the return transportation into the warehouse takes place on behalf of the consumer goods manufacturer.

Finally, distribution of the finished goods from the consumer goods manufacturer warehouse to the customer receiving location is mostly the responsibility of the consumer goods manufacturer. Even though the manufacturer's responsibility is declining due to increasing popularity of factory gate pricing processes, the transportation volume controlled by the manufacturer is still significant (McKinnon and Ge 2006). The prevailing incoterms for this leg are DDP or DDU.

3.2.2 Case Study Objectives and Restrictions

The case study objective is best described as supplying the required transportation service at lowest possible costs. This has to be achieved by managing an outsourced transportation network without controlling the vehicles. Furthermore, origin and destination of all material flows are pre-determined as well as the transportation quantities. The latter may not be subject to alteration in any way.

The restrictions are numerous, and although the high amount of outsourced transportation services suggests high process standardization, a number of consumer goods specific aspects have to be considered. The short-term production schedules as well as the short replenishment times impose considerable requirements on punctuality, which are incorporated using tight pick-up and delivery time windows (Du et al. 2005). In this study, time windows are to be considered for loading and delivery operations. Therefore every transportation order contains four time-stamps that have to be met.

Since consumer goods assortments largely contain fresh food products, they require a certain storage and transportation environment. A significant portion of transportation has to be conducted using special refrigeration equipment in order to create a “chilled” or “frozen” environment (McKinnon et al. 2004). However, temperature requirements may only state a required transportation temperature; a deviation from this recommendation toward a lower temperature level may in some cases be tolerable (e.g., transportation of coffee in a chilled temperature environment).

Finally, the prevailing capacity restrictions in road transportation need to be considered. In the context of the underlying case study the euro-pallet serves as the standard handling unit. Loading space therefore will only need to be restricted according to pallet space. While in central Europe double layer equipment is often available for transportation, this equipment is not as popular in other regions. When using double layer equipment, pallets are usually lower and are loaded into a truck whose loading platform is separated horizontally with bars that the pallets are stacked on. Additionally, when using refrigeration equipment for transportation, the maximum weight capacity is reduced due to the weight of the cooling aggregate.

An overview of the input data for the investigated case study is shown in Table 3.1. This input data is generated from material flow requirements of an underlying MRP system and triggered by production planning, replenishment and customer orders.

Table 3.1 Data definition of a transportation order in the underlying case study

ID	Parameter	Description
Shipment ID	i	ID of the transportation order in the TMS
Origin Location	o(i)	Origin location of the transportation order
Destination Location	d(i)	Destination location of the transportation order
# Pallet Places	PS_i	Number of pallet places as inserted for transportation
Weight [kg]	W_i	Gross weight of the transportation order
Transport Product	t(i)	Temperature class required for the transportation order
Truck Type	p(i)	Truck Type required for the transportation order
Earliest Pickup	EPU_i	Earliest pickup date and time
Latest Pickup	LPU_i	Latest pickup date and time
Earliest Delivery	ESD_i	Earliest delivery date and time
Latest Delivery	LSD_i	Latest delivery date and time

3.2.3 Case Study Dimensions

The underlying case study features the dimensions of the continental transportation network of an international consumer goods manufacturer. They are inspired by some real life transportation management cases. All figures, however, have been derived from publicly accessible data and gaps are eliminated using assumptions as documented in Appendix III. Assuming a turnover of approximately EUR10 billion, which a large consumer goods manufacturer may generate within a large region (e.g., Europe, North America), a combination of the KPI found in Fig. 2.6 (p. 22) and Fig. 2.8 (p. 25) shows that roughly EUR400 million of transportation costs are expected.

These transportation costs cover the transcontinental shipments of the required raw materials and the intermediate and finished products along the consumer goods industry's section of the supply chain until they are delivered to the customer's DC. The shipped volume is estimated to amount to 14 million pallets and about 6 million tons. The average transportation distance of raw materials, intermediate and finished products to the consumer goods manufacturer's production facilities and distribution centers is assumed to be rather large (1,000 km). The distance for distribution to the retailers' DCs is considerably lower, averaging approximately 200 km. With regard to locations, the covered geography contains about 1,000 supplier, plant, warehousing and customer locations that are served. Some of these locations are merely of supplying nature (suppliers) while others are of a receiving type (customers). The plant and warehousing locations are both: sources and drains for transportation volumes. The locations are connected by 5,000 active transport relations, also referred to as lanes (Stank and Goldsby 2000). The resulting number of transport orders adds up to 500,000 orders per year. The weekly demand may vary between 5,000 and 15,000 transportation orders due to seasonal influence. Similarly, not all supplier, plant, warehouse and customer locations are served on a weekly basis. Supply relations are also subject to seasonal variations.

Chapter 4
Transportation Management in a Consumer Goods Industry Network

In this text, transportation management is described in three closely linked dimensions. In order to assess transportation management in the consumer goods industry, a comprehensive view on processes, IT systems and organizational structures is examined (see Fig. 4.1). A few principles have been followed in the preparation of this chapter:

- Transportation management is critical to overall logistics performance and total supply chain success (Caputo et al. 2003) for the consumer goods industry. The tools, methods and approaches collected and generated within this chapter are therefore of relevance for supply chain executives. However, taking into account the specific supply chain requirements of individual businesses, some ideas may not be applicable to every case. Fields of application are not generated, they must be identified. Therefore, this section consists of larger subsections of a purely descriptive nature.
- There are many more sectors of private and public affairs that feature transportation management issues. An in-detail assessment of consumer goods specific applications will, however, provide a deeper insight than a broadened assessment with regard to many industry and service sectors. Based on the results for the consumer goods industry, success factors may serve to identify potential additional fields of applications.
- Within this section, a clear focus will be put on transportation planning processes. As for the assessment of transportation management this material intends to primarily focus on the processes and from there deduct and describe IT systems and organizational structures as suggested by Hammer and Champy (2006). IT systems and organizations will only be assessed as far as they may be used to support these processes (see also Caputo and Mininno 1998).

The focus of this section will be on the three key processes for transportation management, which may be divided into transportation planning, transportation control processes and transportation execution processes. Transportation planning approaches are assessed largely based on a review of academic literature; within the subsection on transportation control the implementation of the generated transportation

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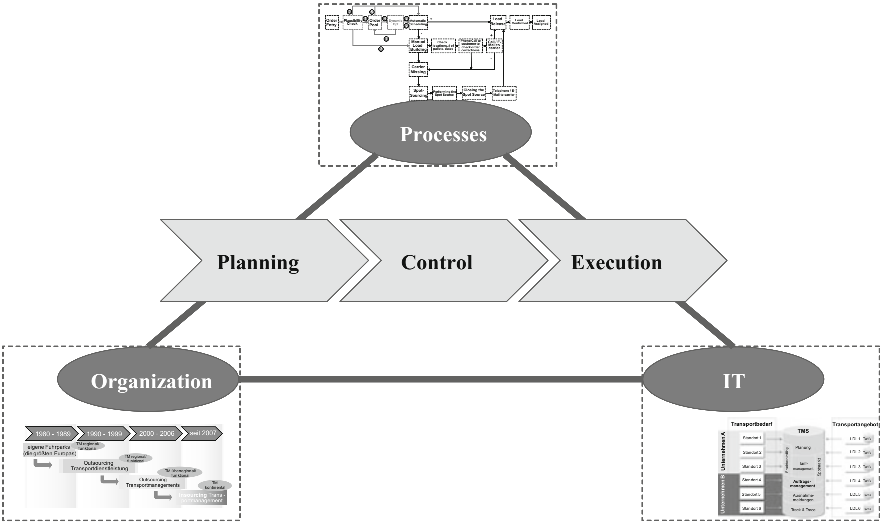

Fig. 4.1 Dimensions of transportation management

plans is addressed. The transport execution processes will only be briefly reviewed due to the fact that the execution process is outsourced to external transportation service providers. There are, however, numerous supporting processes that cannot be covered in this research due to limited problem focus. Processes such as planning data collection, aggregation, as well as the assurance of its quality, accuracy and plausibility, are of little relevance in academic research publications. An exception to this is found in Ballou (1991).

Although IT is by no means the only way of tackling complex supply chain decision making problems (Alicke 2005), the use of information technology in order to support supply chain management processes can no doubt be very fruitful regarding process quality and efficiency. Within the transportation control and execution section, processes have been described that are today already subject to extensive software support in many business environments. The focus of this subsection is therefore put on real life software implementations and their assessment regarding applicability in the consumer goods industry. With supply chain management still being one of the key reasons for extensive IT investments (Grocery Manufacturers Association 2008a), a particular focus will be put on the level of integration of transportation management software in today's complex IT environments.

The outsourcing wave of logistics and manufacturing processes has altered organizational structures significantly and left whole branches in the organization charts orphaned. Tasks that were formerly integrated under one legal umbrella are now shared between different actors with their own economic objectives. The constellations investigated require thorough contractual design and controlling (Wilding and Juriado 2004). In the consumer goods industry, organizational units that were formerly responsible for operational tasks such as transportation or warehousing are now responsible for controlling and adjusting the performance of several external service providers entrusted with the operational tasks (Sheffi 1990).

4.1 Processes

Transportation management processes are driven by a transportation demand, which in turn is deducted from goods demand (Daskin and Owen 2003). The demand of final products with its regional and temporal distribution is exogenously defined as for the multitude of transportation planning processes (Chopra and Meindl 2007). The shortening of the planning horizon will usually increase the number of exogenously defined planning parameters. As for transportation control processes, decision freedom is usually very small and these processes are subject to efficient communication and exception handling. From the perspective of a consumer goods manufacturer the involvement in transportation execution is minor and largely limited to loading and unloading operations.

Within the transportation planning subsection of this chapter a detailed assessment of approaches to transportation planning is conducted. First, the relevant planning horizon and the required planning data are determined. Afterwards planning objectives are investigated and compared. Since transportation cost reduction is the primary objective in the described case study, the representation of real life transportation costs and rates is a key criterion for the applicability of planning approaches. The execution of transportation planning results is subject to transportation control processes. This subsection features an overview over processes within the lifetime of a transportation demand, from demand generation to the settlement of payments associated with it. Transportation execution processes that are of relevance to the shipper will be addressed briefly. As a result of the process assessment, IT and organizational requirements are deduced and will then serve as input for the following subsections.

4.1.1 Transportation Planning

A vast body of literature on transportation planning has been published comprising various aspects of planning requirements. Crainic and Laporte (1997) differentiate three levels of transportation planning:

- Strategic transportation planning takes place with a long planning horizon primarily defining the network structure with relevant locations (i.e., warehouses, distribution centers, cross docks) as well as general transportation processes and desired service levels. Decisions are usually made on highly aggregated data.

- Tactical transportation planning still uses aggregated data for an optimal allocation of resources. In particular, information detailed to a daily level is not incorporated into the decision models (Crainic 2000).
- Operational transportation planning incorporates the most precise planning level where resources and requirements are described at a highly detailed level. It is usually performed by local management in a highly dynamic environment.

Strategic Transportation Planning

The strategic network design process determines the layout of the network — that is, the position of locations within geography and each other's connection with transport relations. The planning horizon covered often exceeds 5 years (Crainic 2000). Within the network design process, the demand locations as well as the temporal distribution of demand volumes are usually given (e.g., derived from demand planning) and not subject to alteration. Often, customer demands are subject to further restrictions, for example, a maximum order to delivery lead time. Within a very long-term planning horizon one of the tasks is to determine the geographical locations of factories, suppliers and warehouses (Crainic 2000); that is, in this step the network nodes are determined within geographical and temporal dimensions (opening or closure of locations). The assignment of products to these nodes then features the production program of a plant or the assortment of a warehouse. In addition, decisions regarding the network arcs — that is, transport relations are made within a network planning process. This usually includes decisions such as which plant is supplied from which supplier location or which customer demand is met from which warehouse. The planning objective is usually an economical one aiming at low costs and high profits. As a result of strategic network design a number of locations will be opened in the future and there are those that may be closed (Wolff and Groß 2008). Furthermore, a production program or storage assortment can be obtained from the results. The sources of supply are given for plants and warehouses. Finally, the product deployment to customer orders is another result of strategic transportation planning, although it is not directly understood as a part of transportation planning (Fleischmann 2008a) but as a material control or ATP function. Its parameterization therefore is part of a strategic transportation planning and network design task. In order to reduce planning complexity and because of flawed data due to the long planning horizon, the aggregation level of the input data is usually very high; that is, products may be aggregated to product groups; customer demand may be aggregated along large time spans, and customer locations may be aggregated to location groups (Crainic and Laporte 1997).

As transportation network design will substantially impact supply chain performance as well as transportation costs (Chopra and Meindl 2007), many contributions on how to assess these problems can be found — for an overview, see Crainic (2000). A broad overview on location problems is given by Daskin and

Owen (2003). Often the following trade-offs are addressed within the problem formulations:

- Transportation and inventory cost trade-off (Chopra and Meindl 2007),
- Transportation and handling cost trade-off (Stank and Goldsby 2000),
- Transportation cost and customer responsiveness trade-off (Chopra and Meindl 2007).

As for problems with an existing location footprint the most common mathematical formulations are based on the *Multi Commodity Network Flow Problem* (MCNFP) (McBride 1998; Schönberger and Kopfer 2005). Problem specific adjustments to the basic formulation can be found in the following:

- The *Multi Commodity Capacitated Network Design* (MCND) approach incorporating capacity restrictions (Crainic 2000),
- The *Path based Multi Commodity Capacitated Network Design* (PMCND) approach (Crainic 2000).

It may surely be argued that the latter problem formulations and solution approaches based on the MCNFP must be regarded as primarily tactical decision problems. Since assortments and supply relations are not necessarily of strategic impact and may be reversed at short notice some detailed problem instances may be regarded as of tactical or even of an operational nature (Wieberneit 2008). However, since changing the capacities of existing locations may also result in substantial investments with long-term effects, the entire problem instance is determined as strategic.

While strategic network design and strategic process planning focus on network arcs as well as on nodes, emphasis of strategic transportation planning is shifted toward the arcs or transport relations (Crainic 2003). The previous processes have determined the requirements for transportation processes that will need to be met within transportation planning. Examples for such requirements are transportation service level and shipment dimensions. They furthermore might arise from product requirements, for example, refrigeration.

Even though the detail level of planning has increased, the input data is still aggregated, partly due to long-term decisions. Decisions regarding the make or buy alternative of transportation services have to be made (Baker and Hubbard 2003). This is usually not determined for the complete transportation network at once, but different parts of the network may be served in different ways. For instance, in many retail networks, transportation into the warehouses is performed by external transportation service providers (and is therefore outsourced) while the delivery of goods into the stores is often taken care of by the retail company's operated vehicle fleet. Furthermore, a mixture of make and buy is sometimes also applied to the same network section: a baseload is covered using the retailer's own fleet of vehicles and excess transportation demand in the event of peak loads may be outsourced to external carriers (Wilding and Juriado 2004). For those network sections that have been identified to be served by a company's fleet, the fleet structure is determined within the strategic transportation process. Planning tasks include the determination of the number of vehicles of each vehicle type, the period of deployment and depreciation if applicable, and the way the vehicles are financed, maintained and serviced (Blauwens et al. 2008). The general sourcing strategy for transportation services concerning network sections served by external carriers is determined within strategic transportation planning. This may include contract durations, single vs. multiple sourcing strategies and bidding procedures (Crainic 2000; Stank and Goldsby 2000). In cases when long-term contracts or contract frameworks are applied, the tendering of these contract volumes is part of the strategic transportation planning process.

Tactical Transportation Planning

Tactical transportation planning decisions are usually made for a mid-term planning horizon (approximately 2–12 months) using aggregated data. Tactical transportation planning is therefore bound to consider seasonal variations and mid-term trends. Products are generally assigned to transportation concepts (e.g., direct transportation, hub shipment or milk run). For material flows with little volatility, these decisions can be fixed. In case of varying shipment sizes they are flanked by according parameters (e.g., if shipment size is smaller than 1 ton then route shipment via hub). For continuous material flows, transportation frequencies are determined. These in turn determine the transportation lot sizes or shipment sizes. Crainic (2000) integrates routing decisions into the tactical transportation planning process and gives very illustrative examples. One alternative is the consolidation of a material flow with other flows going directly to its destination terminal and moving it by using one of the available direct services. Another alternative is moving the flow by using a service that stops at one or several other terminals to drop and pick up traffic. It is furthermore possible to consolidate the shipment into a load for an intermediate terminal where it will be reclassified and consolidated together with traffic origination at various other terminals into a load for its final destination. Finally, it may be put on a dedicated service, truck or direct train, if the freight volume is sufficiently high and the customer contract allows it. Tactical transportation planning is of special relevance in cases when the goods form a steady flow through a transportation network. This can be observed in the automotive industry, where a continuous production line is supplied with material from a number of suppliers.

Tactical planning in terms of service network design is deployed to plan services and operations to answer demand and ensure profitability (Wieberneit 2008). In past years, however, the key objectives have changed from a mere fulfillment approach to a consideration of speed, flexibility and reliability objectives that today have to be met at lowest possible costs (Crainic 2000). An overview of service network design problems and solution approaches is given in Wieberneit (2008).

According to Crainic (2000), tactical planning may again be categorized into a tactical/strategic (frequency service design network models) and a tactical/operational (dynamic service design network models) approach.

- For service frequency determination as a decision variable, a model formulation similar to a.m. PMCND is introduced by Crainic (2000). It may be extended to incorporate service quality regarding delays due to congestion and so on, which will result in a nonlinear mixed integer, multimodal, multicommodity network flow problem.
- Dynamic service network design can be tackled by using a space-time network representation that will replicate the underlying physical network in each period, which increases model size drastically (Crainic 2000). The problem has been solved using different types of heuristics (Crainic 2000).

Within outsourced transportation networks, annual tenders are another important application of transportation planning. Based on historic transportation volumes, lane information and volume forecasts a *request for quotation* (RFQ) is distributed to a pre-defined set of carriers. After their quotes are submitted, the selection of carriers per lane or region is performed; the resulting problem may be characterized as a capacitated auction problem (van Norden et al. 2006).

Additional problems in tactical transportation planning, with little relevance for the presented case study, include (Crainic 2000):

- Problems of traffic distribution along alternative routes,
- Terminal operations policies that determine cross-docking procedures,
- Policies for general empties balancing for transportation equipment (e.g., containers, transportation racks or trailers — see also Mattfeld and Huth 2009).

In summary, tactical transportation planning problems are as numerous as are the solution approaches. With regard to the specific requirements within the consumer goods industry networks, however, only few of these approaches are relevant and not yet subject to application.

Operational Transportation Planning and Scheduling

Operational transportation planning focuses on short-term decisions based on shipping orders. Planning is no longer executed based on continuous material flows but on transportation orders that quantify origin, destination, quantity and date of a transportation task. The availability of this information determines the planning horizon, which usually stretches from a few hours to a couple of days. Operational transportation planning focuses on lane operation decisions determining mode and carrier choice (Stank and Goldsby 2000). The planning scope is mostly limited; Crainic (2000) refers to a local planning process. The implementation of transportation schedules and their adjustment are also part of the operational transportation planning process (Crainic 2000).

As for the described case study, the transportation planning task will have to be classified as operational. However, it is not performed on a local level but at a central organizational unit. In the following paragraphs a selection of well-known operational transportation problems is described and assessed based on their applicability to the described case study.

It is perhaps one of the major misunderstandings in operational transportation planning that vehicle scheduling should only be performed if the vehicles are used exclusively for the supply chain under consideration (Fleischmann 2008a). This is usually the case, if the transportation services are carried out by a company's own fleet of vehicles. However, even though an LSP can use a vehicle for multiple clients outside the considered supply chain and this may be a major contribution to the efficiency of the transportation process, scheduling support from the shipper side may yet increase overall efficiency.

Kopfer (1984) presents a freight optimization concept with a real life freight rate representation of LTL and FTL rates considering both load and distance degression (see also Kopfer 1992). It is the objective to minimize freight costs by consolidating shipments under a given cost structure using a genetic algorithm. However, since the focus is mainly on LTL shipments and does not incorporate strict time window restrictions, the applicability to the given study is limited.

Meixell and Norbis (2008) present a thorough literature review on transportation mode choice and carrier selection, in which they address issues of distance and load degression as one field that requires further research. In this area, Moore et al. (1991) have presented an early approach for solving a central dispatching problem using a mixed integer programming approach for minimizing transportation costs based on a one- to three-day planning horizon. Even though their study is based on a real life case, which is derived from metal production, the absence of time windows and the focus on a rented but dedicated fleet of trucks is limiting the applicability of this approach to the presented transportation planning problem. Caputo et al. (2005) present a thorough analysis of rate structures in a European road transportation network resulting in a decision support system for transportation managers. In their paper, the complexity of carrier and mode selection is described in detail and the presented approach helps to select the optimal mode and carrier for a given set of shipments and rates. The proposed system is designed to support the logistics manager, freeing him from manually comparing each possible shipping alternative and giving him more time to consolidate shipments and negotiate rates. However, this approach does not consolidate the shipments automatically and will therefore not be able to access the cost saving potential resulting from load and distance degression. An approach to consolidate shipments in a distribution network is presented in Caputo et al. (2006). Based on FTL and LTL freight rates that are valid for specific zones, an aggregation approach is developed consisting of three steps, especially designed to consolidate LTL shipments. They decompose the problem regionally into subgroups in the first step, then generate a set of possible solutions for every subgroup in the second step from which one solution is selected using a genetic algorithm in the third step. The solution applies to mainly converging or mainly diverging networks due to the zone-wise freight rate representation. For this and due to lacking time window specification, the approach is of limited relevance for the described planning problem. The upfront decomposition according to freight rate zones and their compatibility is furthermore expected to omit consolidation opportunities that may exist between two zones. It is limited to an implementation environment in which rate zones are the preferred type of contractual agreement regarding freight rates.

Savelsbergh and Sol (1995) integrate the well-known and well-studied Pickup and Delivery Problem (PDP), the Dial-a-Ride Problem (DARP) and the Vehicle Routing Problem (VRP) into one model called the General Pickup and Delivery Problem. They present a review of different problem instances. Since all of them are based on an existing fleet of vehicles, the resulting problem formulations are of minor relevance for the planning problem at hand. However, the VRP is of major relevance for transportation planning tasks performed further downstream the supply chain that supplies the retail outlets from distribution centers and warehouses (Golden et al. 2002).

Chu (2005) presents a problem in which distribution can take place either with a shipper owned fleet (FTL) or with an external LTL carrier. The proposed solution approach is based on an objective function minimizing costs by generating single customer tours that are served by LTL mode and multi-customer routes that are served by the shipper’s own fleet. Although the representation of LTL costs is very flexible and therefore in favor of a realistic approach, the high utilization of the shipper’s own fleet and the absence of time windows is a shortcoming.

It is often stated in literature addressing transportation planning solutions of real life size and complexity that some approaches lack practical applicability (Caputo et al. 2005; Meixell and Norbis 2008). Many approaches are set up to work without dedicated cost functions and minimize fleet size or total distance travelled. The discussion as to what extent these approaches qualify as decision support for questions of economic relevance are left for those bearing the responsibility of transportation costs. However, any approaches implementing cost functions must be measured against how accurate a representation of real life costs is possible. As freight rates in many regions are subject to freedom of contract, the contractual partners can (and will in many cases) create complex cost and cash flow effective clauses whose consideration will lead to a multitude of different components of an objective function to the underlying optimization problem.

4.1.2 Transportation Control Processes

The transportation control processes have received little academic attention from an operations research and operations management perspective. While transportation planning and scheduling processes determine the use and deployment of resources, transportation control is mostly associated with the preparation of transport execution and with exception management (Stank and Goldsby 2000). In environments with continuous material flows, transportation control determines the actual selection of transportation mode and the authorization of the assigned carrier. In the dynamic consumer goods industry this feature is covered by the operative transportation planning tasks. And since the consumer goods environment is not characterized by continuous material flows, transportation control is largely an order-triggered process of informing the relevant parties (dispatcher, recipient, carrier etc.) of the status of material movement (Caputo et al. 2003). Transportation control processes in the consumer industry today are largely managed by relying on IT systems. In accordance with Klug et al. (2009), these processes are subject to detailed description in the IT section of this chapter (see especially 4.2.1).

4.1.3 Transportation Execution Processes

For the investigated transportation processes in the consumer goods industry, transport execution is the key task of the contracted logistics service provider because transportation is usually outsourced. Therefore, operational decisions such as route choice in cases of road congestion are not addressed in this text but are left to the service provider. According to the applicable incoterms that clearly define the roles and responsibilities of the involved parties in the transportation process (see Sect. 2.1.3), vehicle loading and vehicle dock scheduling (Fleischmann 2008a) are usually the responsibility of the shipper, that is, the consumer goods manufacturer. Dock operations at origin locations include the loading of the vehicles that represent a bin-packing problem with additional restrictions such as weight distribution (for balanced axle weight exposure) or for arranging the goods according to the unloading schedules (Stank and Goldsby 2000). In addition, loading and unloading also account for the majority of quality issues either due to damages at loading operations or to inappropriate load securing measures. The prevention of damages is of special importance due not only to scrapping expenses but to rising stock-out risks if goods that have been planned for are not available as result of quality issues.

4.1.4 Summary

In this subsection several transportation planning tasks, problem formulations and solution approaches have been presented. However, many authors have addressed their concerns regarding the practical applicability of some of the proposed approaches (Caputo et al. 2005; Meixell and Norbis 2008). The key question on how to increase transportation efficiency in the consumer goods industry as observed in Sect. 3.1.3 has to be answered on different levels. Strategic network design problems have been subject to many contributions in academic literature, which cover the specifics of the consumer goods industry to a great extent.

The decision toward broad outsourcing of transportation activities has been adopted by all key players in the relevant markets. This, together with the very dynamic behavior of material flows as a result of production planning and scheduling, has limited the applicability of tactical transportation planning to mostly network specification and carrier management, which are largely met. Operational planning and scheduling is today mainly left to the carriers and only selected tasks of transportation control and execution remain with the consumer goods manufacturers.

Therefore, when looking at transportation processes in the consumer goods industry the question on how to increase transportation efficiency must be answered in a deductive manner. If available network design methods were insufficient or used inadequately the loss in efficiency would be too serious to maintain competitiveness. Tactical implications are, however, of minor relevance for transportation processes. Therefore, the operational planning level remains the key area in which to induce overall efficiency improvements. It has been pointed out that existing operational planning approaches lack applicability for real life planning problems in the consumer goods industry for two main reasons:

1. Outsourcing — this leads to an almost infinite transportation capacity available to the shipper. Models that focus on fleets are usually bound to optimize asset utilization and not overall efficiency.
2. Freight rates — as a result of outsourcing, freight costs are subject to freedom of contract and will in many cases take very complex structures. Most planning approaches are limited to a few freight rate representations of which some are questionable regarding the actual forces on transportation markets.

Even in areas where methodical process support seems sufficient in availability and actual level of implementation is high, approaches that focus on the solution of partial problems must be integrated into a complete transportation process landscape. Therefore, information availability for the relevant decision makers is a key enabler of efficient transportation processes. This is one of the emphasized aspects within the next subsection.

4.2 IT Systems

IT support has been one of the main drivers for process innovations in recent years. And the involvement of information technology in transportation planning has been identified as a vital means to decrease cost and increase responsiveness in a transportation network (Chopra and Meindl 2007). However, current broad ERP and APS implementation only feature very limited functionality with respect to transportation planning on a tactical or operational level (Fleischmann 2008a). The specific functions are often rather simple: rule-based heuristics or mathematical operations (Fleischmann 2008a).

In recent years, transportation management systems (TMS) have gained attention across all industries (House and Jackson 1995). They are defined as "software applications that facilitate the procurement of transportation systems, the short-term planning and optimization of transportation activities, and the execution of transportation plans with continuous analysis and collaboration" (Helo and Szekely 2005). And while in the past information availability has been a key obstacle in many cases to performing high quality transportation planning (Stank and Goldsby 2000), with the implementation of TMS, this information does become available at high quality standards. The consumer goods industry has been aware of the importance of transportation problems for a long time (Lebensmittel and PwC 2002), and as such has been the first to implement TMS for a broad process scope.

As TMS suites are integrated, they are extended to include all aspects of transportation management from planning to real-time tracking and tracing, and from freight tendering to payment services (Woods 2006). Today, in those cases in which ERP software vendors offer some TMS functionalities, these have often been acquired by mergers and acquisitions, probably the largest being the takeover of G-Log by Oracle and more recently the acquisition of i2 by JDA.

Woods (2006) explicitly differentiates between true TMS solutions and fleet based routing and scheduling software. The described functions are related to this understanding of TMS due to the high proportion of outsourced transportation services in the consumer goods industry. Producers of consumer goods will need the efficient management of numerous transportation orders conducted by several carriers. McLaughlin et al. (2003) present a case study on the implementation of a TMS, although they do not use the term TMS but refer to the implemented system as a "business process tool for freight management." This may be understood as a very suitable definition, as essentially today's TMS are transaction-based order management tools.

In the past, demand for TMS services was mainly triggered by managers of large transportation networks, confining the number of potential users to a few enterprises. With transportation costs taking up a larger part of total supply chain costs, the implementation of TMS solutions is also becoming increasingly worthwhile for small and medium-sized businesses. At the same time, the innovation focus has shifted from strategic planning processes (e.g., support of total cost sourcing decisions) toward improving the operative planning and scheduling features (Cap Gemini Nederland 2007). However, the number of TMS vendors that operate successfully on a global scale is very limited (Connaughton 2008). The leading global vendors of TMS are currently i2 and Oracle (G-Log), closely followed by JDA (Manugistics) and Manhattan Associates (Woods 2006; Connaughton 2008). Lauterbach et al. (2009) indicate that SAP introduced the first release of its TM module in November 2007 (release 6.0). However, Connaughton (2008) notes that the customer base is still very small and market feedback from customers is limited. It is expected after the second release of SAP TM and after the ramp-up of the first customers has been completed, the system will become a serious competitor. However, there are also a large number of small TMS vendors that challenge these software companies successfully in their home markets, since the regional TMS markets have been dominated by a large number of local players who are best at understanding the specifics that apply to the transportation markets in their home regions (Cap Gemini Nederland 2007).

4.2.1 The Basic TMS Process

The basic TMS process can best be described by dividing it into six process steps (see Fig. 4.2). It is triggered by a transportation demand resulting from a sales order, a purchase order or a stock relocation (Daskin and Owen 2003) and therefore usually initiated by the according transaction in the ERP system (Faber and Ammerschuber 2008).

1. In step one a transportation order is generated, usually based on a material movement triggered in an ERP system. Data concerning the dispatching location, the receiving location, the transportation load and the planned dispatching and receiving times is consolidated — in addition, process specific fields may be added (e.g., hazardous material classification, temperature restrictions and so on). With the transportation order coming from an ERP system, a great deal of ERP-specific information may be abandoned — since a transportation order may (and will in many cases) contain a number of different goods and articles (material), this information will only be taken into account as long as it is relevant to the transportation process (McLaughlin et al. 2003). The TMS will therefore in most cases not need detailed material master data.

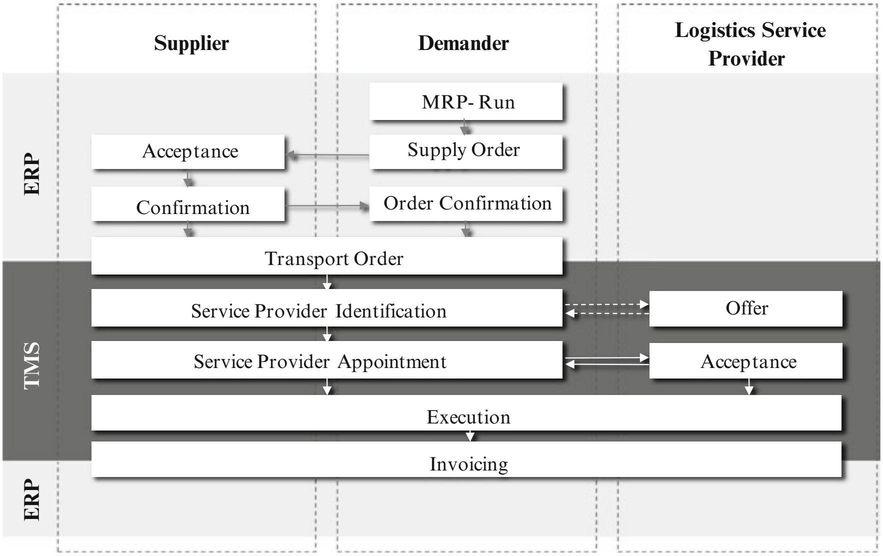

Fig. 4.2 Transportation management process

2. Once an order has entered the TMS, the mode and carrier selection is performed. Mode and carriers are selected based on costs, service (e.g., transit time) and other criteria specified in the order (e.g., lead time, equipment requirements). This way transport orders are transferred to loads that can then be automatically assigned to a preferred carrier. This process step is therefore often referred to as load building.
3. The information on the created load is transferred to the carrier within a defined lead time — once the carrier receives the order a confirmation (or rejection) has to be released within a defined time frame.
4. Step four consists of the physical execution of the transport order. Within this process deviations may occur due to delays, waiting times or product damages. This information may be inserted into the TMS at the dispatching or receiving location using a scheme of reason codes for the incorporation of surcharges or discounts. Reason codes can also be a major contribution toward a root-cause analysis of transportation process irregularities (Thonemann et al. 2004).
5. After physical transportation is concluded, the billing process is conducted according to freight rates, surcharges and rebates (based on reason codes) as well as further terms and conditions (e.g., payment terms). Different billing processes may be incorporated. Standard processes supported by TMS may range from freight bill auditing (carrier invoice) to self-billing. As the former is usually a very time-consuming and error-prone process if conducted manually (Sheffi 1990), a TMS implementation may not only increase efficiency but will also result in a considerably lower number of erroneous invoices.
6. The final process step consists of the settlement of freight invoices through payment. This process step is very likely to include the second major system break because the settlement of payments usually takes place within a company-wide system (Helo and Szekely 2005). Therefore all payment information is usually transferred from the TMS.

The process overview serves as a rough description of the standard transportation control process in a TMS. Due to the described procedure spanning the lifecycle of a transportation order, a TMS can be described as transaction-based, since it is transactions that lead to changes in every order status. However, TMS functionality is more than mere process support as the following paragraphs show.

4.2.2 Key Functions of TMS

There is a variety of functions offered by different TMS vendors; however, it is understood that from a shipper's point of view, the following may be considered core functions (Woods 2006; Neft 2004; Werle 2010) (see also Fig. 4.3):

- *Transportation Order Management and Status Tracking:* The major tasks of the transportation order management function are order input, order specification and carrier selection (House and Jackson 1995). Order input and generation may

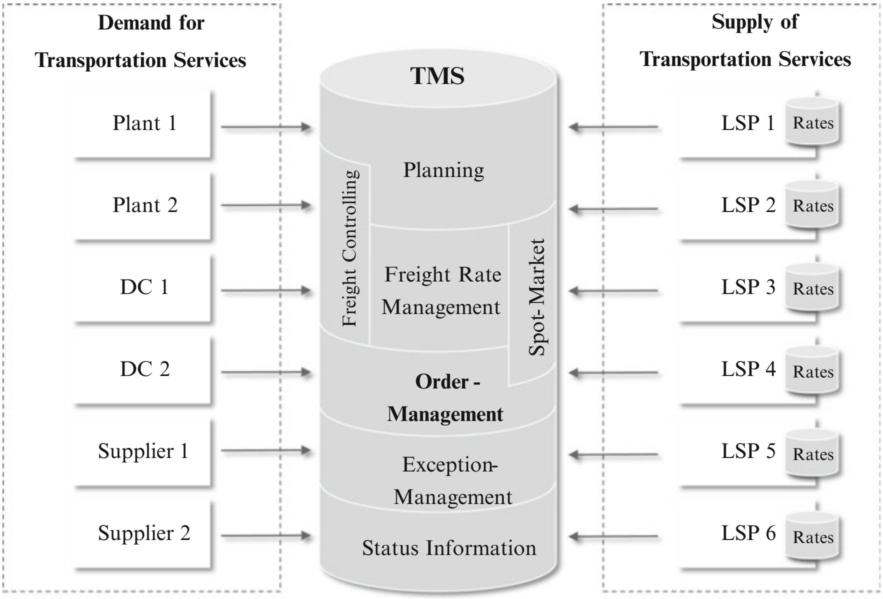

Fig. 4.3 Overview — functions of transportation management systems

take place via interfaces to an ERP system. Order specification is usually rule based (e.g., a product that requires chilled transportation or a customer location that can only be served with small trucks) and may contain requirements regarding transportation equipment as well as time windows. Transportation order management therefore includes operational transportation planning, carrier communication, load building and freight rating (Stank and Goldsby 2000; Bierwirth et al. 2002). Since status tracking requires a large amount of frequently updated information, interfaces to the surrounding IT infrastructure are of vital importance for a consistent and valid status report (Helo and Szekely 2005). Advanced solutions do not merely focus on ERP connectivity but extend toward the telematics and tracking-and-tracing systems of the carriers and service providers (Schweikl 2007). This information is then used for a pre-defined, rule-based path of escalation that determines the appropriate and prompt reaction to process exceptions (e.g., unpunctual shipments). Order management also includes shipping documentation and may be extended toward carrier specific labeling of the handling units (Helo and Szekely 2005).

- *Freight Rate Management, Freight Cost Management and Billing:* Apart from storing the complex contract structure that prevails between shippers and carriers, this function is also designed to support the long- and short-term tendering processes. Advanced systems do not only price several offers from different bidders, but they can also dynamically determine contracting volumes by assigning groups of lanes or regions to certain carriers so that minimal costs can be achieved (Stank and Goldsby 2000). Short-term tendering (spot sourcing)

focuses on ad-hoc bidding for rare lanes that are not covered by long-term contracts and must be considered a core functionality (Helo and Szekely 2005). This function is vital in order to control a flexible network using standardized processes. Even though many enterprises have outsourced freight payment and audit functions (House and Jackson 1995), the implementation of an integrated TMS might be a reason to revisit the outsourcing decisions (Werle 2010). The billing functionalities range from invoice checking and self-billing to automatic credit memo procedures. The extended functionalities will also allow non-asset based third party logistics providers to bill their customers with the opportunity of splitting costs between different customers.
- *Performance Measurement:* These functions cluster around detailed transportation controlling and mainly focus on the cost/budget alignment (Rider 2003). They entail opportunities for service provider assessment and location performance measurement. Those include carrier performance concerning shipment punctuality and transportation damage evaluation. Network controlling may produce KPI such as the carbon footprint.

TMS solutions are often enriched with further specific add-ons such as strategic network planning capabilities or packaging monitors organizing the inventory management and distribution of empty containers. Still, TMS can generally be understood as transaction based order management tools that continue to lack specific features for transportation planning.

4.2.3 Extended Functions of TMS

While the key functions of TMS focus around the efficient processing of transportation orders throughout their lifecycle, some TMS extensions feature additional functionality. The form and degree of integration of those extensions differ largely between the different vendors of TMS. In many cases functional extensions are software products supplied as add-ons by vendors other than the TMS vendor (Vastag and Kellermann 2006).

Geo Information Service Components

One central add-on that has become a very common extension for TMS implementation is Geo Information Services (GIS). These services are built around digital representations of geographical maps and can be subdivided into three categories:

- *Geo-Encoding Services*: Based on location address data such as country, zip code, city and street name, the geo-coordinates of relevant locations are determined. Geo-coordinates are a prerequisite to display locations on maps and extend the common location master data (House and Jackson 1995). They form the basis of the two following categories.

- *Routing Services*: Transportation routes between two locations can be determined based on the geographic information of locations. Similar to satellite navigation in today's cars, different routing parameters can be specified and weighted against each other: short distance vs. short transit time, avoidance of toll sections and so on. In addition, road restrictions for heavy vehicles, height limitations or restricted access for dangerous goods transports can be taken into account when determining routes. Due to the strong prevalence of these services for private and commercial road traffic, data availability and accuracy for road networks in industrialized regions of the world is very good. In other transportation modes such as rail networks, ferries or shipping lines the informational aggregation within one service is usually poorer. Road-based transportation management processes are fulfilled by routing services in order to determine the applicable distance and transit times between locations (Neft 2004). Distance information is particularly relevant when transportation rates have a distance dependent component. Routing information may serve as actual driving instruction for the execution.
- *Mapping Services*: These services allow the presentation of locations, transport relations and routes on maps. This may support decision making as to carrier or route selection.

There are currently two global players on the market for digital maps — namely, Navteq and Teleatlas, the former was acquired by Nokia in 2007 (Navteq 2010). In addition to licenses for the usage of their digital maps, the two companies also offer service packages including routing and such geo-encoding services as add-ons for software packages such as TMS.

Planning and Controlling Components

The current focus of TMS implementations is on transportation order processing and service provider management. However, they usually lack an integrated network and transportation planning approach. Again, such components can be offered as software add-ons for TMS originally supplied by other vendors. Functionality may include the following:

- *Advanced Transportation Controlling*: Some TMS can be extended using standardized controlling features and reporting functionalities. These may be the same ones as supplied in the ERP environment and are in accordance with a company's reporting standards. They may also be used to monitor transportation performance and therefore serve as an indicator for network design measures.
- *Network Design*: Based on the available data, network design measures may be investigated and prepared for implementation. The customer/DC assignment (which customer is served by which DC) may be changed, for example, due to capacity shortages in one DC. In this case some customers may be re-assigned to other DCs with sufficient capacity. The according parameters can be adjusted in the TMS (and — if required — in the ERP). However, the integration of

strategic/tactical processes in a TMS is rarely found in current TMS implementations, and integration of these processes may therefore be regarded as generally poor with only few exceptions.
- *Tactical Transportation Planning*: In cases with continuous material flows with little volatility, tactical transportation measures such as transportation modes or even tours may be incorporated using add-ons. Since these planning tasks are often very specific, their implementation is usually not subject to strong standardization but to individual system adaption. As for the consumer goods supply chain these approaches lack applicability due to non-continuous material flows.
- *Transportation Tendering*: Tendering add-ons support large transportation tenders (e.g., for annual tenders). These tenders are usually split into several bid packs that are subject to quotation by several carriers. The allocation of carriers to bid packs may be understood as a capacitated auction problem as described in Sect. 4.1.1. For full-scale tendering add-ons, distribution is also limited to a few implementations.

Track and Trace Components

Detailed status data for shipments are valuable information for all involved parties engaged in the transportation process (Schweikl 2007). The timely knowledge of potential delays may allow early countermeasures such as the re-scheduling of connecting transports or other process steps, for example, production. Furthermore, detailed status data will help to monitor carrier performance in terms of on-time deliveries and time-window adherence. Moreover, such data can be a valuable contribution to the calculation of penalty charges such as demurrage. In TMS implementations two types of status tracking can be differentiated (Sulzmaier and Barthel 2006):

- *Integration of Service Provider Status Tracking*: Many parcel and document shipping companies are known to offer their own status tracking via their websites. They usually obtain the shipment information from the identification processes that take place at every location at which the shipment is handled. This information is not only available at the shipping company's website but can be obtained using proprietary interfaces and thus be made directly available in other systems such as TMS. Many TMS suites already have interfaces to some of the large carriers. The information may get even more detailed when integrating information on vehicle location and vehicle speed. This data may be obtained using telematic information systems. The propagation and standardization of these systems and the obtained data is currently limited to isolated application environments.
- *Implementation of Independent Tracking Technology*: In order to be independent from potentially flawed carrier information, the shipments may be tagged using shipper owned Geo-RFID systems. If a transmitter is added to the shipment it

will broadcast its position using mobile-communication networks in a predefined interval. Making this data available in the TMS will increase shipment visibility independent of the assigned carrier. However, the implementation of this technology is currently still in progress and is only used in very specific circumstances. Still, this implementation may prove very worthwhile for the fresh food section of the consumer goods industry, as cool chain monitoring may be integrated into the transmitters, and failure to retain the agreed transportation or storage temperature may be detected immediately using temperature sensitive transmitters.

The application of extension services to TMS implementations seems without boundaries yet many of these add-ons lack broad applicability. The number of available add-ons shows that the ability to integrate transportation management solutions in surrounding process and system environments may increase the acceptance and effectiveness of a TMS implementation. In this regard, TMS align with the demand for supply chain management software to be of a highly integrative profile. The following paragraphs demonstrate the way TMS may be integrated into a shipper's IT landscape.

4.2.4 Overview on TMS Technology

As TMS are understood to be transaction-based systems managing large amounts of data, a TMS is usually based on a central database structure. Any addition, removal or manipulation of data in this database is usually performed in one of the following ways:

1. *Direct TMS user access*: Via a proprietary Graphical User Interface (GUI) that serves as an interaction layer. This GUI can be implemented using any programming technology that directly or indirectly supports database integration. Three set-ups are common:
    (a) The TMS is installed as a standalone program on the user's computer and will access a central database directly. This setup is referred to as a standalone deployment.
    (b) The TMS will not access the database directly, but it connects to a central host version of the TMS that controls all database traffic. This setting allows for easy ERP integration because cross system transactions may be executed between the ERP host and the TMS host. Furthermore, this rich-client architecture may allow the client to perform standalone calculations and optimization runs.
    (c) For a thin-client deployment, the TMS software is not installed at the client but is accessed by means of a standard device (most commonly a web-browser, Langley et al. 2007). The generation of all forms, tables and other GUI objects is taken over by a central web-service. Analyses or calculations

are no longer performed on the client's computer but may only take place on the server with the results either displayed in the browser environment or downloaded from the server in a pre-defined format (e.g., MS Excel, comma-separated values and so on). Communication with other systems will be conducted via standardized or dedicated interfaces. One advantage of this set-up is fast propagation because no specific software distribution is necessary. In this way the TMS may fulfill the task of being a communication platform between all related parties within the transportation process chain.

2. *Access to TMS functionalities from other systems*: TMS access may be possible from other systems and its functionality is provided as a service for a more general application environment (e.g., the ERP).

Systems integration is a key factor for successful TMS integration and a precondition for a profitable operative transportation planning process. In the next section an example of a transportation systems design with potential extensions is given. Many TMS vendors currently offer full service packages that include the hosting of the TMS application. Their software sales model is often referred to as "software as a Service" (Cap Gemini Nederland 2007).

4.2.5 TMS Integration into an IT System Environment

The integration of TMS in a shipper's existing IT environment is a key success factor for its implementation and efficient transportation management process support. The TMS process as described in Sect. 4.2.1 has already addressed areas of necessary data exchange with the ERP system as well as with independent other organizational units, especially the carriers. Within the description of extended TMS functionalities the requirement for additional interfaces has been pointed out. For this section a differentiation between mere data interfaces (e.g., for the exchange of master and transaction data) and service interfaces for the call of hosted services is necessary (Faber and Ammerschuber 2008).

Data Interfaces

Since one of the main tasks of a TMS is the management of communication between shippers and carriers, a number of interfaces are necessary to ensure a seamless information flow. As to the parties involved in communication, two types of data interfaces are differentiated; namely, external interfaces and internal ones. Furthermore, a subdivision is drawn between the exchange of master data and location data.

- External Interfaces between Shippers, Receivers, Dispatchers and Carriers
    - *Master data:* In order to guarantee data integrity, only master data that is exclusively required for the transportation management processes is stored in the TMS master database. For example, location master data stating an address of a supplier location should be stored in the ERP supplier master since this information may be required for customs and duties processes in the ERP. The opening times of this supplier location are usually not required in the ERP environment and are therefore usually stored within the TMS master data. The same may apply to transportation specific material master data. Since data volume and updating frequency are usually rather low, Internet-based processes (sometimes with spreadsheet upload functionalities) are often utilized for initialization and updating the master data.
    - *Transaction data:* The key element that is subject to frequent exchange regarding transaction data is the transport order. After it has been initialized it will need to be transferred to the applicable carrier that has been requested to accept it. Within the order lifecycle, status information is frequently exchanged until final closure and after all relevant payments are settled. In addition to web-based user interfaces, proprietary interfaces to carrier systems are worthwhile considering for the preferred carriers.
- Internal Interfaces within a Shipper's Organization
    - *Master data:* The above mentioned example has already shown that a great deal of information relevant to the transportation processes is usually present in the shippers ERP systems. In order to avoid data redundancy and guarantee high data integrity, the responsible systems and modules for each data element need to be identified. High frequency consistency checks (usually in a nightly batch run) ensure that master data changes are passed on.
    - *Transaction data:* As for external communication, the transport order is a data object that is subject to extensive exchange in the internal IT systems. In this context it is of minor importance whether the order is generated in the ERP or in the TMS.

As the level of integration differs largely among different TMS implementations, additional data objects may be subject to exchange. Additional interfaces may be necessary, particularly in cases of TMS add-ons by software providers other than the TMS vendor. However, these may also be integrated as a service using highly standardized interfaces that allow for easy integration (see Fig. 4.4).

Service Interfaces

External services may be called by TMS applications in order to cover additional functions and provide additional features for specific processes (Albrecht 2007). Since these services are often supplied by parties other than the TMS vendor, they may be integrated using service-oriented architecture (SOA) (Connaughton 2008;

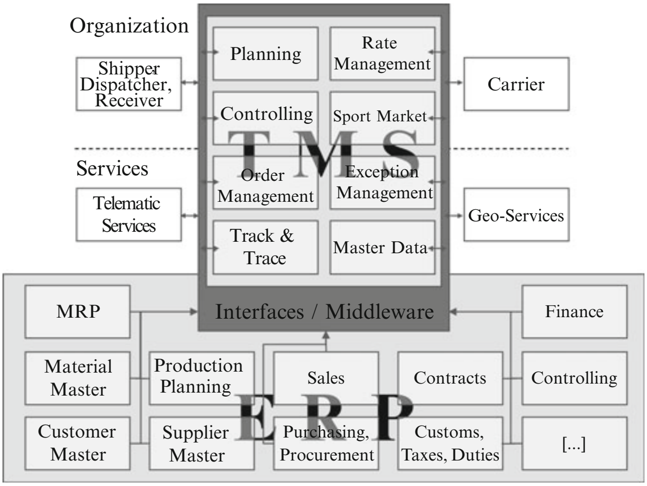

Fig. 4.4 TMS integration into an ERP system environment

Cap Gemini Nederland 2007; Faber and Ammerschuber 2008). Standardized service requests are sent out by the TMS and the required information is given back shortly after the call. The architecture does not require the service to run in local proximity of the TMS application but could be called from virtually anywhere. Two examples of integrated services are shown below:

- *Geo Information Services (GIS)*: These services may include geoencoding, routing (i.e., distance calculation and driver directions) and map displays. For geoencoding the service request may contain address data and the reply will contain geocoordinates for the given address. As for routing information a request will contain an origin and a destination location and some routing parameters. The reply may include driving instructions, distances and driving times. As for map-displays a number of objects with geocoordinates are put in a service request and a graphic object is returned that will feature these objects on a map. The design of the service interfaces is usually determined by the provider of the services using established interface standards.
- *Telematics*: Similar to geo information services, telematic services supply geographic information for the transportation management process; however, in contrast, this information is more dynamic (Bierwirth et al. 2002). Telematics information may be supplied by externally hosted services using similar request and reply mechanisms as described for GIS.

The integration of services into IT systems has been identified as one of the major trends in recent years within systems development (Cap Gemini Nederland 2007). Services may supply software functionalities for process support that can be easily integrated.

The number of required and potential interfaces that TMS use to consolidate the relevant information together with the goal of seamless information flow and communication between all involved parties along the transportation processes illustrates that TMS may be perceived as being an integration and communication platform. And communication with external parties has been emphasized throughout the whole process. Throughout the rest of this text it is important to note that additional process and planning support may be easily integrated in a given TMS IT environment and its underlying processes.

4.2.6 Assessment of Existing TMS Suites

In order to assess transportation management process support by current TMS standards an assessment scheme containing different criteria has been devised. These criteria encompass basic TMS functionalities as well as extended functionalities always with regard to the demands of transportation management in a consumer goods industry environment. Particular focus is put on the process support regarding increasing transport efficiency and achieving lower overall transportation costs.

Transport Order Management

Order Entry: Transport order entry covers the assessment of interfaces for systems integration in the field of transport order generation. Possibilities range from purely manual entries at a client computer, entries at a thin client (e.g., web interface), the upload functionality of standardized file formats (e.g., .xls, .csv), standard interfaces to common ERP systems and easy interface customization using .xml documentation (Trautmann and Krause 2007).

Transport Order Specification: Once a transport order has been generated in the system its specification is often subject to the application of business rules. Potential specification may include transport equipment (e.g., tank or silo trailers, flat bed trailers), special transportation requirements (e.g., temperature controlled environment) or the addition of location parameters such as time windows. Transport order specification may be understood as the enrichment of basic transport order data from an ERP system with transportation specific data from the TMS. As transportation requirements differ largely across different industries, but may also be different between different companies within the same industry, high flexibility toward the implementation and application of business rules is important.

Assignment of Service Providers: The assignment of the best carrier for a shipment is the key functionality of today's TMS implementations. However, the assessment of which provider is the right one may depend on many specific criteria (e.g., minimum costs for a given transportation time). It may in some cases involve the rating of a transport order with many different freight rates including very different rating schemes. This must be performed quickly since this process step may in some cases be user supported and order lead time should not be wasted in the assignment process.

Service Provider Communication: Since TMS may also be regarded as communication platforms, carrier communication is another key factor for efficient process support (Bierwirth et al. 2002). Carrier communication succeeds service provider assignment and is followed by order approval. Today, e-mail and web-based communication may be considered as standard means and may be extended toward proprietary interfaces directly into some carriers' IT systems. Again, the ease of implementation of such interfaces may constitute a competitive advantage regarding process efficiency.

Status Tracking

The request of shipment states and their collection (over several systems together with extensive use of the telephone) is one of the most time consuming tasks in every expediting process and not only in the consumer goods industry. The integration of shipment states from different systems may therefore constitute a first step toward better transparency on the whereabouts of every shipment. Such states could be advanced shipping notes, goods receiving postings or goods issues as well as further information. Advanced systems may enrich this information with the integration of telematic data. Integrated status tracking will not only reduce the time consumption for manual status requests within the expediting process but is also a prerequisite for a timely and rule-based escalation process in case of unpunctual shipments or missing items.

Invoicing

Checking transportation invoices may be a very complex task that requires major effort when done manually due to complicated freight rate structures. TMS is expected to substantially reduce this effort by using self-billing or credit-memo processes. These are based on an overall process layout in which all payments are triggered and settled in an IT system different to the TMS. With self-billing a pro-forma invoice is created that can be matched against the actual carrier invoice by the TMS. In cases where the amounts are equal the payment may be approved for settlement. When there is a credit memo procedure the payment is settled without an invoice from the carrier. In both cases TMS is also expected to support the resolution of invoice deviations. Additional charges such as demurrage may be claimed by the carrier using reason-codes, and approvals (e.g., by the responsible dock manager) may be attached in electronic form.

Controlling

Freight Cost Controlling: TMS is expected to cover the complete range of freight cost controlling beginning with general budget monitoring (e.g., by locations or business units) to special budget alignment (e.g., express services) and its cross-charging to the responsible organizational units (House and Jackson 1995). Furthermore, the determination of KPI such as transportation costs per article unit may be of use to the underlying controlling systems.

Service Provider Controlling: For the assessment of service quality of each carrier, additional KPI may be generated by the TMS. This can include punctuality as well as transport damages. The contract volumes per carrier for risk assessment can be subject to detailed analysis.

Location Controlling: As for service providers, controlling the calculation of some location specific KPI may for the mid-term planning horizon show some areas of improvement. This can include increasing punctuality, leading to lower demurrage charges but might also include damages or planning KPI such as order lead times.

Network Controlling: Shippers have recently started to report on the carbon footprint of their transportation activities. TMS may be used to help calculate emissions from transportation and monitor key drivers such as transportation volume, supplier and customer footprint.

General Planning Support

Material Flow Analysis: As a basis for transportation planning, as well as network design, the modeling of current and future transportation activities including locations, relations costs and processes is necessary. This model may be used for analyses and identification of improvement measures supported in different scenarios.

Budgeting: Transportation cost budgeting and forecasting may also be supported by TMS taking future material flow data (e.g., from sales forecasts or production plans) into account. This information may be merged with tariff data to form a reliable transportation cost forecast.

Transportation Costing: Planning support for sourcing decisions can be supplied by the TMS for tasks such as total cost calculation or factory gate pricing. This process can increase cost transparency for supplier sourcing decisions and may help to find the ideal terms and conditions for supply and customer relationships (especially incoterms) (McKinnon and Ge 2006).

Transportation Planning

Strategic: TMS may support strategic decision making processes based on historic and expected transportation volumes. Such questions can include location decisions, changes in supply or customer assignment or assortment allocation.

Tactical: Tactical planning tasks such as transportation lot sizing through frequency adjustments may be supported by TMS. With regard to the specific case study from the consumer goods industry, tactical transportation focuses largely on assignment problems.

Operational — Consolidation: Increasing transportation efficiency in the consumer goods industry while at the same time lowering costs by utilizing degression effects is assessed in this section. As an example, the alteration of scheduling decisions may lead to consolidation opportunities in operational transportation.

Operational — dock scheduling and Yard Management: As for operational support, dock scheduling represents a typical task that remains with the shipper. In order to manage dispatching, warehousing and stocking according to the available resources, dock scheduling functionality (i.e., the time and location of a truck for loading or unloading) provides powerful means to reduce demurrage times. This criterion therefore assesses to what extent TMS provide this capability.

Freight Rate Management

The storage and maintenance of all freight rates is a key requirement for any TMS. However, this may be extended by spot-market capability, tender management or freight rate benchmarking, for example.

In all, 39 different TMS suites have been assessed according to these criteria. Since the relevance as well as a detailed assessment is subject to the special circumstances that accompany every real-life TMS implementation, a ranking of the examined systems is not provided within this study. The results of the assessment are based on detailed TMS reviews and deployment studies.

As a result, the individual assessment can be found in Appendix II. The key findings of the assessment are as follows:

- Two types of TMS vendors can be differentiated:
  - For some TMS vendors their TMS suites constitute only a part of their systems portfolio. These software companies often focus on ERP or WM solutions. However, the TMS offered by these vendors often lack functional width and depth in comparison to vendors that are specialized in TMS. Vendors with a larger software solutions portfolio often focus on existing customers and stress integration aspects in their external communication.
  - The other group of vendors specializes in TMS suites, and transportation solutions account for the greatest share of their software sales. Even though the suites offered by these vendors often lack in dedicated interfaces with ERP systems, basic integration is usually obtainable using standard interface technology.
- A differentiation between shipper deployed TMS and carrier deployed fleet management systems is necessary. While the first focuses on transportation process management without the deployment of the shipper's own assets, the

latter will take assets such as transport equipment and drivers into account. An approximation of one of these processes with the other seems impractical. Fleet management systems are therefore not part of this study's assessment.

- A differentiation between TMS and tour planning software must be made. The latter is not subject to assessment within this study.
- The market for TMS is — like the transportation market—regionally fragmented. On the first level of this fragmentation it can be noted that there is a continental trench between the North-American and the European software market. There are only two vendors that show a substantial number of users on both continents. However, the European market is itself subject to further fragmentation into some country-specific submarkets. Again, only a few vendors manage to show strong presence in all European markets.
- Many TMS vendors have gathered experience in systems integration in the past and have equipped their TMS suites with a number of standardized interfaces, which is why the integration of TMS into a given system landscape is expected to be much easier today than it was 5 years ago (Connaughton 2008).
- The assessed TMS are mere transaction systems. Their functionality is focused on maximum process support for expediting tasks in the field of transportation management. This usually includes carrier connectivity and communication. Therefore, the central object of transportation planning in these TMS is the transport order. These processes, however, largely lack cross-functional capabilities such as general planning support or transportation planning. Although some of these features may be provided by add-ons, none of the assessed TMS provide a sound approach to transportation planning tasks in the consumer goods industry.

The assessment of different TMS suites has shown that in expediting processes current implementations are very well able to support the consumer goods transportation management processes. Along the lines of transparency and functionality to assign the cheapest carrier to a shipment and to tender shipping volumes with a large number of participants, TMS have been able to account for substantial savings in transportation costs for the companies that deploy them (Werle 2010; Esper and Williams 2003). And if it is assumed that the carrier that quotes the lowest transportation costs is the one providing a service most efficiently it may be possible to indirectly increase transportation efficiency. However, today's TMS lack the ability to actively increase transportation efficiency to the extent that exceeds a single carrier's capabilities.

4.2.7 Expected Future Development of TMS

The future of each single TMS suite, as with any software, depends on its user acceptance and on high distribution. While the first may be reached by the implementation of seamless business processes and high added value through additional functionalities, the latter may be obtained by integrating the TMS functionalities with systems that already have a strong distribution: in this case, most likely ERP-Systems (Shehab et al. 2004). From these two approaches two strategic development scenarios may be taken into account for TMS vendors:

1. Improve processes coverage and functionality, or
2. Move close to an ERP vendor and offer fully integrated TMS as part of the TMS processes.

The TMS market is likely to grow in the future (Woods 2006). TMS integration into ERP processes is expected to reach a new level of functionality, enabling a seamless process from order to delivery within an ERP system — this development will be particularly interesting for large shippers in highly integrated ERP environments (Cap Gemini Nederland 2007). Since shippers are trying to keep the number of software vendors and systems small in order to achieve lower maintenance costs, future competition is expected to take place in ERP software markets rather than in the specialized markets for TMS suites. Still, TMS vendors that focus on industry specific, region specific or process specific requirements are expected to gain a sustainable market position. These vendors are very flexible toward changing requirements and usually offer sufficient integration with common ERP systems (Cap Gemini Nederland 2007). In this area, on-demand software solutions may therefore become the preferred mode of implementation (McCrea 2007).

While it may seem visionary but reasonable to tackle all supply chain related planning, scheduling and execution processes within one integrated "SCM suite," the past few years have shown that software buyers take a different view. And it has been this problem-oriented approach by practitioners that opened the gap for TMS vendors to position an isolated application with limited capabilities and focus within a SCM environment that is usually connected with the term "integration." Taking the APS publications into account, this is a task that has been mainly attributed to APS. Subsequently, TMS should have no reason to exist, which is probably why they have been largely spared by academic publications in the past.

4.3 Organization

After a thorough analysis of transportation management processes and supporting IT systems the organizational aspects of transportation management are briefly addressed with a special focus on the consumer goods industry. In order to better understand past, current and future development of transportation management in the consumer goods industry a brief history is provided in the following paragraphs.

The perspective on organization in this text is one that focuses on responsibility regarding costs and performance (see also Caputo and Mininno 1998). Since transportation management in general and transportation planning in particular is based on decision making, it is important to understand the relevant parameters upon which transportation decisions are based. If, for example, a transportation expediter is responsible for transportation costs without being responsible for the

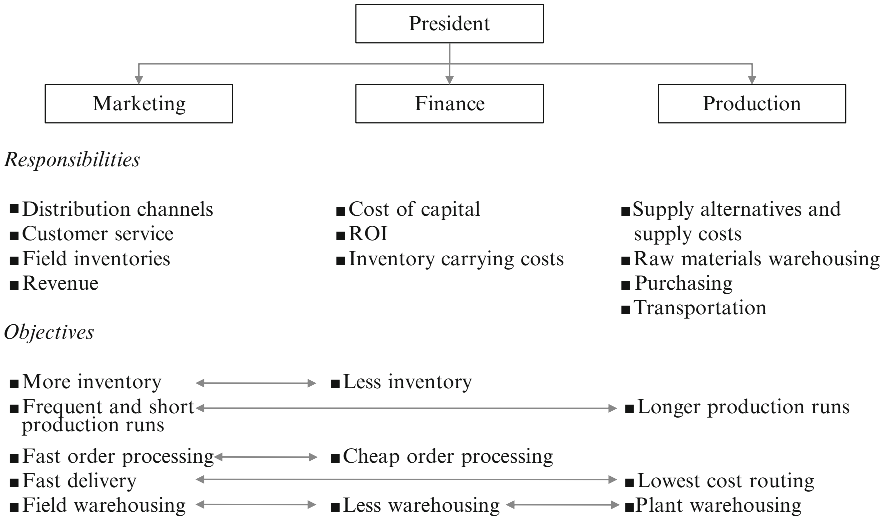

Fig. 4.5 Logistics activity fragmentation (Ballou 2007)

on-time delivery of shipments, an unreliable but cheap carrier may be preferred to a reliable but more expensive one. Similar conflicts of objectives are addressed in Fig. 4.5. This invariably leads to the question as to where the organization transportation responsibility should be located and to what degree it can be centralized.

4.3.1 *Transportation Management in the Consumer Goods Supply Chain*

As far as the responsibility for transportation management is concerned, the recent history within the consumer goods manufacturers' organization can be divided into four phases since the 1980s:

Phase 1: Transportation Management as Fleet Management

Since market regulations had a direct pricing impact on outsourced transports in Europe and the United States in the 1980s, consumer goods manufacturers have been among the biggest owners of trucking fleets (Sheffi 1990). The management of one's own vehicles has proven to be the only way of avoiding the fairly high transportation rates imposed by legislation. However, these fleets were not managed as one unit but trucks were assigned to warehouses and plants from where they were controlled. In this phase, transport execution and management were performed in-house and transportation management was decentralized and was largely the responsibility of the locations where the trucks were assigned.

Phase 2: Outsourcing of Physical Transportation

After strict regulation was abandoned in the United States in the 1980s and in Europe in the early 1990s the transportation market was liberalized and transportation rates dropped substantially (Zimmermann 2004). It was therefore no longer necessary for the consumer goods manufacturers to operate their own fleet in order to obtain a competitive transportation cost structure (Zobel 1988). The physical act of transportation was outsourced; however, transportation management remained largely the responsibility of the sites that were once managing their own fleets. This phase is therefore best described as outsourced transportation, yet with in-sourced transportation management that was still largely decentralized.

Phase 3: Outsourcing of Transportation Management

With the development of large logistics service providers, so-called 3PLs that not only control their own fleet but use subcontractors for a share of shipping volume for which they had originally been contracted, it seemed natural to hand over transportation management tasks to these transportation specialists (Win 2008). These service providers were referred to as “Lead Logistics Providers” or LLPs. In order to generate attractive tendering packages and good prices, they no longer focused on single sites but extended their service to whole sections of the consumer goods industries’ transportation network. This phase, which took place at the turn of the century, is therefore best described as outsourcing and centralization of transportation management (Schmitt 2006).

Phase 4: In-sourcing of Transportation Management

In 2005, the first consumer goods manufacturers realized that rising transportation costs as a result of internal and external trends constituted a threat to their competitive position. Subsequently, transportation management became a core competence on the agendas of the operations executives, and they decided to in-source transportation management from their service provider (see N.N. 2008a). This process has experienced additional centralization of transportation management in largely independent organizational units, referred to as “load control centers” (Rider 2003). Therefore, this phase may be described as continued centralization of transportation management with parallel insourcing.

The re-integration of transportation in a centralized organization has prompted the implementation of TMS at the organizational units responsible for transportation management. The blueprint for such a transportation management organization was developed in 1996 and received some attention both academically and in a practical manner. It is often referred to as the 4PL approach and is discussed in the following subsection (Schmitt 2006).

4.3.2 Modern Transportation Management Organizational Structures

In the last several years, recent TMS implementations have shown a shift from a local toward a central end-to-end supply chain transportation operations organization (Aberdeen Group 2006). This effort toward centralization has been enabled by improved IT-functionality, which allows the user to cope with the increasing complexity and greater amounts of data (Stank and Goldsby 2000). Modern transportation management is fully integrated in the relevant supply chain management processes. This is vital to achieve a competitive cost base that reflects the overall cost and profit situation. It also reveals the second key issue of a modern transportation management organization — it is fully responsible for its own cost/profit situation and its process quality is constantly measured.

The organizational unit performing transportation management tasks is therefore well integrated but can in legal terms remain an independent entity. It controls transportation networks by communicating with the carriers — the parties that own the transportation devices (assets). These organizations may therefore qualify as a 4PL (KPMG 2000). According to Skjøtt-Larsen (2000) a 4PL can be defined as a non-asset based company that acts as a single interface between the client and multiple (asset-based) logistics service providers (such as carriers). Whether it is a necessity, within the definition of a 4PL, that it is an economically independent company remains open. Anyway, boundaries here are hardly carved in stone; constructions such as joint ventures or specific profit sharing models may be applied creatively. Given that a sound contract may allow an external 4PL to operate as well as an internal one, the question of insourcing vs. outsourcing becomes merely a question of strategic importance to transportation management, which must be assessed individually. Still, the prerequisite of contract design is one of the remaining fields for further research in the area of 4PL (Selviaridis and Spring 2007).

4.4 Summary

It is this section's objective to assess transportation management in today's consumer goods industry according to its ability to increase transportation efficiency. The analysis has been subdivided into the segments of process, IT and organization.

The core processes in transportation management are planning, control and execution. In particular, transportation planning has been identified as a major influence on transportation efficiency. Planning approaches for strategic horizons have been fairly exhausted. Tactical instruments are furthermore of little influence with regard to the specific production planning and scheduling processes in batch production. The concepts for operational transportation planning do not meet today's requirements in the consumer goods industry. The key requirements are the incorporation of real life freight rates together with the objective of minimizing costs and the consideration of multiple restrictions such as vehicle capacity, time-windows and quality requirements — all this in a large scale transportation network, which is run by a number of external carriers.

In contrast to transportation planning processes for operational transportation management, IT support for general process assistance seems suitable for today's consumer goods industry. However, the functionality offered by modern TMS usually ends at the "least cost carrier and mode choice" function. Today's TMS implementations therefore lack the supply of broad functionality that may directly influence transportation efficiency.

The extensive fragmentation observed at the large consumer goods manufacturers may in many cases make it difficult to implement improvement measures that affect many organizational units. Yet, the trend observed in the recent past reveals new opportunities. The concentration of responsibility for distinguished functions from the great field of supply chain management to single organizational units that are accountable for their own financial contribution may facilitate the implementation of improvement measures within these areas. The organizational basis is therefore laid out for implementation of operational improvements as long as they account for defined restrictions.

A road map for implementation is therefore bound to concentrate on the design of a process for operational transportation planning. In the second step, it is necessary to make this process available in a TMS environment. The following section gives a detailed description of such an approach from process development to IT implementation.

Chapter 5
Solution Approach

A review of contributions suggesting measures to increase transportation efficiency was provided in the previous chapter. According to Stank and Goldsby (2000) in operative transportation decision making, primary cost saving opportunities include:

- Inbound/outbound consolidation,
- Temporal consolidation,
- Vehicle consolidation,
- Carrier consolidation.

Detailed approaches have been presented by McKinnon and Ge (2006) and Mentzer (1986), focusing on the above mentioned inbound/outbound consolidation to take the form of backhauls, by Moore et al. (1991), who suggest continuous moves consisting of several pick-up delivery operations along a trip, by Du et al. (2007), describing the consolidation of shipments from one origin within one vehicle in a tour as a milk run, and by Caputo et al. (2006), who suggest appropriate mode and carrier selection.

Within this chapter all the above mentioned measures will be employed with regards to their effect on transportation costs according to the transportation cost structure presented in Sect. 3.1. In that section, freight rate degression was identified in two main dimensions, load degression and distance degression. The current section is determined to consolidate the measures into a process that is supported by TMS solutions and can be integrated into modern transportation management organizations.

The focus lies on the case study of an operational transportation planning problem from the consumer industry that was introduced in Sect. 3.2. In the following subsection a general solution approach is outlined. It is then detailed and split into different process steps for which mathematical formulations are presented. Finally, integration into a TMS is suggested and requirements for real-life implementations are illustrated.

T. Seiler, *Operative Transportation Planning*, Contributions to Management Science,
DOI 10.1007/978-3-7908-2792-7_5,

5.1 General Solution Approach

In the presented solution approach, consolidation shall be obtained by combining transportation orders in a way that the cost for the order combination is lower than the sum of the costs of each individual order. The resulting cost savings solely depend on the carrier's freight rates. In the following examples, two orders i and j will be combined in pairs to form an order combination k that may in the next iteration be combined with an additional order.

The order combinations should be performed in ways that make use of freight rate degression in at least one of the two dimensions. As for load degression, the load of two transport orders must be transported together within an order combination–such combinations will be referred to as *simultaneous combinations,* since loads of all transport orders will be on the truck at the same time. Such combinations may cover vehicle consolidation as well as temporal consolidation as long as time-window restrictions are kept. In order to obtain distance degression, transport orders may be combined so that first one order and in direct succession the second order is served by the same carrier using the same vehicle. This type of combination is referred to as *sequential combinations* and cover the above mentioned carrier and vehicle consolidation.

The following mixed-integer linear programming (MILP) model describes the approach to benefit from the discussed efficiency gains in operative transportation planning. Transportation orders may be assigned to a set of pre-defined tours in a way that total transportation costs can be minimized, considering capacity restrictions.

Indices

$i \in I$	Transportation orders in the planning horizon
$l, m \in L$	Locations
$o(i) \in L$	Origin (dispatching location of order i)
$d(i) \in L$	Destination (receiving location of order i)
$r \in R$	Tours
$p, q \in P$	Positions of stopover locations on a tour

Parameters

am_i	Transportation load of order i
dc_i	Transportation cost of order i if served individually, i.e., not on a tour combined with other orders
tc_r	Transportation cost of tour r
$tp_{l,r,p}$	$=1$, if location l is served at position p on tour r (0, otherwise); defining the stops on a tour and their sequence
fp	First position of a tour
lp	Last position of a tour
PC	Maximum transportation capacity (maximum load)

Decision variables

rco_r	Transportation costs of tour r (> 0 only if the tour is employed)
$load_{r,p}$	Load carried by the truck on tour r after loading and unloading at position p
$tor_{t,r}$	$=1$, if transportation order t is assigned to tour r (0, otherwise)

Objective function

$$min \sum_{i \in I} dc_i \left(1 - \sum_{r \in R} tor_{i,r} \right) + \sum_{r \in R} rco_r \tag{5.1}$$

The objective is to minimize total transportation costs including costs for individually serving transportation orders and costs for serving them on dedicated tours. Constraints to be considered are the following:

Tour construction constraints

$$rco_r \geq tc_r \cdot tor_{i,r} \quad r \in R; i \in I \tag{5.2}$$

$$\sum_{r \in R} tor_{i,r} \leq 1 \quad i \in I \tag{5.3}$$

$$tor_{i,r} \leq \sum_{p \in P: p < lp} tp_{o(i),r,p} \quad r \in R; i \in I; o(i) \in L \tag{5.4}$$

$$\begin{gathered} tor_{i,r} \cdot tp_{o(i),r,p} \leq \sum_{q \in P: q > p} tp_{d(i),r,q} \\ i \in I; o(i) \in L; d(i) \in L; r \in R; p \in P: p < lp \end{gathered} \tag{5.5}$$

Capacity restrictions

$$\begin{aligned} & load_{r,p} \geq \\ & load_{r,p-1} + \sum_{i \in I} tp_{o(i),r,p} \cdot am_i \cdot tor_{i,r} - \sum_{i \in I} tp_{d(i),r,p} \cdot am_i \cdot tor_{i,r} \\ & \qquad\qquad\qquad\qquad\qquad r \in R;\; p \in P: p > fp \end{aligned} \tag{5.6}$$

$$load_{r,p} \geq \sum_{i \in I} tp_{o(i),r,p} \cdot am_i \cdot tor_{i,r} \quad r \in R;\; p \in P: p = fp \tag{5.7}$$

$$load_{r,p} \leq PC \quad r \in R; p \in P \tag{5.8}$$

Variable domains

$$rco_r \geq 0 \quad r \in R \tag{5.9}$$

$$load_{r,p} \geq 0 \quad r \in R, p \in P \tag{5.10}$$

$$tor_{i,r} \in \{0,1\} \quad i \in I; r \in R \tag{5.11}$$

This model formulation is based on pre-defined tours r. An order can thus be served individually or combined with other orders on a tour. The latter allows for consolidation, backhauls, as well as distance extension, and therefore qualifies for potential efficiency gains as described. Even though the tours have to be defined upfront, the complexity of realistic problem sizes described above is considerable. A more realistic model formulation would have to consider time windows, refrigeration levels, hubs, cross docks, multiple depots, and individual trucks with different transportation capacity. Yet, the more constraints and variables added, the smaller the chances are of generating a good solution within reasonable computational time.

A promising approach for practical application consists of developing a heuristic solution procedure that exploits the opportunities of cost savings by stepwise combining feasible pairs of transportation orders. This way tours comprising several orders can be generated and a considerable overall cost saving can be achieved.

5.1.1 Introduction to Combination Schemes

The analysis of carrier freight rates has shown possibilities of increasing transportation efficiency for outsourced transportation services, which can lead to substantial cost saving opportunities. In order to access this potential in the consumer goods industry, operative transportation planning will have to identify the above mentioned measures with very short reaction time, combining existing transportation orders. This approach is facilitated by the production planning and scheduling approach in the consumer goods industry. Based on the MRP quantities and the production schedule the resulting inbound and outbound material flows are determined. The planning horizon for operational transportation planning should therefore be congruent with the planning horizon for production planning and scheduling. A 1 week period has proven practicable (Thonemann et al. 2004).

The input data for the designed operational planning process is the transport order, a data element only too well known within the TMS environment. The transport order clearly states an origin, a destination, a transportation load as well as additional information regarding load requirements or time windows. Based on the combination of transport orders, so-called order combinations are to be generated. In addition to the cost assessment of individual transport orders any combination that is generated is to be assessable using real-life freight rates. A cost saving opportunity is identified, if the combination of two transport orders is less

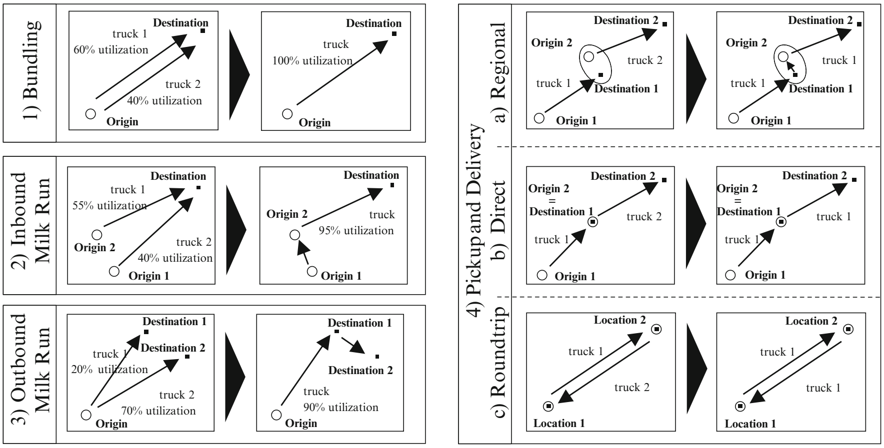

Fig. 5.1 Combination schemes for obtaining efficiency gains in road transportation

expensive in terms of transportation costs than the sum of costs that would be charged for individual transportation of each transport order.

Four elementary combination schemes–namely, bundling, inbound and outbound milk run, and pickup and delivery–are defined as a basis to systematically generate order combinations. These combination schemes directly address the degression effects as described in Sect. 3.1. Figure 5.1 provides an overview of measures for gaining efficiency based on existing transportation orders. The described measures are referred to as combination schemes.

1. *Bundling*: Consolidating two transportation orders from the same origin to the same destination is referred to as bundling. This combination is designed to benefit from load degression effects. However, the extent of load degression is dependent on the transportation distance. Largest relative savings are expected for short transportation distances and small transportation loads.
2. *Inbound Milk Run*: Consolidating two transportation orders to the same destination from different origins thereby going from the first origin to the second origin and further on to the common destination is referred to as an inbound milk run. This combination scheme mainly addresses load degression by consolidating the loads of two orders after the pickup of the second order has been performed. However, the consolidation comes at the price of a potential detour. On the other hand, idle time for unloading may be shorter for a truck delivering the total quantity of two orders compared to two deliveries with the according shares. The highest savings are achieved when the origins are close together and the destination is far away from the origins (Du et al. 2007).
3. *Outbound Milk Run*: The outbound milk run describes the consolidation of two transportation orders from the same origin to different destinations thereby going from a common origin to the first destination and further on to the second destination. Again, this scheme aims at lower transportation costs mainly through

load degression. The highest savings are achieved when the destinations are close together and the origin is far away from the destinations (Du et al. 2007).

4. *Pickup and Delivery*: Combining transportation orders to create longer transportation distances is referred to as pickup and delivery. Two transportation orders may be combined to be served successively with the same truck thereby increasing the transportation distance of the order combination (Hall 2003). The measure aims at the utilization of distance degression effects resulting in lower per mile costs (Rider 2003). However, the *Regional Pickup and Delivery (4a)* scheme comes at the price of an additional transportation leg, a distance that is driven empty (Liedtke and Schepperle 2004). Lower transportation costs will therefore only be applicable when the empty running distance is shorter than the sum of repositioning distance for the affected individual transport orders. Ideally, an order ending in one location is combined with another order beginning at the very same location. This is referred to as a *Direct Pickup and Delivery (4b)*. Another variant to this combination scheme is constituted in case the initial pickup location is identical to the final delivery location. This is referred to as a *Roundtrip (4c)*. The suggested route reduces the carrier's risk of finding an adjacent order out of his major service region (in a bidding process this is likely to result in more carriers participating).

Measures 1–3 mainly aim at increasing the utilization of the means of transportation whereas Measure 4 only increases the travel distance per order. Since load degression is usually the stronger of the two, higher savings are expected from Measures 1–4.

For every potential combination, the following restrictions are subject to detailed inspection within combination building:

- Capacity restrictions regarding weight capacity utilization and pallet space on the regarded truck type.
- Time window restrictions regarding earliest pickup time, latest pickup time as well as earliest delivery time and latest delivery time. A combination-scheme specific parameter can be used for additional time-window adherence in case of combination; that is, minimum overlap for loading and unloading operations at a location.
- Temperature class restrictions are accounted for regarding the transported products. A combination specific parameter is defined (parameter $t'(u,v)$). This incorporates to what extent different temperature classes may be combined and which temperature class will result. Two types of temperature requirement combinations are differentiated. Simultaneous combination accounts for orders that are shipped together using the same vehicle (schemes 1–3). A transportation order that would usually be shipped in an ambient environment, for example coffee, may also be shipped together with yogurt in a chilled reefer trailer. Sequential combinations apply to combination schemes 4a–c. Here, a reefer trailer that has been used to carry frozen food can for a consecutive journey be adjusted to serve an ambient load, simply by switching off the refrigeration aggregate.

Truck type restrictions regarding the required transportation equipment are defined by the parameter $r^J(p;q)$. Similarly to temperature class restrictions, simultaneous and sequential combinations are differentiated.

5.1.2 *Application of Combination Schemes*

The above measures are applied in a batch run to a pool of transportation orders (see Fig. 5.2) containing all valid orders within a defined planning horizon. First, orders are combined pair-wise using the scheme of bundling. Whenever a feasible order combination has been found, a distinct order combination-ID is assigned. This order combination is then assigned to the pool of order combinations. Furthermore, it may be combined with an additional order from the pool of orders generating a new order combination, which again is transferred to the pool of order combinations and may then be extended with another order from the pool of orders. This approach is pursued until no additional order combinations can be generated or an exit criterion is reached.

The generated order combinations are passed on to the next two combination steps, which consist of the schemes inbound and outbound milk run. Here the approach is similar to bundling–two orders (either taken from the pool of orders or a combination generated by the scheme of bundling applied beforehand) are combined generating an order combination with a unique order combination-ID.

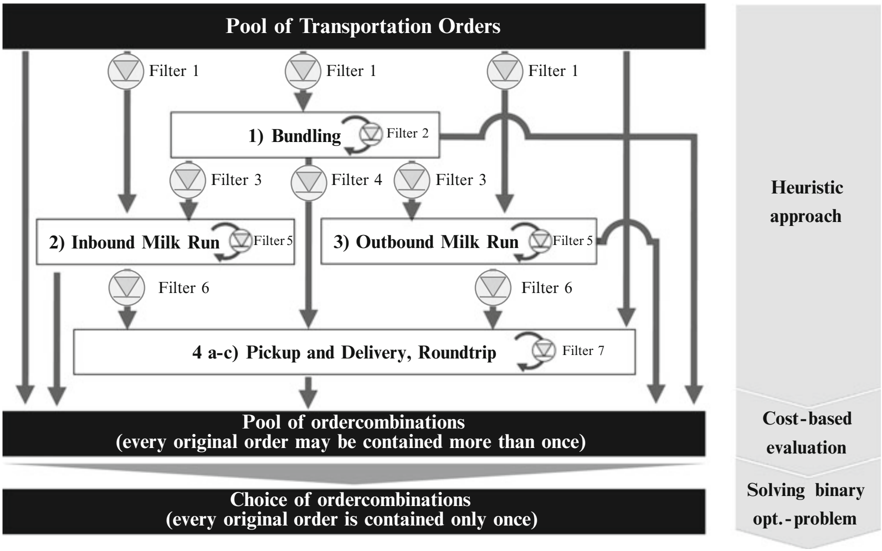

Fig. 5.2 Combination generation and selection process

Again, every generated combination can be extended by adding an additional order until no further combinations can be generated or an exit criterion is reached.

After the milk run combinations have been generated, all combinations as well as all original orders will be processed for combination schemes of pickup and delivery (4a–c). These will combine transportation orders sequentially, thereby constantly performing pair-wise combinations, adding additional transportation orders (or combinations generated with the schemes of bundling, inbound or outbound milk run) until no further combinations can be generated or an exit criterion is reached.

5.1.3 Selection of Combinations

As a result of the combination process it is possible that one original order is used in multiple order combinations and in different ways. An initial order "01" may be combined with another initial order "02" according to the combination scheme *1 – Bundling* generating order combination "11". The very order "01" may, however, also be combined with another order "03" according to the combination scheme *2 – Inbound milk run* generating an order combination "12". It is assumed that an additional combination for order "01" is possible using a *Roundtrip* combination scheme together with order "04" resulting in order combination "13". It is obvious that from these four orders and three order combinations only one combination may be chosen for actual implementation, since the same order may not be part of more than one combination scheme.

The selection of order combinations shall take place according to cost criteria; that is, those combination schemes that result in the lowest total transportation costs will be chosen. Therefore, every order and order combination has to be rated according to the applicable freight rates. After rating has taken place, some order combinations may already be eliminated from the pool of order combinations, if transportation costs for these order combinations exceed the cost for individually processing the orders that are part of the combinations. It is assumed that, in the above mentioned example, transportation costs for order "01" are EUR100 and costs for order "04" are EUR400. The costs for order combination "13" that is constituted by orders "01" and "04" is assumed to be EUR600. In such a situation, order combination "13" may be eliminated from the pool of order combinations, since EUR600 for the combined processing of orders "01" and "04" is more expensive than their individual processing, amounting to EUR500.

The order combinations that remain in the pool are all characterized by the fact that it is less expensive to process them as an order combination than processing the contained orders individually. However, an individual order may still be subject to assignment to different order combinations within the pool of combinations. The task to reduce the order combinations, in which each original order may be represented more than once, into a pool of order combinations, in which each original order is only represented once, can be considered a set partitioning problem (Baker et al. 2005). In Sect. 5.3 two approaches for a solution to this problem are presented and discussed.

5.2 Combination of Transportation Orders

After describing the general solution approach this section provides a detailed mathematical model on how order combinations may be generated and their applicable restrictions. Since the number of combinations that are constructed using this approach may be very large, the application of filter criteria is introduced thereafter. Finally, the procedure for the cost-based combination assessment is described.

5.2.1 Simultaneous Combination

The necessary parameters for simultaneous and sequential order combination are as follows:

$i, j \in I$	Transportation orders in the planning horizon
$k \in K$	Order combinations
$l, m \in L$	Locations
$p, q, r \in P$	Equipment (truck types)
$t, u, v \in T$	Temperature classes, transportation products
$o(i) \in L$	Origin (dispatching location of order *i*)
$d(i) \in L$	Destination (receiving location of order *i*)
$p(i) \in P$	Equipment type required by transportation order *i*
$t(i) \in T$	Temperature class required by transportation order *i*
$r'(p;q) \in P$	Resulting equipment type when combining truck type *p* and truck type *q* according to combination scheme 1–3, if existing, else Ø
$r''(p;q) \in P$	Resulting equipment type when combining truck type *p* and truck type *q* according to combination scheme 4, if possible, else Ø
$t'(u;v) \in T$	Resulting temperature class when combining temperature levels *u* and *v* according to combination scheme 1–3, if possible, else Ø
$t''(u;v) \in T$	Resulting temperature class when combining temperature levels *u* and *v* according to combination scheme 4, if possible, else Ø
PS_i	Pallet space required by order *i*
W_i	Gross weight of order *i*
$PC_{p,t}$	Pallet space capacity of truck type *p* at temperature level *t*
$WC_{p,t}$	Weight capacity of truck type *p* at temperature level *t*
EPU_i	Earliest pickup date and time of transportation order *i*
LPU_i	Latest pickup date and time of transportation order *i*
ESD_i	Earliest delivery date and time of transportation order *i*
LSD_i	Latest delivery date and time of transportation order *i*
$TT_{l,m}$	Transit time between location *l* and location *m*
$D_{l,m}$	Distance between location *l* and location *m*
MD	Minimum distance between a delivery location and the following pickup location according to combination scheme 4a

1. *Bundling*: For a consolidation of two transportation orders *i* and *j* from the same origin to the same destination, equations (5.12), (5.13), (5.14), (5.15), (5.16), (5.17), (5.18), (5.19), (5.20) will need to be fulfilled simultaneously. According to this combination scheme the sequence of the two orders is of no relevance.

   Locations: The origin and the destination of the two transportation orders have to be identical.

$$o(i) = o(j) \wedge d(i) = d(j) \quad i,j \in I; i \neq j \tag{5.12}$$

   Capacity, truck type and temperature level: For combined transportation a suitable truck type and temperature level need to exist. This is ensured by equations (5.13) and (5.14). Restriction (5.15) limits the sum of the gross weight of both transportation orders to the available payload of a suitable truck type. In equation (5.16), the sum of the amount of pallet places required by both transportation orders must not exceed the total amount of pallet places available in a suitable truck type $r'(p(i);q(j))$.

$$r'(p(i);q(j)) \neq \emptyset \quad i,j \in I;\; i \neq j;\; p(i),q(j) \in P \tag{5.13}$$

$$\begin{gathered} t'(u(i);v(j)) \neq \emptyset \\ i,j \in I; i \neq j; u(i),v(j) \in T \end{gathered} \tag{5.14}$$

$$\begin{gathered} W_i + W_j \leq WC_{r'(p(i);q(j));t'(u(i);v(j))} \\ i,j \in I; i \neq j; p(i),q(j) \in P; u(i),v(j) \in T; r'(p(i);q(j)) \in P; t'(u(i);v(j)) \in T \end{gathered} \tag{5.15}$$

$$\begin{gathered} PS_i + PS_j \leq PC_{r'(p(i);q(j));t'(u(i);v(j))} \\ i,j \in I; i \neq j; p(i),q(j) \in P; u(i),v(j) \in T; r'(p(i);q(j)) \in P; t'(u(i);v(j)) \in T \end{gathered} \tag{5.16}$$

   Time windows: Pickup time windows of both transportation orders and delivery time windows of both transportation orders must be overlapping.

$$EPU_i \leq LPU_j \quad i,j \in I; i \neq j \tag{5.17}$$

$$EPU_j \leq LPU_i \quad i,j \in I; i \neq j \tag{5.18}$$

$$ESD_i \leq LSD_j \quad i,j \in I; i \neq j \tag{5.19}$$

$$ESD_j \leq LSD_i \quad i,j \in I; i \neq j \tag{5.20}$$

2. *Inbound milk run*: Consolidating two transportation orders *i* and *j* from different origins to the same destination, thereby going from the first origin *o(i)* to the second origin *o(j)* and further on to the common destination $d(i) = d(j)$ will have to adhere to the following restrictions, which are to be considered simultaneously. The highest savings are achieved when the origins are close together and the destination is far away from the origins (Du et al. 2007). For this combination scheme the combination sequence is of relevance due to sequence dependent tour distances and transit times.

   Locations: The destinations of the two transportation orders have to be identical.

$$d(i) = d(j) \wedge o(i) \neq o(j) \quad i,j \in I; i \neq j \tag{5.21}$$

   Capacity, truck type and temperature level: Restrictions (5.13), (5.14), (5.15), (5.16) apply (see bundling).

   Time windows
   The pickup times between the two dispatching locations must match considering the required transit time between the two origins. In addition, delivery time windows of both transportation orders will need to be overlapping according to restrictions (5.19), (5.20).

$$EPU_i \leq LPU_j - TT_{o(i);o(j)} \quad i,j \in I; i \neq j \tag{5.22}$$

$$LPU_i \geq EPU_j - TT_{o(i);o(j)} \quad i,j \in I; i \neq j \tag{5.23}$$

3. *Outbound milk run*: Consolidation of two transportation orders *i* and *j* from the same origin $o(i) = o(j)$ to different destinations going from the common origin to the first destination *d(i)* and further on to the second destination *d(j)* (Liu et al. 2003) is bound to adhere to the following restrictions. Combination sequence is also of relevance in this scheme.

   Locations: The origins of the two transportation orders have to be identical.

$$o(i) = o(j) \wedge d(i) \neq d(j) \quad i,j \in I; i \neq j \tag{5.24}$$

   Capacity, truck type and temperature level: Restrictions (5.13), , (5.14), (5.15), (5.16) expressed for bundling are likewise applicable.

   Time windows
   The pickup time window restrictions (5.17), (5.18) as stated for bundling must be obeyed. In addition to that, delivery time windows need to match regarding the transit time between the two receiving locations.

$$ESD_j \leq LSD_i + TT_{d(i);d(j)} \quad i,j \in I; i \neq j \tag{5.25}$$

$$LSD_j \geq ESD_i + TT_{d(i);d(j)} \quad i,j \in I; i \neq j \tag{5.26}$$

5.2.2 Sequential Combination

After having defined the applicable rules and restrictions for simultaneous order combination, the sequential schemes are detailed below. Enumeration is continued with regard to Fig. 5.1.

4. *Pickup and delivery, round-trip*: In order to create longer transportation distances, the following examples will combine transportation orders i and j in a way that transportation order i is served before j. Note that the sequence of orders is of relevance in this case. In this process an order ending in one location is combined with another order beginning at a location nearby (Regional pickup and delivery – 4a). This proves beneficial due to the distance degression of freight rates. A special case is constituted if the two locations are identical and no empty transit needs to take place (direct pickup and delivery – 4b). Furthermore, a second case can be distinguished if transportation orders can be combined in a way that the first dispatching location is also incorporated as the last receiving location of an order combination. The suggested route resembles a round-trip reducing the carrier's risk of finding an adjacent order out of his major service region. For the combination scheme according to 4a constraints (5.27) and (5.30), (5.31), (5.32), (5.33), (5.34), (5.35) need to be met; in case of a direct pickup and delivery equation (5.28) will need to be satisfied instead of (5.27). As for meeting the conditions of a round-trip, equation (5.29) needs to be fulfilled in addition to constraints (5.27) and (5.30), (5.31), (5.32), (5.33), (5.34), (5.35).

   Locations: The distance between the destination of the first order and the origin of the second one needs to be smaller than parameter MD (5.27). A special case is constituted if they are identical (5.28). If the destination location of the second transportation order is matching with the origin location of the first transportation order, a round-trip is identified (5.29).

$$D_{d(i);o(j)} \leq MD \quad i,j \in I; i \neq j \tag{5.27}$$

$$d(i) = o(j) \quad i,j \in I; i \neq j \tag{5.28}$$

$$o(i) = d(j) \quad i,j \in I; i \neq j \tag{5.29}$$

   Capacity and truck type: As stated in equations (5.30) and (5.31), a truck type as well as temperature levels suitable for sequential transportation need to exist. The gross weight of each transportation order is restricted to the available payload by equation (5.32). The amount of pallet places required by each transportation order must not exceed the amount of pallet places available as stated by restriction (5.33).

$$r''(p(i); q(j)) \neq \emptyset \quad i,j \in I; i \neq j; p(i), q(j) \in P \tag{5.30}$$

$$t''(u(i);v(j)) \neq \emptyset \quad i,j \in I; i \neq j; u(i), v(j) \in T \tag{5.31}$$

$$\begin{gathered} MAX(W_i;W_j) \leq WC_{r''(p(i);q(j));t''(u(i);v(j))} \\ i,j \in I; i \neq j; p(i), q(j) \in P; u(i), v(j) \in T; r''(p(i);q(j)) \in P; t''(u(i);v(j)) \in T \end{gathered} \tag{5.32}$$

$$\begin{gathered} MAX(PS_i;PS_j) \leq PC_{r''(p(i);q(j));t''(u(i);v(j))} \\ i,j \in I; i \neq j; p(i), q(j) \in P; u(i), v(j) \in T; r''(p(i);q(j)) \in P; t''(u(i);v(j)) \in T \end{gathered} \tag{5.33}$$

Time windows: The delivery time window of the first transportation order and the pickup time window of the second transportation order, including the transit time between the two locations, must overlap (in case of scheme 4b, the first delivery location and the second pickup location are identical, therefore $TT_{d(i);o(j)} = 0$).

$$EPU_i \leq LSD_j - TT_{o(j);d(j)} - TT_{o(i);d(i)} - TT_{d(i);o(j)} \quad i,j \in I; i \neq j \tag{5.34}$$

$$LPU_i \geq EPU_j - TT_{o(j);d(j)} - TT_{o(i);d(i)} - TT_{d(i);o(j)} \quad i,j \in I; i \neq j \tag{5.35}$$

5.2.3 Filter Criteria

Depending on a multitude of factors such as the amount and the structure of shipments, as well as the geographical distribution of dispatching and receiving locations, the number of order combinations may become very large. In order to keep this amount controllably small and to achieve shorter computational times, several filters have been devised to reduce the number of economically less promising order combinations (see Fig. 5.2). In order to limit computational time, a maximum number of iterations are implemented for all combination schemes. Furthermore, a global limit for combinations is defined. If the number of generated combinations exceeds its threshold value, combination is aborted.

The first set of filters (filter 1) determines the type of orders admitted for combination schemes 1–3. It guarantees that no orders that already utilize a truck completely regarding weight and volume restrictions are considered for combination. The same function is fulfilled by filter 2 within the combination process according to the scheme of bundling. As for generated bundling combinations (filters 3–4), it has proven more promising to keep highly aggregated combinations for further combination purposes than keeping those that have served as intermediate steps. In a simplified example orders 1, 2 and 3 may be combined by bundling, creating different order combinations $k_1 = [1;2]$; $k_2 = [2;3]$; $k_3 = [1;3]$ or $k_4 = [1;2;3]$. Instead of passing on all four order combinations for further combination schemes, only the highest aggregation level of bundling (here: k_4) may be chosen for further combination.

As for the inbound milk runs, the filter determines which combinations are processed further, by trying to add additional orders and generating longer milk runs (filter 5). Since the highest savings are realized when the two pickup locations are very close and the destination is very far, specific parameters are defined in order to evaluate the efficiency of the generated combinations. The featured examples contain an inbound milk run combination *k* of two orders *i* and *j*, served in this sequence, which are to be extended for combinations containing additional orders.

The *detour factor* DTF_k limits the generation of an inbound milk run combination *k* of two orders *i* and *j*.

$$DTF_k = \frac{D_{o(i);o(j)} + D_{o(j);d(j)}}{D_{o(i);d(j)}} \tag{5.36}$$

Only inbound milk runs with a detour factor smaller than a pre-defined threshold value DT_x are considered for additional inbound milk run combinations. The value of the threshold parameter is influenced by the direct trip length. For very small trips the detour factor may be greater, for long trips it should be small. Therefore, the parameter is indexed by *x*, the distance cluster for direct trip length $D_{o(i);d(i)}$. Order combinations with a detour factor greater than $\mathrm{DT_x}$ will neither be considered for inbound milk run extensions (additional inbound milk run combinations) nor will they be passed on to the next level of combination since no cost savings are expected. For those order combinations qualifying for further processing according to the detour parameter, the two parameters *overall average utilization* U'_k and *last leg utilization* U''_k of an inbound milkrun combination *k* of two orders *i* and *j* are regarded for next level processing. These parameters are based on the *capacity utilization* $cu_{l,m}$ on a transportation leg between two locations l and m.

$$U'_k = \frac{cu_{o(i);o(j)} \cdot D_{o(i);o(j)} + cu_{o(j);d(j)} \cdot D_{o(j);d(j)}}{D_{o(i);o(j)} + D_{o(j);d(j)}} \tag{5.37}$$

$$U''_k = cu_{o(j);d(j)} = MAX\left(\frac{PS_i + PS_j}{PC_{r'(p(i);q(j));t'(u(i);v(j))}}; \frac{W_i + W_j}{WC_{r'(p(i);q(j));t'(u(i);v(j))}}\right) \tag{5.38}$$

The further filtering of inbound milk runs proceeds as follows where *MU′ and MU″* indicate a pre-defined minimum overall average utilization and minimum last leg utilization, respectively. The following cases may be distinguished:

- *High Overall Average Utilization ($U'_k \geq MU'$) and High Last Leg Utilization ($U''_k \geq MU''$)*: This combination is very promising since either the distance between the two pickup locations is comparably small or the load picked up at the first location is rather large. In both cases additional orders may still improve profitability, which is why additional inbound milk run combinations are searched for. Nevertheless, these orders will also be selected for processing in the next combination steps searching for round-trip and pickup and delivery combinations.

- *Low Overall Average Utilization ($U'_k < MU'$) and High Last Leg Utilization ($U''_k \geq MU''$):* This combination is characterized by low utilization on the first leg, possibly combined with a long distance trip between the two pickup locations and high last leg utilization. Due to the latter it is not possible to sustainably increase overall average utilization by adding further well utilized transport orders to this combination. Therefore, there are no more searches for additional inbound milkrun combinations and this combination is not considered for combination schemes 4a–c.
- *Low Overall Average Utilization ($U'_k < MU'$) and Low Last Leg Utilization ($U''_k < MU''$):* In cases of low last leg and low overall utilization, additional orders may well be added to the identified inbound milk run. Therefore, further transport orders will be searched for in the next iteration looking for extended inbound milk run combinations. Due to expected poor profitability the order will not be considered for further processing in the form of a round-trip and pickup and delivery combinations at this stage.

The case of high overall utilization and low last leg utilization cannot be observed for an inbound milk run combination, since the load levels of the truck are increasing with every additional pickup stop toward the final transportation leg.

After the candidates for the next iteration have been identified they are matched against the suitable objects within the pool of orders for further combinations. In this process a new order is added at the beginning of the existing order combination, defining a new starting point. It has to be guaranteed that no order combination contains the same order more than once. From this point onward the process is performed as mentioned above and further combinations are generated until no more combinations can be formed or an exit criterion is reached. After all combinations have been created according to combination scheme 2, they are selected for propagation to the next level of combination schemes. For outbound milk runs (scheme 3) filters 5 and 6 work accordingly with the detour factor being defined between the common origin and the according destination locations. The last-leg utilization being substituted by the first-leg utilization (which is the leg with the highest capacity demand) is defined as follows.

$$cu_{o(i);d(i)} = MAX\left(\frac{PS_i + PS_j}{PC_{r'(p(i);p(j));t'(u(i);v(j))}};\frac{W_i + W_j}{WC_{r'(p(i);p(j));t'(u(i);v(j))}}\right) \tag{5.39}$$

As for the sequential schemes (4a–c) the number of potential and feasible order combinations is expected to be much greater than for the simultaneous combinations. It is controlled in filter 7 by applying the following rules:

- A minimum distance *MD* for empty truck transfer between the receiving location of the first transportation order and the dispatching location of the second transportation order is defined. This criterion has already found its way into the model formulation in equation (5.27).

- For the tour combinations only orders and order combinations with a total distance of smaller than a predefined threshold value *TL* will be admitted for combinations that do not result in a round-trip.
- Tour combinations that form a round-trip will not be considered in the next combination cycle.
- Since the highest savings are obtainable if one transportation order only covers a very short leg, one set of combination partners is limited to a distance smaller than a critical value of *SD*, a maximum distance. This step is implemented by starting the combination process with orders that contain short distance relations and by continuing toward orders with longer distance relations until the maximum distance *SD* is reached or a maximum number of combinations *MC* are generated.

In the following cycle all round trips and combinations spanning a total tour distance greater than a critical value of *TD* are eliminated for further combination before the combination process starts again, extending generated combinations with additional orders. All filters are part of the combination procedure in the form of the pre-determined set of parameter values that may be specified according to runtime and quality requirements. This will help to adjust the model to specific characteristics of the examined problem instances.

5.2.4 Combination Assessment

As a result of the combination run, the pool of order combinations is filled with newly generated combinations. Due to the chosen approach, an original order may be part of many different combinations. However, for the implementation of order combinations it must be guaranteed that every original order is selected only once. The selection of combinations for implementation is performed based on cost criteria whereby the set of order combinations is chosen that will generate the highest savings compared to the execution of each order individually. In order to perform this selection, every order and order combination needs to be priced according to freight rates.

Combination scheme 1 is exclusively subject to freight degression and it is the only combination scheme that may be rated using FTL and LTL freight rates. Since the other combination schemes create multi-stop tours, LTL rates are usually not applicable. LTL rates imply that the load of one shipper may be consolidated with the loads of additional shippers by the carrier; a detailed routing instruction, as it is required for combination schemes 2–4, is therefore usually not possible. However, when the whole equipment is placed at a shipper's disposal, as it is the case for FTL mode, transportation order fulfillment may include specific routing instructions.

As described in Sect. 3.1.4 freight rates can take very complex structures. Freight costs have so far not played a role in the combination process and there has been no need to integrate these complex structures into the model. For the cost based assessment of orders and order combinations, freight costs must be taken into account; the chosen approach will, however, only consider freight costs for orders and combinations. The question as to how these freight costs are calculated is not subject to the described approach, but the whole freight cost calculation is performed by an outside rating engine. The big advantage of this procedure is the fact that it is not restricted to a pre-defined rating model or freight rate scheme but can work with any rating scheme. Not only will such an approach support the application of many different rating schemes, but it may also encourage a very detailed and realistic application of actual rates, including different surcharges and additional pricing components.

Ideally, this step is performed by the rating engine of the TMS. Not only are these systems designed and set up to calculate freight costs with an accuracy that self-billing processes are possible, they are also very fast and efficient in calculating freight costs for a given number of orders (or order combinations) because this is their key functionality.

5.3 Selection of Combinations

After every original order and every order combination has been rated, the savings of each combination are determined as the difference between the sum of the costs for individual execution of every order contained in the combination and the shipping costs of the order combination. In case of negative savings, the order combination is directly removed from the pool of order combinations. Thus shipping the orders individually is less expensive than combining them.

Two approaches for selecting the "right" combinations from the remaining combinations in the pool have been devised. The first approach is based on the formulation of a binary optimization problem that may be solved by standard software. The second one is based on a very simple greedy heuristics approach that may be implemented directly into almost any runtime environment. While the first approach can be used to obtain optimal results concerning the selection problem the second one may be implemented directly into the source-code of any TMS.

5.3.1 Formulation of a Binary Optimization Problem

The solution approach presented in the following paragraphs is applied to the pool of order combinations, which at this stage only contains combinations with positive cost saving prospects. The problem of selecting the set of combinations for implementation can be described in the form of a binary optimization problem as follows.

Indices

$k \in K$	Order combinations
$i \in I$	Original orders
$k \in K(i)$	Order combinations that contain original order i

Parameters

s_k	Savings of order combination k compared to individual transportation of original orders contained in k

Variables

x_k	=1, if order combination k is selected for implementation; 0 otherwise

Objective function

$$\mathrm{MAX}\sum_{k\in K} x_k \cdot s_k \tag{5.40}$$

Subject to

$$\sum_{k\in K(i)} x_k \leq 1 \quad i \in I \tag{5.41}$$

Variable domains

$$x_k \in \{0, 1\} \quad k \in K \tag{5.42}$$

The objective function aims at maximizing the potential savings while the single constraint ensures that every original order may only be selected for implementation in one order combination.

5.3.2 Formulation of a Heuristic Approach

The binary optimization problem formulated above can be solved using commercial software. Since these programs may require additional interfaces an alternative heuristic approach has been developed, which can directly be integrated into a TMS environment. In some IT-systems, this may prove advantageous since all TMS functions may be deployed using the same codebase within a common runtime environment resulting in lower IT service and maintenance effort. The approach resembles a greedy procedure first selecting the combination that promises the highest overall transportation cost savings and subsequently removing all combinations from the pool of order combinations that contain the same original orders as the chosen order combination. The procedure is repeated until the pool of order combinations is empty (see Fig. 5.3).

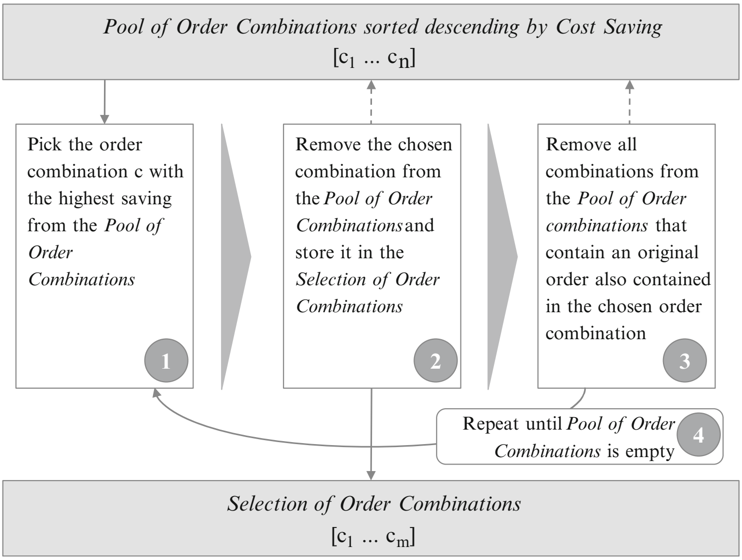

Fig. 5.3 Deployment of the greedy approach for the selection of order combinations

5.4 Extended Combination Possibilities

In addition to the four presented combination schemes, further schemes can be subject to application. The presented simultaneous combination schemes all require a common location for the transportation orders in question. An additional scheme has been devised that is referred to as "in- and outbound milk run" and is depicted in Fig. 5.4. Here, a simultaneous combination of two orders is permitted, even though neither dispatching nor receiving locations are shared. This combination scheme may be viewed as the more general formulation of combination schemes 1–3. Scheme 1 constitutes the special case in which O1 = O2 and D1 = D2. If D1 = D2, the inbound milk run (scheme 2) is defined and for O1 = O2 scheme 3, the outbound milk run is constituted.

With regard to combinability of temperature levels, truck types and load capacity, restrictions analogue to combinations schemes 1–3 apply. However, for time window adherence, the above example comes in four different variants with regard to the sequence locations visited (O determining an origin, D a destination):

(a) [O1-O2-D2-D1], as depicted in Fig. 5.4,
(b) [O1-O2-D1-D2],
(c) [O2-O1-D1-D2], and
(d) [O2-O1-D2-D1].

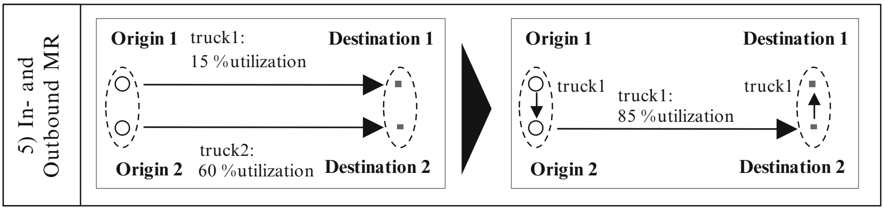

Fig. 5.4 Additional combination scheme 5—inbound and outbound milk run

Time window constraints may therefore reduce the number of feasible combinations. Yet, for practicability reasons, the number of combinations needs to be limited. In the European consumer goods industry box trailers are mostly used for road transportation. In comparison to curtain-sider trailers they may be loaded from only the back. For combination variant (b), goods are first loaded at location O1 against the back of the trailer wall. At the second stop, at location O2 additional goods are loaded. When arriving at location D1, the goods loaded at location O1 need to be offloaded. However, these are now behind the goods for location D2. In order to access them, all goods for location D2 would need to be unloaded before accessing the required material. Afterward the remaining goods have to be loaded before the vehicle can resume its journey to location D2. This process usually requires substantial additional handling operations and results in additional waiting time. The same applies for variant (d). Therefore these variants may be omitted.

In order to limit the number of combinations that are generated a proximity constraint is imposed on the dispatching and receiving locations. Such a restriction can take place in different forms. A maximum distance between the affected origins or destinations comparable to the MD parameter used for combination scheme 4a may avoid the generation of disadvantageous combinations. Furthermore, the distance can also be limited by a parameter such as the detour factor used for filtering milk run combinations putting the trunkline (or line-haul) distance in relation to the pre- and post-carriage. Furthermore, a criterion based on the geographical position of the affected locations could be used to favor the generation of advantageous combinations.

The above described combination scheme has been subject to extensive testing in order to determine its advantageousness compared to the results that are achievable using combination schemes 1–4. The combination scheme has been implemented in addition to combination schemes 1–3, and results from above described scheme 5 have also found their way into combination schemes according to 4. Results have, however, been disappointing. Computational time has for very basic test-sets increased by 20%. Yet only few additional combinations were identified and even fewer were selected for implementation. On average, an increase of transportation cost savings by 0.2% points was observed.

Due to the increased computational effort and its poor results, the above mentioned combination is of no relevance for the further numerical investigations with regard to the underlying case study. For different network structures it may, however, be worth considering.

5.5 Implementation Guidelines

In the first parts of this section, a general implementation approach is described beginning at the functional data requirements and from there defining a procedure to profit from freight rate degression. This subsection focuses on some implementation details for a real life deployment. It describes the targeted IT implementation and gives an overview on potential enhancements and alternatives.

5.5.1 Data Requirements

The basic data required to run the above mentioned processes of order combination and selection has already been described within the functional description of the solution approach. It is based on the information required to process a transportation order from generation to closure in the TMS.

Order Data

The order data is the data that is required to generate a valid transportation order. It contains the following data objects:

- The pickup and delivery locations of a load: $o(i) \in L$; $d(i) \in L$.
- The load size in the dimensions pallet spaces and gross weight: PS_i; W_i.
- The specified truck type: $p(i) \in P$.
- The required transportation temperature: $t(i) \in T$.
- The opening and closing of the receiving/dispatching functions at the specific location (location dependent) or, if stricter, the completion of the last production step and possible quarantine/waiting time before transfer of the complete load, resp. availability of the latest partial load that is destined for the inserted transportation order (pickup location). Analogously, at the delivery location, the earliest time the complete load or a partial load is required for further processing: EPU_i; LPU_i; ESD_i; LSD_i.

Most data is available in the ERP system and used for the MRP run; therefore, data availability is guaranteed through standard TMS-ERP interfaces. Alternatively, manual insertion of orders and associated order details is usually possible (Rider 2003).

Geographical Data

In order to consider distances ($D_{l;m}$) between locations as well as transit times ($TT_{l,m}$), geographical data is a necessity for the optimization process. In the TMS, this data may be used for calculation of freight cost components based on distance (e.g., distance dependent rates or rate components such as road pricing) or based on time. Transit times will be necessary not only in the TMS but already in the ERP to perform correct backward scheduling in the MRP run. The determination of road distances based on digital maps can be a time consuming process (~ 1 s per origin/destination relation), it is therefore useful and customary to store these distances in a distance matrix. Transit times are usually calculated based on an average road speed per road category (e.g., motorway) and also stored in a matrix for fast accessibility. These matrices form a vital element of TMS data and are therefore best stored within the TMS environment.

Functional Parameters

Functional parameters, for example, truck types or temperature classes are used to restrict possible combinations due to load specific requirements. They, in turn, influence the available vehicle capacity ($PC_{p,t}$; $WC_{p,t}$). Furthermore, this data is necessary to calculate freight costs based on freight rates and is as such part of the TMS data model. In order to perform integrity and plausibility checks within the TMS, information on the feasibility of combinations must be available. Therefore, parameters $r'(p;q) \in P$; $r''(p;q) \in P$; $t'(u;v) \in T$; $t''(u;v) \in T$ should also be obtained using the TMS data model.

Optimization Process Parameters

These parameters influence speed and quality of the generated solutions within the combination processing step and can be used to adjust the system set-up according to case-specific characteristics. As such, they will not be found within a "standard" TMS environment, they are therefore specific for the described process. It is suggested that they are stored within profile datasets (e.g., files) and influenced using either standard editing software or through a dialog within the TMS Graphical User Interface (GUI). Examples for this data are constituted by filter parameters such as MD.

This description shows that the major data elements can be taken from the TMS using only a few interfaces for data input. In this implementation scenario, no direct interface is required with the ERP system. The following paragraphs will detail how this data can be processed and then handed back to the TMS.

5.5.2 Process Integration

The basic process layout in TMS has been described in Sect. 4.2.1. This description is extended here, taking into account possible adjustments required for the above combination approach. The number of potential process variants may be unlimited in practice, considering regional, sector and company-specific processes and restrictions. Nevertheless, with respect to the operative planning process there are two major areas are of special interest, one being data availability and the other data quality and reliability (Ferrer and Karlberg 2006; House and Jackson 1995). Two process variants will be described here in order to approach each of the areas from a planning process point of view.

5.5.2.1 Basic Process

Transportation demand: The basis of operative transportation planning is the demand for goods to be transported between two locations. This demand may rise from many sources; it may be direct customer demand or production demand; it may be destination-driven (demand of goods) or source driven (supply of goods). The consumer goods supply chain is mostly a pull supply chain; transportation demand arises from customer demand that needs fulfilling from warehouses; warehouse demand that will need fulfilling from plants, and raw material demands in the plants that will need fulfillment by suppliers. In most supply chains, the supply, demand and inventory planning is usually performed within the ERP environment in the material requirement planning MRP module (Rider 2003). It is of vital importance for the transportation planning process that the transportation orders are very reliable within the planning horizon and are not subject to short-term change. This proposes high requirements on the optimal length of the planning horizon (see Fig. 5.5) – usually a planning horizon of 1 week can be described as sufficiently stable (Thonemann et al. 2004). If for transportation orders toward the

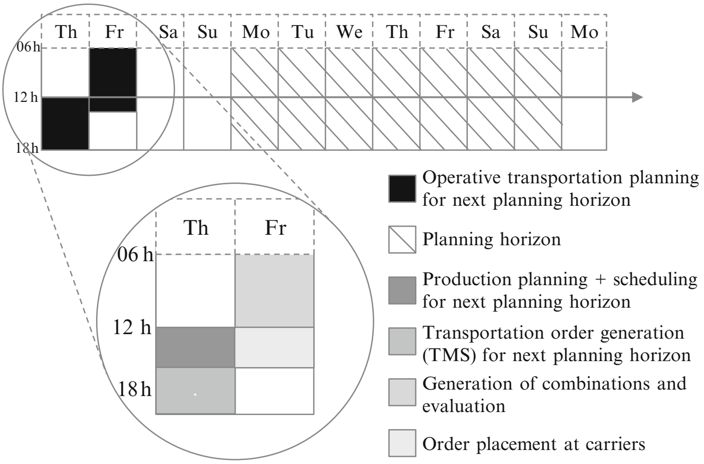

Fig. 5.5 Process schedule for operative transportation planning

end of the planning horizon, volatility increases substantially, a shortening of the horizon may be inevitable.

Transport order generation: Once the production planning and scheduling is executed, the material flow toward the production and the material flow out of production is determined and transportation lot sizes can be devised and loads can be scheduled. This is the moment transportation orders can be generated in the TMS. Since all preceding process steps were performed in the ERP, the ERP can launch the order generation process in the TMS issuing the relevant data (e.g., time windows from production plan and location master data, temperature requirements from article master data, and so on) yet some data may also be drawn from TMS-specific master data (e.g., time windows of specific locations). Since transportation orders will usually be generated after production planning and scheduling is done, all transportation orders are generated at once on a weekly basis.

Combination of transportation orders: Once the transportation orders are in the system, those destined for the following planning horizon are locked against manipulation and handed over to a combination service that will generate order combinations according to section 5.2.

Evaluation of the combinations: After the combinations have been built, they are returned to the TMS to be evaluated with the valid set of transportation tariffs. The transportation costs for the order combinations are then compared to the transportation costs for each single order (if served individually). In cases where the combination is cheaper, the difference is regarded as a transportation cost saving; only order combinations with savings >0 will be regarded for implementation. All transportation orders that are not part of any order combination or only part of order combinations with negative savings are unlocked in the TMS database. All others stay locked.

Choice of order combinations for implementation: Based on the generated order combinations every original order may be utilized in more than one order combination. Therefore, it may not be possible to implement all order combinations. A selection has to be made so that the highest total savings can be generated (see Sect. 5.3). The selected order combinations are implemented as new carrier orders. All original orders that are not part of any order combination can be implemented individually.

Execution and invoicing: The implementation steps of a transportation order include carrier selection, order placement, reception of order confirmation (fixation), generation of shipping documents, monitoring and status update, proof of delivery, invoice verification and billing.

Process Enhancement 1: Reactive Scheduling

The stability of the described operative transportation planning process largely depends on how many orders are still subject to change after the order entry. Changes may occur for several reasons: for example, due to sudden supply bottlenecks, truck breakdowns or poor production equipment availability. Implications of changes have to be evaluated within two conditions that an original transportation order falls under:

1. The transportation order is not part of any order combination. If some of the order parameters change (e.g., time windows due to later completion or amount of pallet space required due to smaller lot-sizes) these may be directly transmitted to the carrier, which is required to confirm the changed order parameters. It may nevertheless be possible that due to the changed order parameters, combinations with other transportation orders that have so far not been part of any order combination may prove profitable. It may therefore be beneficial to perform another combination run with these orders after they have been changed. Only those orders not part of any order combination can be taken into account as potential combination partners. In cases where another order combination is found, the affected original orders are withdrawn from their carrier assignments and the order combination is assigned anew. This process requires detailed contractual terms on how long a period before order fulfillment that an order may be withdrawn from a carrier. Only if the time is sufficient can this process prove to be worthwhile.
2. The transportation order that is subject to change is already part of an order combination. It is then necessary to assess whether the combination's feasibility is affected. If, for example, due to shifts in the time-window parameters or load sizes, the order combination is no longer feasible, the whole combination needs to be withdrawn from the assigned carrier. It may still be possible that other, uncombined orders may form combinations with one of the original orders, combined in the withdrawn order combination. In this case another combination run can be performed, this time trying to combine the orders from the withdrawn order combination with so far uncombined orders. As above, a contractual statement and prompt reaction is advisable in order to benefit from the highest degrees of freedom and to achieve the lowest cost-base.

This example shows how much the process can benefit from a structured scheduling approach. Its implementation success will greatly depend on a set-up that allows very prompt optimization results with very few input orders on the one side and a large number of orders of which they may potentially be combined. The presented approach will generally support such a process. Nevertheless, it must be made clear that these examples are process exceptions. However, a good exception management is unlikely to be able to replace a well-dimensioned planning horizon.

Process Enhancement 2: Spot Sourcing

Whereas process enhancement 1 is aimed at a process design that is more robust toward parameter changes, enhancement 2 is designed to disclose options in the event of lacking data availability. When missing order specification details, data may be completed with assumptions or approximations. A key factor toward the successful implementation of this operative transportation planning approach is the availability of transportation cost data in the form of transportation rates. A great number of order combinations may be generated in the combination step. All of these combinations meet the required restrictions but will need to be evaluated according to their transportation cost impact. This can only work with available transportation rates.

In industry practice a wide coverage of rates is, however, not often available, since only the relevant transport relations are subject to regular negotiation (e.g., 1-year contracts). In FTL networks or FTL network-structures, these will often be agreed on based on a lane relationship (e.g., from Berlin to Essen: EUR550 per trip for ambient single truck). If tours (multi-stop lanes) are part of the transportation process portfolio, then these will usually be predefined. This approach may work for recurring tours but will not support the described operative transportation planning approach, since it would hardly be possible to negotiate all possible tours with a multitude of carriers, especially since a majority may never be used.

A potential solution may be the use of benchmark rates or cost sets. Benchmark rates are generated from real transportation costs performing a regression analysis on distance and costs. The result is a fixed cost per trip and a variable cost per distance unit (e.g., kilometer). The analysis needs to be performed for all relevant equipment types. Accuracy may be increased by differentiating the rates even further taking regional attributes into account (e.g., countries). This will not only help to account for market imbalances (typical market imbalances may occur in a trip to Great Britain or from the Iberian Peninsula), but also costs for ferry crossings or special tolls can then be easily included within the rates (McKinnon and Ge 2006). There may be other ways to obtain benchmark rates than employing the company's transportation network, for example, standard rates such as GVE (Germany). Those benchmarks that are generated based on a company's own data may often take additional and industry specific parameters into account, which can be underweighted in public benchmark figures. In contrast to freight rate benchmarks, which are usually surveyed by the shipper, cost sets are issued by a carrier. They indicate transportation costs using a structure similar to the benchmarking approach.

If no contractual rate for an order combination is available for the combination assessment phase of the process, the benchmark rate or cost set is chosen to calculate the savings and assess the order combination for implementation. If the combination is chosen for implementation, it is tendered using a specific tendering platform, which may be part of the TMS implementation (see Sect. 4.2.2), or a commercial tendering website (Bierwirth et al. 2002). Tendering results will benefit from a restricted and informed circle of participants. If the costs that result from the tender will support a cost base lower than the original orders, the order combination will be awarded, otherwise the orders will be implemented uncombined.

The results from the spot sourcing process have to be analyzed on a regular basis and may contribute toward an update of the constructed benchmark rates. According to the tendering results, benchmarking rates should be adjusted in order to achieve a high probability of implementation when tendering the order combinations.

This section's focus on the process environment not only described the standard proceeding but also concentrated on two relevant process enhancements, which can substantially ease practical implementation. An implementation will need to cover many different aspects with more process variants; nevertheless, the two examples show possible approaches and illustrate that deviations from the process blueprint may also be considered using a flexible process design.

5.5.3 Systems Integration

The described optimization approach may be integrated into an existing TMS based on service oriented integration (Trautmann and Krause 2007). Such a service is called by the TMS (see Fig. 5.6), triggered from the user interface or triggered by other processes and passes on the necessary transaction data (necessary master data can be directly accessed within the TMS). This guarantees independence from the TMS technology and may therefore be offered as a service to different TMS implementations (Albrecht 2007).

Along with the service call, the relevant transportation orders are handed over and the *pool of orders* is filled. After the combinations are generated and the *pool of order combinations* is filled, the combinations have to be rated by the TMS.

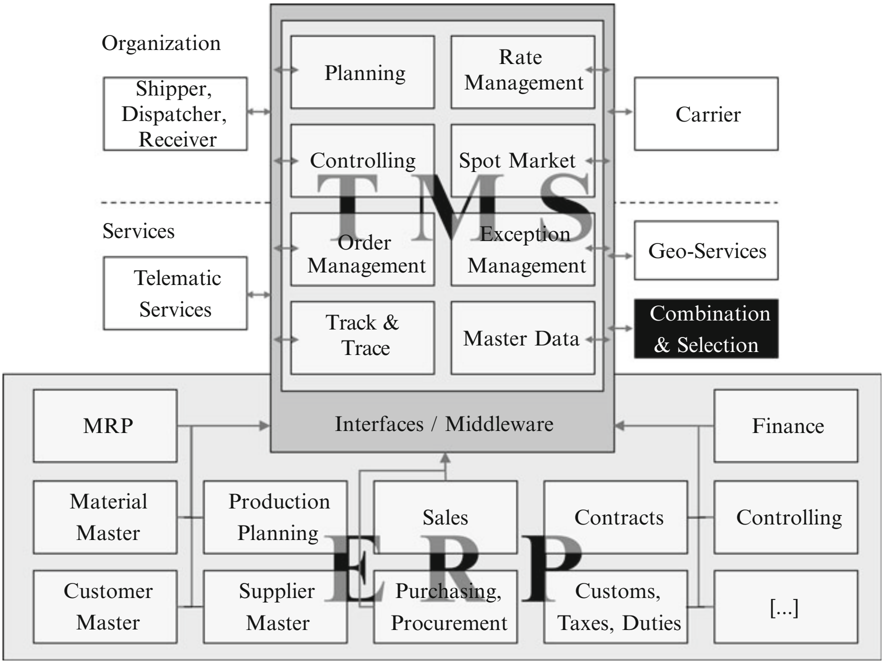

Fig. 5.6 System architecture including integration of combination and selection services

The combinations are therefore handed over to the TMS. Results are either processed within the TMS environment (e.g., using the greedy heuristics approach described in Sect. 5.3.2) or returned to the optimization service for selection. After the order combinations for implementation have been identified, they are made available for further processing within the standard TMS processes. This may include process steps such as spot sourcing or carrier assignment and communication. However, freight controlling may require some additional adjustments on how transportation costs are assigned to the initial orders contained in an order combination.

5.5.4 *Organizational Integration*

The organizational set-up within the described operational transportation planning approach imposes hardly any objections on real life implementation. However, two aspects shall be addressed due to practical relevance. Depending on the relevant process extensions (see Sect. 5.5.2) combinations may only be generated when the orders are made available to the combination service within the same combination run. Transportation management organizations are often subdivided into regions or sections of the supply chain (e.g., supply versus distribution). In order to be able to combine orders from different organizational units they will ideally adhere to the same planning horizon having the relevant orders available before the combination process is started. Furthermore, standards on how to share the achieved transportation costs savings have to be developed.

The on-time availability of transport orders is an operational necessity for a seamless process. The schedule for transport order processing is especially tight regarding order assignment and carrier notification. Based on the schedule suggested in Fig. 5.5 (p. 117) the notification and acceptance period for transportation orders starting on the first day in the planning horizon (Monday) only comprises the Friday afternoon and the weekend. This defines the minimum order lead time. All processes should ensure that lead time is not reduced any further by providing transport orders by Thursday evening, the latest.

5.6 Summary

In this section an operational transportation planning approach for the consumer goods industry has been presented. With regard to implementation the three areas that have been subject to detailed analysis in Chap. 4 – namely, process, IT and organization – have been addressed.

As for process implementation, the approach is designed to consider real life complex freight rates, an issue that has been critically addressed for existing planning approaches. It supports transportation planning tasks employing real life freight costs in an environment where transportation is outsourced to several carriers. In addition, the most common restrictions have been implemented with regard to transportation in the consumer goods supply chain. The suggested criteria can be extended easily to cover additional restrictions. Process enhancements and variants that allow a flexible implementation have been introduced.

The approach for operational transportation planning is designed for seamless integration into a TMS environment and is therefore suitable for implementation into the system landscape prevailing in the consumer goods industry. Implementation according to modern systems design standards, such as service-oriented architecture and software-as-a-service, for example, is supported. The suggested variants also leave space for closer integration (see Sect. 5.3.2 for implementation of the heuristic selection approach). The approach is therefore qualified to close the functional gaps identified in Sect. 4.2.6. Finally, an organizational implementation was also assessed.

For an overall assessment of the presented approach, a numerical investigation has been performed. The results are described and discussed in the next chapter and they complete the picture of the suggested operational planning approch.

Chapter 6
Numerical Investigation

It is the primary objective of the numerical investigation to assess to what extent the chosen approach is valid for different cases. The investigated cases all center around operative transportation planning in the consumer goods industry, as described in Sect. 3.2. In this section, the following will be outlined: First, a general description of the chosen test-cases and implementation environment is given and initial results of the numerical investigation are introduced. In the second subsection, the input data is varied in several scenarios and the results are presented and discussed. Subsequently, some control and filter parameters are subject to manipulation and the consequences are investigated. Further variations to the structure and specification of the input data are assessed afterwards. Finally, the findings are aggregated and compared to instances based on real life data, and an overall conclusion is drawn.

Since the chosen model set-up is designed for cases similar to the one described in Sect. 3.2, another objective of the numerical investigation is to locate the limits of this approach and hence identify areas for future research activities. The choice of an implementation environment for conducting numerical investigations is influenced by four major factors:

- *Performance.* For transportation planning in the consumer goods industry, the performance requirement results from the planning process. It is typically conducted once per week and should not take longer than 1 h.
- *Solution quality.* Due to the tight time schedule, a good solution quality (i.e., highest possible savings) must be obtained reliably within 1 h.
- *Stability and scalability.* Since implementation is designed to take place along a highly time-critical process, stability is a key factor for a successful deployment. This will also require good scalability characteristics.
- *Integration in real life IT-architecture:* The testing environment should sample a real-life IT-architecture using software and hardware components, which are commonly used to support business software applications.

T. Seiler, *Operative Transportation Planning*, Contributions to Management Science, DOI 10.1007/978-3-7908-2792-7_6,

6.1 Test Case Generation and Setup

The IT environment used for investigation has been devised to match hard- and software requirements that can be met in real life business environments. As for hardware configuration, mostly office machines have been deployed. The performance and reliability is easily matched by standard server equipment that is used to host current TMS implementations. The software environment that has been deployed for numerical investigations is similarly based on global IT standards. Although all tests have been performed using MS Windows-based operating systems, the chosen runtime environment is founded on Java and MySQL, which extends the potential operating environments toward almost any UNIX-based operating system without major additional implementation effort. Overall, the test environment has to be characterized as substandard with regard to real life transportation management environments. Better performing data base engines are commonly deployed, especially for the chosen database system MySQL. However, results show that for the test instances the hard- and software specifications used for these investigations will fully suffice.

A basic test case was devised for the numerical investigation. It was constructed from 10,000 transportation orders comprising 1 week. Dispatching locations, receiving locations, load, time windows, temperature and truck requirements were generated in a randomized process, but based on a network structure of a real life consumer goods manufacturer that resembles the shipments among suppliers, plants, distribution centers and retailer's warehouses. The generation of locations was performed by randomly distributing them in a square of 1,000 × 1,000 km. A total of 500 locations have to be served within a 1-week planning horizon, time windows ranging between 2 h and 8 h are normally distributed. Transportation loads average 79% with truck types being 75% single layer trucks and 25% double layer trucks. 53% of the original transportation orders require ambient transportation while 29% require a temperature controlled and 18% a chilled environment. The average transportation distance amounts to approximately 500 km. The presented results were generated on a test-set with five instances that only differ by the values of the randomized order parameters. In the process of randomization the distribution of parameter values was kept while the actual values were replaced. Transportation costs were rated according to a set of distance dependent German benchmarking rates "GVE" (N.N. 2009) with an additional 7.2% discount on round-trip (scheme 4c). In a European industry context these network sizes are covered by the top-selling industrial enterprises including some consumer goods manufacturers. However, transportation distances in this case suggest a rather localized production footprint. From a network as well as from a shipment structure point of view, the generated datasets are a good representation of a real life case. All details for the generated test data can be found in Appendix III.

6.1.1 Description of the Implementation Environment

Concerning the numerical investigations the chosen systems set-up is based on a mixed java[1]/SQL[2]/OPL studio approach. Within the SQL database all combinations are generated and stored and all input data is loaded directly into the database. All combinations are built and evaluated using database transactions. Transactions are called and controlled by a Java runtime environment; all parameters are implemented there. The implemented architecture is a MySQL database engine that is controlled by a Java environment (Computer A: Intel Core2 Duo 2.2 GHz, 2 GB RAM, Operating System MS Windows XP). After combinations are generated, the optimal choice of combinations has to be assessed. This is performed alternatively using ILOG OPL Studio[3] together with ILOG CPLEX[4] or the greedy heuristic approach (see Sect. 3.4) implemented in a Java runtime environment (Computer B: Intel Xeon 2.5 GHz, 4 GB RAM, Operating System MS Windows Server 2003).

First, the orders and all necessary master data are loaded into the database. The database tables are already constructed upfront. The import of data is performed from structured .txt files and triggered by Java commands from a Java runtime environment. All further queries are also triggered by a Java program. This program furthermore controls the combination progress and intervenes with parameters such as filter parameters and exit criteria as described in Sect. 5.2.3. Once all combinations are constructed, they are evaluated according to applicable freight rate. Afterwards all order combinations with positive savings are exported into a .txt file that is suitable for further processing in OPL studio in order to solve the binary optimization problem described in Sect. 5.3.1. For some test instances the relevant data is handed over to an additional Java program that performs a heuristic approach for the selection of order combinations (see Sect. 5.3.2). Results are once again exported into a .txt file and then processed for KPI analyses.

6.1.2 Parameter Choice

Nine sets of filter parameters have been implemented into the proceeding of numerical investigations for the basic scenario according to the seven filters described in Sect. 5.2.3. Since filters 1 and 2 do not limit the number of successfully generated combinations, but only the numbers of combinations that will be omitted due to failure to adhere to the restriction, these filters are not subject to investigation within numerical investigations. The remaining filters are identified below for further assessment.

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[1] Java 1.6.0_15.

[2] MySQL 5.1.

[3] ILOG OPL Studio 6.1.1.

[4] ILOG CPLEX 11.2.0.

Filters 3 and 4: Bundle Propagation Filter

Within the bundle propagation filter, only those combinations with the highest levels of order aggregation are passed on to the subsequent combination steps. The standard settings allow a propagation of the order combinations with the two highest aggregation levels. This parameter was varied to allow an additional aggregation level in one investigation and was reduced by one in another run.

Filters 5 and 6: Milk Run and Milk Run Propagation Filter

Within the milk run filter, four parameters have been identified. The first two are the detour factor and the utilization KPI. These have been adjusted toward stricter and less strict parameter values. In addition, filters for transit time and buffer time have been enforced and relaxed in additional scenarios.

Filter 7: Pickup and Delivery Filter

With regard to the filter for pickup and delivery combinations, five filter parameters have been identified. First, the maximum distance to run empty for regional pickup and delivery operations has been varied. Second, the total distance restriction has been tightened and loosened. In addition, the number of maximum combinations per iteration has been altered as well as the total number of maximum combinations. Finally, the maximum number of iterations has been subject to variation.

These filter parameters have been designed to serve as influencing measures in order to adjust system performance as well as the quality of results in order to meet the requirements of specific deployment environments. The numerical assessment based on a variation of these parameters promises an important insight into the extent to which the approach may be adjusted in order to suit other implementations. It furthermore gives a good recommendation for initial parameter choice for practical implementations.

6.1.3 Sub-Scenario Development

The necessary time for generating a solution as well as the solution quality depends on many factors. Some of these factors cannot be influenced at all, some may be influenced in the long run and some may be influenced as part of the operative planning process. For the developed approach, eight influencing factors were investigated in detail; namely, the number of involved locations and transport relations, the number of orders to be processed within one combination run, the

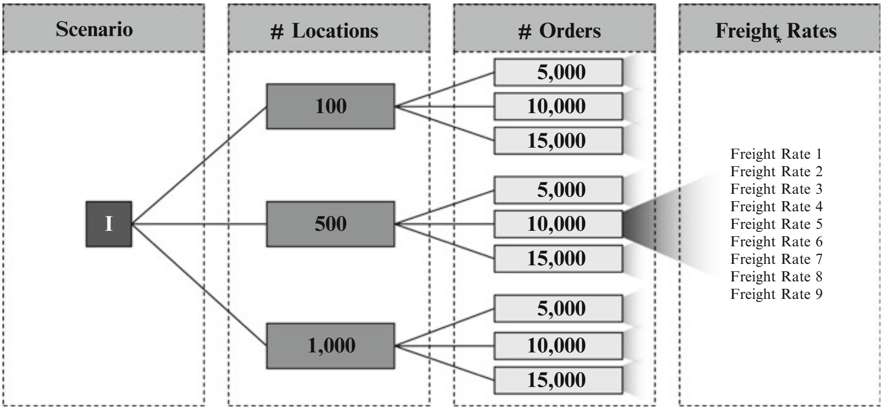

Fig. 6.1 Sub-Scenario structure of test-cases in every scenario

structure of freight rates, the length of time windows, the load size per shipment, the distribution of different required transportation temperatures, the length of the planning horizon as well as the transportation distance. Since all these factors are surely interdependent, the scenarios have been assessed using a two stage approach. First, a basic input data variation takes place with regard to the first three influencing factors (i.e., the number of locations and transport relations, the number of orders and the freight rates — see Fig. 6.1). The results are discussed in Sect. 6.3. An extended variation takes place with regard to the remaining factors in Sect. 6.4.

Variation of the Number of Transportation Orders

The amount of shipments per time period determines the system load on a transportation network. For the described model it determines the number of potential combination partners and therefore the amount of potential combinations. A large number of shipments are expected to result in longer runtimes. This factor is investigated in order to quantify a practical amount of shipments to be processed within one run.

Three different scenarios are defined with 5,000, 10,000 and 15,000 transportation orders. In the focus industry of consumer goods manufacturing and in a continental FTL transportation network this will account for EUR 100–1,000 million in annual transportation costs. In a European industry context these network sizes are covered by the top-selling industrial enterprises including some consumer goods manufacturers. These figures therefore represent an ambitious but realistic test case.

Variation of the Number of Locations

The number of locations served with a given number of shipments is expected to influence two aspects of the solution. First, a large number of locations will result in a large matrix regarding transit-times and distances. Finding the information in this matrix will result in longer database transaction times. Second, the applicability of the combination schemes is based on a location/order relation. The same number of shipments between fewer locations will result in a higher number of contacts per location, increasing the probability for the application of combination schemes 1–3 and 4b–c.

In the chosen testing environment the realized number of contacts per location was distributed according to an ABC-distribution. There are few locations that have the majority of contacts due to their designation as central warehouses or distribution centers. Other locations, such as plants, may have fewer contacts per locations, since more plant locations are existent. Finally, some suppliers of low-volume raw material may have very few contacts. Three test-sets including 100, 500 and 1,000 locations are part of this investigation. This results in average location throughputs between 300 and 1,200,000 t per annum. Again, these are top-values, only achieved by a few industrial enterprises.

Variation of Freight Rates

The described solution approach takes advantage of freight rate degression in the form of load and distance degression. The extent of degression is therefore expected to have a major influence on the solution in terms of cost savings. The influence in terms of runtime and solution quality is, however, limited to the selection of order combinations (and not their generation). Rates may furthermore be influenced by negotiations and may vary strongly over a short period; nonetheless they are also a result of pricing in a market environment. Understanding the market structures may therefore contribute substantially toward an adequate rate structure that supports the operative transportation planning process.

The set of rates chosen for testing purposes was selected from GVE 2007 (Stolletz and Stolletz 2008) and has a distance as well as a load degressive component (see Appendix III). The degree of degression is varied in three steps of the dimensions of distance and load. This results in nine different sets of freight rates. Even though the base rates may have originally been published to describe the German road transportation market, they resemble the structure of transportation rates on the European continent. Based on the freight rate structure, these may be taken to represent an almost global freight rate structure with strong resemblance to North American as well as some South American, Australian and selected Asian transportation markets.

In total, the variation of input parameters will for each scenario result in 81 sub-scenarios (three accounting for the number of orders, three accounting for the number of locations and nine accounting for different levels of freight rate degression). Each of the sub-scenarios is tested in five randomly generated instances of transportation orders. Therefore, a total of 405 sub-scenarios are assessed per scenario. However, since the generation of order combinations is independent of the freight rates, the combining process only takes place for 45 sub-scenario instances.

6.1.4 Head-Scenario Development

After three major influences have been identified, additional factors have been subject to further investigation. The generated scenarios are shown in Fig. 6.2. Concerning transportation management process improvements, time windows impose a major restriction on the combination process. Therefore, two scenarios have been developed in which time windows are tightened and relaxed compared to the basic scenario. Another restriction is imposed by load sizes in relation to truck capacities. Here as well, restrictions have been tightened and relaxed in two scenarios. Temperature and truck type requirements constitute the third restriction covered by scenario variation. They have also been altered toward tighter and less tight values in order to better assess their influence. With regard to the specific transportation management process applied to the consumer goods industry, the planning horizon has been shortened and prolonged in two scenarios in order to assess its impact on solution quality and speed. Finally, with specific regard to significant growth rates in emerging markets (The Economist Intelligence Unit 2005), the influence of transportation distance has been subject to investigation in two additional scenarios.

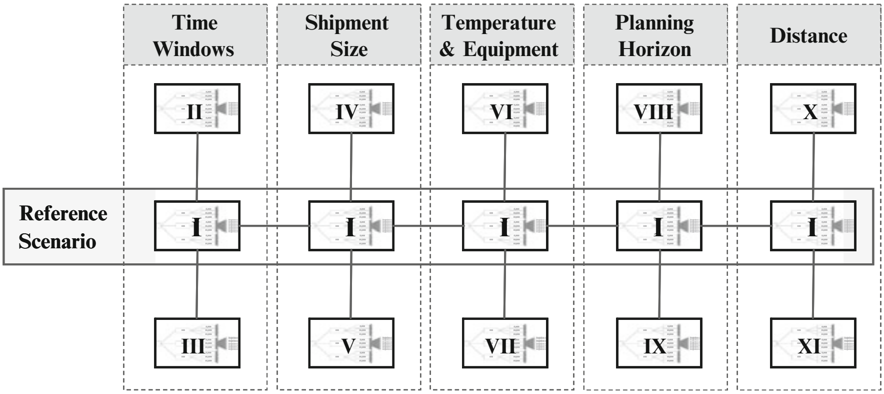

Fig. 6.2 Scenario definition

Shipment Size

The presented operational transportation planning problem is characterized by high equipment utilization due to shipment sizes being rather large. Although much of the transportation is performed in FTL mode, the average shipment size will determine how many potential combinations are created using combination schemes 1–3. Many of the combinations created within these schemes are subject to further investigation in the successive combination schemes 4a–c and will therefore increase problem size. Shipment sizes are not to be influenced in the operational transportation planning process but are the result of the production planning and scheduling as well as replenishment processes that takes place beforehand.

In this respect, not only an average shipment size is taken into account, but also the distribution of different drop-sizes is subject to investigation (Scenarios I, IV and V). Therefore, three different distribution patterns are taken into account, which are all characterized by high average equipment utilization. Compared to the vehicle fill reported by the Department for Transport 2006, the utilization rates are above average (69% of deck space utilization, 52% cube utilization). Since these, however, cover the entire consumer goods supply chain including retail, shipment sizes assumed for the industry's section are considerably larger and realistically represented within the test data.

Time Windows

Time window length is an influencing factor regarding the possibility of combining shipments. The longer the time windows are, the higher the probability that two shipments can be joined in an order combination. Longer time windows extend the flexibility of the transportation network and hence enlarge the solution space.

Changing the time windows in the replenishment process may seem to be a difficult task in the short run; however, this investigation is designated to sensitize the planner to regard the information with care and accuracy. In the long run, measures that optimize time-window distribution may prove effective (increase buffering space at plant locations, manipulation of ERP parameters such as deliver day and so on). Time windows have been varied in Scenarios IV and V.

Temperature and Equipment Type

Different temperature levels and equipment types limit the possibility of combining shipments and therefore restrict the solution space. However, there are some measures to increase the likelihood of combinations for different temperature levels and truck types. Product composition may be the most obvious one; that is, giving products a better resistance toward different temperature levels. However, because product composition is often driven by quality and cost aspects, transportation concerns may in most cases be insignificant (Lütke Entrup 2005). Often temperature restrictions may apply for the packaging rather than for the product itself. This, for example, is true for many products that are sold in glass jars and usually have paper labels. If these are put into a cold environment for a longer period the content and the glass cool down, often without any negative effect on the quality of the contents. If they are then placed in a warmer and more humid environment directly afterward, condensation may form on the outside of the glass and in interaction with the paper label leave undesired water marks. Since the product's appearance becomes less appealing such situations are avoided. Attempts to improve packaging (e.g., water resistant labels) may result in a higher probability for an order to be approved for combination. Also a standardization of pallet heights and stackability can improve probability for combination, if different truck types are employed. Furthermore, the availability of multi-purpose transportation equipment (e.g., trailers that are equipped with different chambers for different temperature levels) may increase the number of combinations that can be generated for savings assessment.

These measures have been regarded in the numerical investigations indirectly by manipulation of the share of the required transportation equipment. The chosen parameters are varied in three different scenarios from an even distribution (Scenario VII) of three different temperature levels and two equipment types to a scenario in which only one truck type and one temperature level are prevailing (Scenario VI). The reference scenario (Scenario I) completes this investigation.

Planning Horizon

Shortening the planning horizon from 1 week to a few days is expected to limit the amount of possible combinations, because at the very beginning/end of the planning horizon potential combination partners are very limited. However, the reduced number of orders in a shortened planning horizon may on the other hand increase solution quality due to more combinations being generated. This might in turn compensate for fewer combination possibilities.

The approach to shorten the planning horizon is of major relevance due to potential uncertainties within the production planning and replenishment processes. Potential implementations may therefore have to adjust to a potential planning horizon of half a week, which is included in one scenario (Scenario VIII). Another scenario is used to describe an extended planning horizon of 2 weeks (Scenario IX).

Distances

The transportation distance influences transportation costs because freight rates are largely distance dependent. Distance is therefore closely related to the structure of freight rates and their degree of degression. In the case of combination scheme 4c, the distance between two locations will also influence the solution space due to the probability of finding a suitable starting point close to a destination of an existing one extending the total travelling distance. Three scenarios with different distances were designed, comprising an average distance of 235 (Scenario X), 470 (Scenario I — reference) and 940 km (Scenario XI).

The factors identified in the sub-scenario definition and also in the head scenario extensions are suitable for investigating the sustainability and the borders of the described approach. They may also address further measures that can be taken in order to access additional savings potential.

6.2 Basic Scenario Evaluation

The general results presented in this subsection are based on five instances of the basic test-case. This basis is regarded as the reference for all investigations concerning input data and parameter variation and is therefore presented in greater detail. The selection of order combinations is performed in two ways using the binary optimization approach and the greedy heuristic approach.

An average of 64,067 combinations were generated in the combination phase for the test cases—an average of 17 for the bundling scheme, 559 for inbound milk runs, 97 for outbound milk runs and 63,394 for the sequential schemes of round-trip and pick-up and delivery (for details, see Table 6.1). On average, 51,558 order combinations were rated with positive savings and were therefore considered for selection. Average total runtime for this approach amounts to 435 s. About 15% of the computational time is spent on pre- and post-processing. During pre-processing, all information including the geographical data (transit times and road distances) is loaded into the database and the relevant information according to the inserted transportation order data is pre-selected. Post-processing involves the freight cost calculation based on freight rates and the export of all relevant data for further processing.

Average runtime selecting the optimal solution by use of the binary optimization model (relative MIP Gap of 1.0 E^{-04}) amounts to 3 s, while the heuristic approach requires 14 s of CPU time on average. The combination approach largely benefits from a solution space that is restricted by parameters such as time windows, high upfront equipment utilization, different temperature levels and truck types.

Although the simple greedy approach takes longer for the presented examples than the optimization approach, it generates solutions that result in transportation costs savings of approximately 9% lower than the optimal solution, while selecting fewer combinations. As for the heuristic approach, an average of 32% of transportation costs were influenced resulting in average transportation costs savings of 4.82%. In the optimal approach, an average of 36% of transportation costs were influenced, resulting in average transportation cost savings of 5.25% (see Fig. 6.3).

In particular, the combination scheme “Regional Pickup and Delivery” (4a) appeared to be very effective followed by “Direct Pickup and Delivery” (4b) and

Table 6.1 Results of the numerical investigation for five instances (the number of combinations in the "comb's generated" column for "post-processing" states the number of combinations that have been rated with costs savings > 0 EUR)

Problem Instance	1		2		3		4		5	
Transport. Costs before Optimization [€]	7,546,997		7,517,558		7,491,593		7,511,223		7,548,331	
Generating Combinations	**Computational Time [s]**	**Combinations generated**	**Computational Time [s]**	**Combinations generated**	**Computational Time [s]**	**Combinations generated**	**Computational Time [s]**	**Combinations generated**	**Computational Time [s]**	**Combinations generated**
Pre-Processing	11		10		14		13		8	
Bundling	41	16	52	19	42	18	53	20	42	10
Inbound Milk Run	68	582	79	609	71	556	81	557	74	493
Outbound Milk Run	77	82	87	96	84	100	89	111	84	97
Pickup and Delivery	158	56.735	154	63.734	192	71.263	155	58.349	160	66.891
Post-Processing (Comb's w. Savings > 0 €)	51	46.576	48	52.083	65	57.486	52	47.382	58	54.265
Total Time for Combination	406		429		469		443		426	
Selecting Combinations for Implementation using CPLEX	**Computational Time [s]**	**Combinations generated**	**Computational Time [s]**	**Combinations generated**	**Computational Time [s]**	**Combinations generated**	**Computational Time [s]**	**Combinations generated**	**Computational Time [s]**	**Combinations generated**
Selection of Combinations	1.9	1.801	2.2	1.749	4.1	1.771	2.4	1.814	2.2	1,750
Transport. Costs after Optimization [€]	7,157,162		7,115,128		7,101,529		7,102,921		7,166,512	
Cost Savings [% of Transportation Costs]	5.17%		5.35%		5.21%		5.44%		5.06%	
Selecting Combinations for Implementation using Greedy Heuristics	**Computational Time [s]**	**Combinations generated**	**Computational Time [s]**	**Combinations generated**	**Computational Time [s]**	**Combinations generated**	**Computational Time [s]**	**Combinations generated**	**Computational Time [s]**	**Combinations generated**
Selection of Combinations	11	1.518	17	1.503	14	1.501	11	1.592	16	1.512
Transport. Costs after Optimization [€]	7,191,013		7,148,550		7,133,804		7,131,791		7,169,487	
Cost Savings [% of Transportation Costs]	4.72%		4.91%		4.78%		5.05%		4.66%	

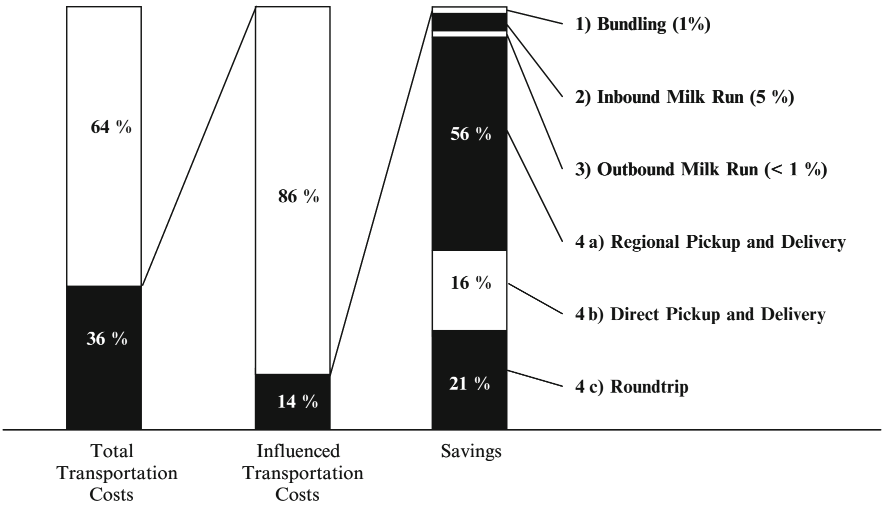

Fig. 6.3 Distribution of influenced transportation costs and cost savings per combination scheme (averaged over five instances and solved optimally)

the "Round-trip" (4c) schemes, while "Bundling" and the two milk run schemes did not produce large cost savings in the investigated case.

6.2.1 Solution to the Underlying Selection Problem

After the order combinations have been generated, they are assessed according to their savings contribution using actual freight rates. With realistic rate structures around 75% of the generated combinations contribute positive savings; that is, it is less expensive to ship the order combination than ship the individual orders. As explained in Sect. 5.3, the resulting problem of which orders to select can be formulated as a binary optimization problem in which the number of combinations (with positive savings contribution) determines the number of binary variables. Two solution strategies have been described and shall now be evaluated according to the results generated in the tests.

Solutions Selected Using CPLEX

Using standard software tools to solve the binary optimization problem has the advantage that the tradeoff between solution quality and computational time may be explicitly influenced using the parameter "MIP Gap." This parameter determines the difference between a currently best identified solution and the *bound*, a solution to a relaxed problem formulation that does not satisfy all restrictions (Williams 2008).

The MIP Gap does therefore indicate the maximum deviation from the optimal solution. The standard parameter was set at 2%. Investigations in this subsection are based on 405 instances of Scenario I including the complete set of sub-scenarios. The time required to solve the binary optimization problem is very short, especially when taking into account the time consumed for the generation of the order combinations. Figure 6.4 shows that the solution time largely depends on the number of binary variables. As shown, the computational time even for a large number of combinations does not exceed a few seconds.

Time consumption solving the binary problem to optimality is considerably higher, especially for larger problem instances. Figure 6.5 shows the computational time required to solve the problem optimally compared to the time consumption with an MIP Gap parameter of 2%.

The actual solution quality (since the MIP Gap only defines the maximum deviation) also shows higher variance with an increasing number of variables. This is shown in Fig. 6.6. Investigations show that standard software is a very well suited tool to tackle the order selection process. Whichever the timing restrictions are, the MIP Gap Parameter serves very well to balance between computational time and solution quality. However, a parameter value above zero is only necessary for larger problem instances; for smaller instances, optimality can be reached in very short computational time.

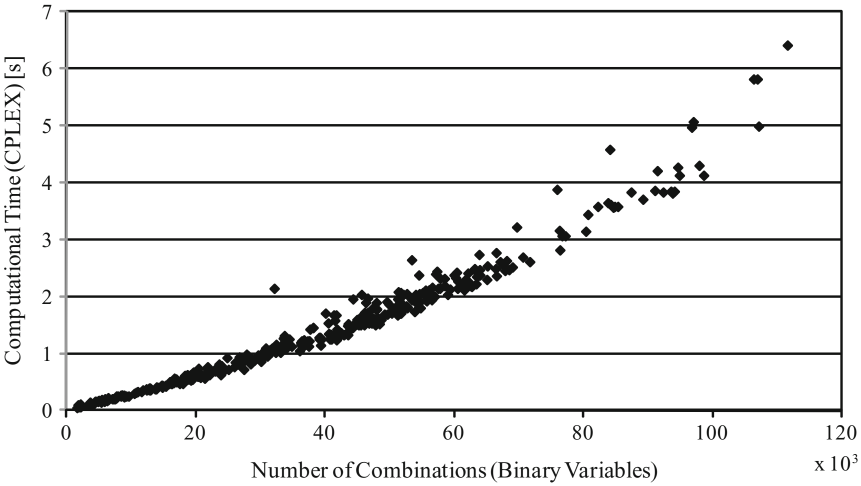

Fig. 6.4 Computational time solving the binary optimization problem using ILOG CPLEX with an MIP gap of 2%

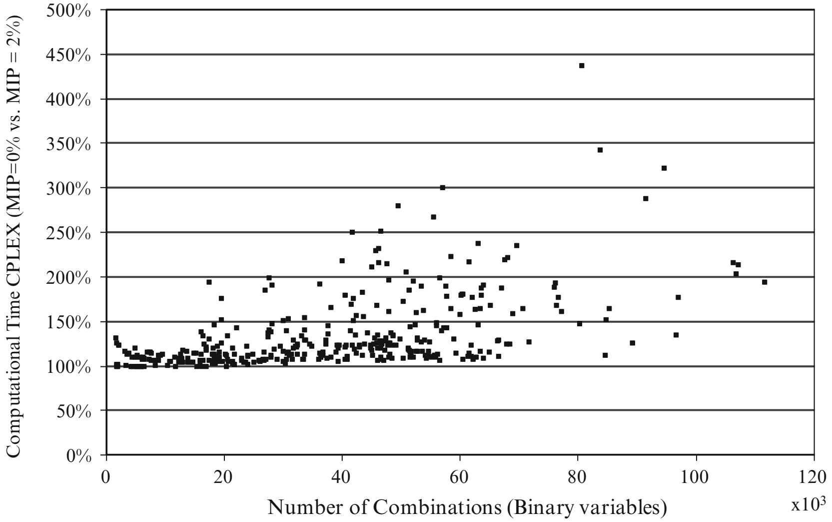

Fig. 6.5 Computational time relation solving the binary optimization problem using ILOG CPLEX with MIP gap parameters of zero compared to a MIP gap parameter of 2%

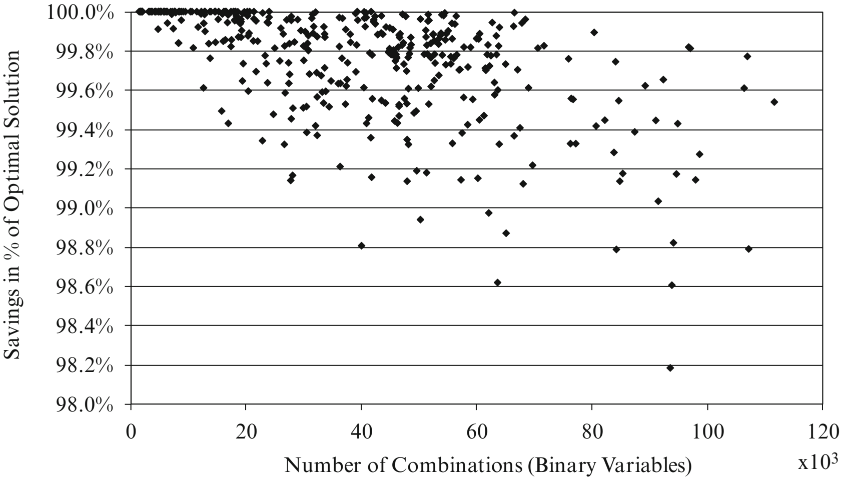

Fig. 6.6 Solution quality, objective value with a MIP gap parameter of 2% compared to the optimal solution

Solutions Generated Using the Heuristic Approach

Solution behavior for the selection problem is not as rapid as for the CPLEX deployment when using the greedy heuristic approach (see Fig. 6.7). The prolongation is substantial and it increases with growing problem instances.

Furthermore, the heuristic approach does not deliver results of similar quality (see Fig. 6.8). The average objective value is expected to be approximately 6%

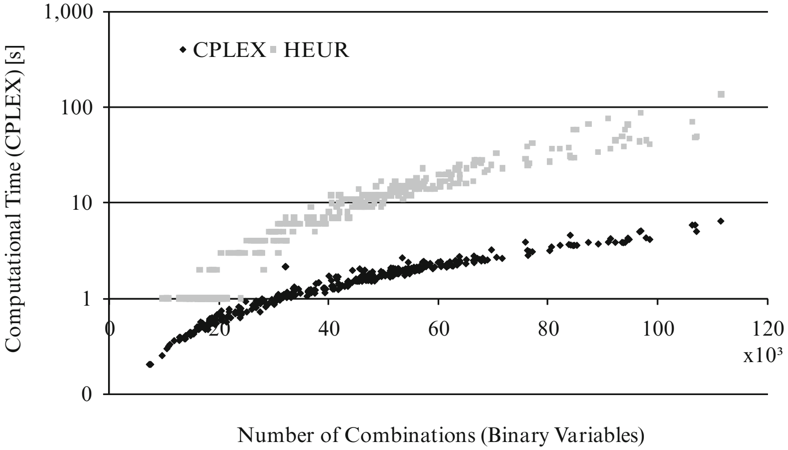

Fig. 6.7 Computational time solving the assignment problem using CPLEX standard software vs. the heuristic approach

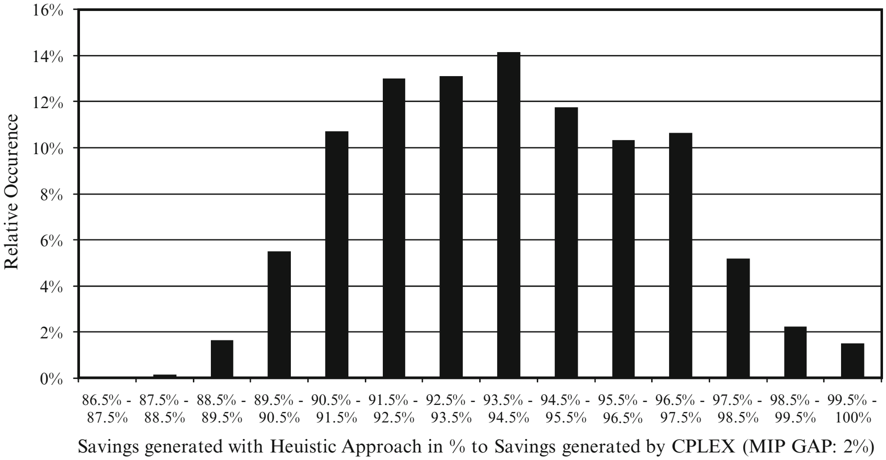

Fig. 6.8 Objective value generated using the heuristic approach compared to the deployment of CPLEX (latter with a MIP gap of 2%)

lower than the results that can be obtained with standard software; however, values of up to a 10% decrease in objective value are likely to be obtained. The extended time requirements as well as the poorer qualitative performance make the heuristic approach disadvantageous compared to the standard software CPLEX approach. Economically, an investment into software license proves worthwhile in most cases. Therefore, a general recommendation toward the use of standard software is given at this stage.

6.2.2 Comparison of Instances Subject to Randomized Order Generation

In order to investigate the influence of general variation, the order data has been varied within defined ranges — always making sure that the distribution (e.g., regarding load, location contacts, time window length and so on) remains similar to the according scenario definition. Insights into solution behavior within a generally varying deployment environment are expected from this investigation. Every scenario and sub-scenario has therefore been investigated within five randomly generated instances. Based on a total of 4,455 test instances, it was observed that the randomized variation of input data only had minor influence on the transportation costs. Comparing the transportation costs across a set of five randomly generated instances in each (sub-) scenario, a standard mean deviation of 0.6% was observed. However, the variation of costs subject to influencing was observed to be much higher resulting in a standard mean deviation of 9.9%. Accordingly, a standard mean deviation of 8.3% was observed regarding transportation cost savings. A relation between the deviation of influenced transportation costs and the deviation of transportation cost savings can be observed as shown in Fig. 6.9. The coefficient of correlation is 0.85.

This investigation is of special interest for the practical deployment of this transportation planning approach. As mentioned above, the consumer goods industries' transportation networks are very volatile to seasonal volume variations. This might not necessarily result in a drastically changed network structure over the whole network simultaneously due to a broad assortment; it might rather lead toward a shift of volume between affected locations. Therefore, a rather constant

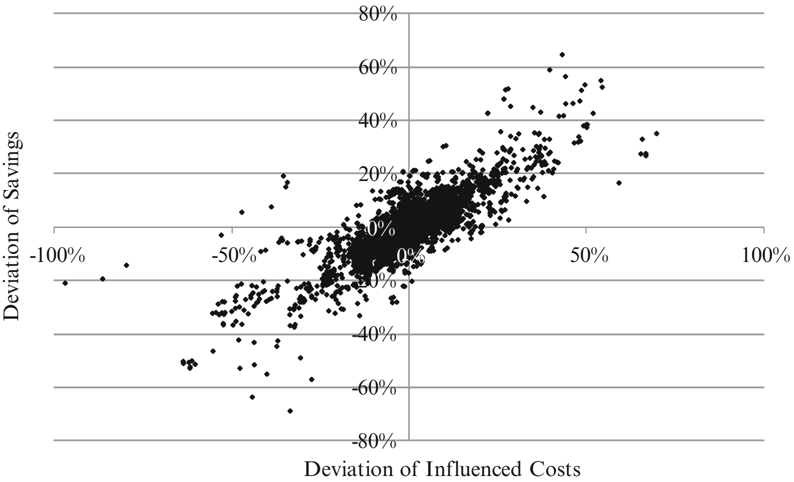

Fig. 6.9 Deviation of influenced costs from mean influenced costs and deviation of savings from mean savings due to randomized order generation

level of transportation costs as well as a rather constant number of transportation orders per week can be observed throughout the year. Still, the achievable savings with this approach may vary more strongly, which is why an average range of approximately +/−10% standard mean deviation has to be taken into account. On the other hand, a repeated deviation greater than these 10% should be a trigger to search for systematic influencing factors that can subsequently be taken into account.

6.2.3 Variation of the Number of Orders

One influential factor determining computational time as well as transportation cost savings is the number of initial transportation orders provided for combination. In these sub-scenarios they are varied as input parameters, while all other parameters (e.g., shipment size, time windows, planning horizon and so on) are unchanged. The number of transportation orders is expected to increase the number of combinations that are generated, and therefore a disproportional increase in transportation cost savings is expected at the price of a disproportional increase of computational time.

However, the presence of filters and exit criteria limits the number of generated combinations with respect to the total runtime. Therefore, a disproportional increase of generated combinations can be observed, together with a disproportional prolongation of computational time for an increase between 5,000 and 10,000 transportation orders. This however, results only in a minor augmentation of absolute savings and a decrease of relative savings. The results show that for larger problem instances a decomposition approach may be required.

6.2.4 Variation of the Number of Locations

Since the number of locations involved in the transportation planning processes is a major driver for the amount of geographical data required, an influence of this parameter onto computational time is of interest in this investigation. The geographical data required for the transportation planning problem is stored in the *distance matrix* and in the *transit time matrix*. For the testing environment both matrices are non-symmetric; that is, travelling distance from location A to location B may be different from the travelling distance from location B to location A. Before the combination process is started, these matrices are reduced to contain only the locations relevant for the chosen orders.

The relative distribution of contacts per location as well as their role within the transportation network are kept unchanged (see Appendix III). However, the absolute number of locations has been varied between 100, 500 and 1,000 locations. A change in the number of locations is expected to have major influence on the number of combinations generated and therefore on the computational time generating these combinations. It is furthermore expected to influence the level of transportation cost savings as well as their distribution according to the combination schemes.

The number of combinations generated generally decreases with the number of locations. An explanation for this behavior can be found in the number of combination schemes applicable in case more locations are served. For fewer locations, many transportation orders serve the same locations. The probability that transportation orders can be combined according to combination schemes 1–3 or 4b–c is therefore high. All these schemes require the orders in question to have at least one location in common. When increasing the number of locations, the contacts per location are considerably lower, which, in consequence, results in a decreasing probability that two orders have one location in common. Due to the increased amount of geographical data the computational time increases with additional locations (see Fig. 6.10).

Still, the transportation cost savings achieved are higher with additional locations than they are with very few locations. Furthermore, they follow a completely different structure — while for 100 locations the regional pickup and delivery combination scheme accounts for about 30% of the total transportation cost savings, this figure climbs to about 80% for 500 locations and will reach over 90% for 1,000 locations (based on 15,000 orders — see Fig. 6.11). For a larger number of locations the generation of transportation cost savings will therefore largely depend on distance degression of the underlying freight rate structure.

The investigation allows the determination of how the existing approach can be applied for different types of networks as well as for networks whose structure is subject to change temporarily, for example, due to seasonal variations. Even more

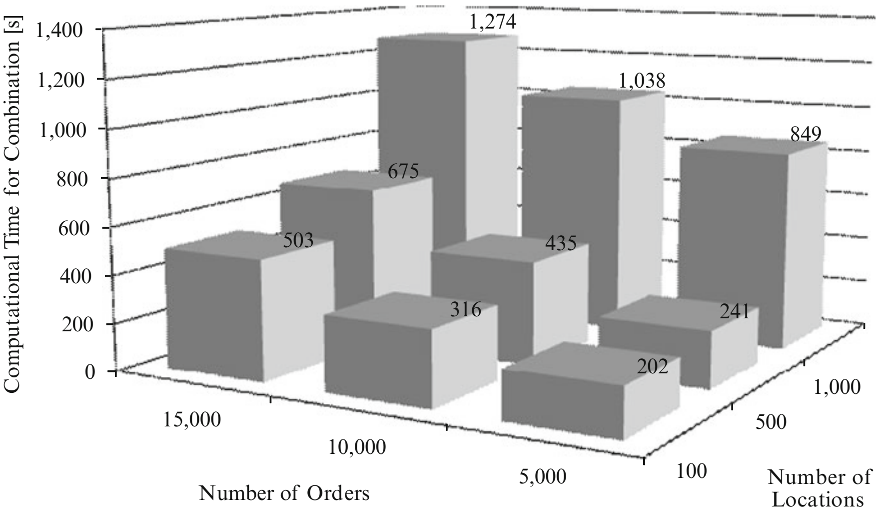

Fig. 6.10 Computational time required for combination averaged over five instances after variation of the number orders and the number of locations

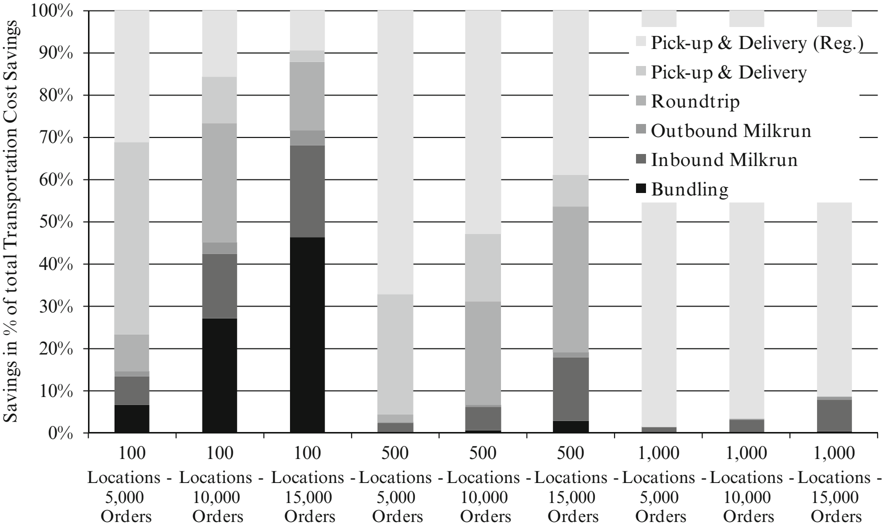

Fig. 6.11 Transportation cost savings averaged over five instances after variation of the number orders and the number of locations

relevant from a practical point of view is the fact that, when introducing transportation management measures, these are usually not applied to a complete network but rather to different sub-sections (e.g., inbound transports into plants) and are rolled out sequentially. This investigation may therefore support decisions on what transportation management processes to implement for which network sections.

6.2.5 *Variation of Freight Rates*

The basic set of freight rates has been derived from GVE benchmarking rates and is therefore applicable to the German transportation market. Germany's geographic situation in the center of the European Union, whose transportation markets are characterized by strong competition, may qualify the rates to be representative for a great part of the European continent. In order to find out to what extent this approach is affected by changes in the freight rate structure (i.e., especially the degree of distance and load degression) these have been varied in this sub-scenario.

The major effect is expected to be substantiated within the breakdown of cost savings according to the combination schemes. The influence on computational time within the combination process is not significant, however. Freight rates are of no relevance within the combination process. Only after all combinations have been generated and placed within the pool of order combinations, are freight rates the basis to assess these combinations. The result of the rating process — that is, the

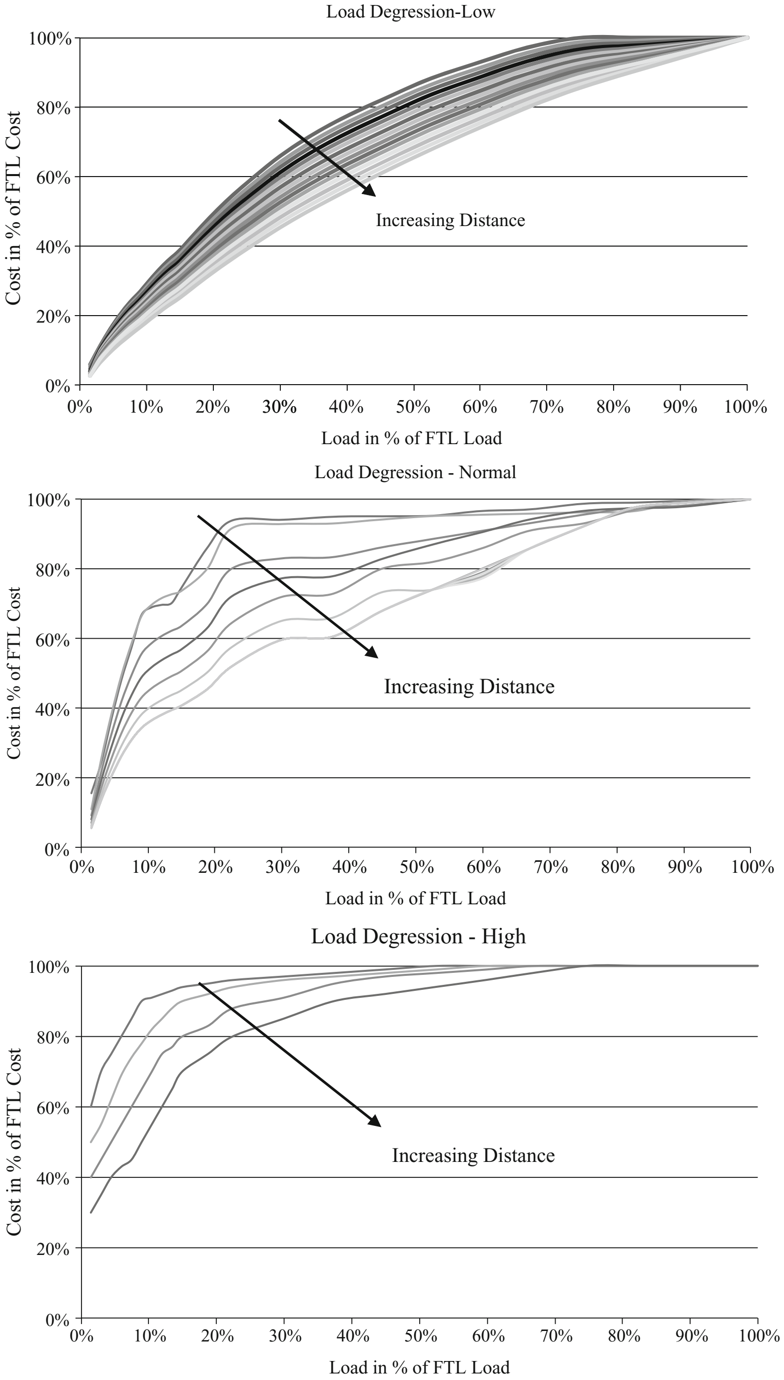

Fig. 6.12 Variation of load degression in three instances

number of combinations rated with positive transportation cost saving — is expected to be subject to change.

Freight rate variation has taken place in two dimensions. Along the first dimension, the degree of load degression has been altered (see Fig. 6.12). Degression effects with regard to load sizes are higher for small distances and decrease with longer distances. When decreasing the degree of load degression, the relation between load and cost is almost linear for greater distances. For short distances, degression is, however, stronger, yet still much weaker compared to standard rates. Transportation cost savings are expected to be reduced in cases of weaker load degression and to increase for stronger degrees thereof.

The second dimension subject to variation is distance degression. In order to create instances with a lower degree of distance degression, fixed costs were practically omitted from the distance dependent model rate and the per-km rate was kept constant within the relevant distance cluster (see Fig. 6.13). For the creation of instances with a stronger degree of distance degression, the fixed costs per trip were raised, but the per-mile costs were lowered. Again, transportation cost savings are expected to show an increase for instances subject to higher distance degression.

Overall, nine rating instances are applied to the generated combinations. Based on the *GVE* instance (medium degression in both dimensions), distance degression is varied to be stronger as well as weaker in two additional instances. Furthermore, load degression is also altered in relation to the basic *GVE* instance in order to be stronger as well as weaker totaling in nine instances.

The results for different degrees of freight rate degression support the theses established above. With higher degrees of degression a higher share of generated combinations shows positive transportation cost savings after they have been rated. And while absolute transportation costs are very similar for all nine instances,

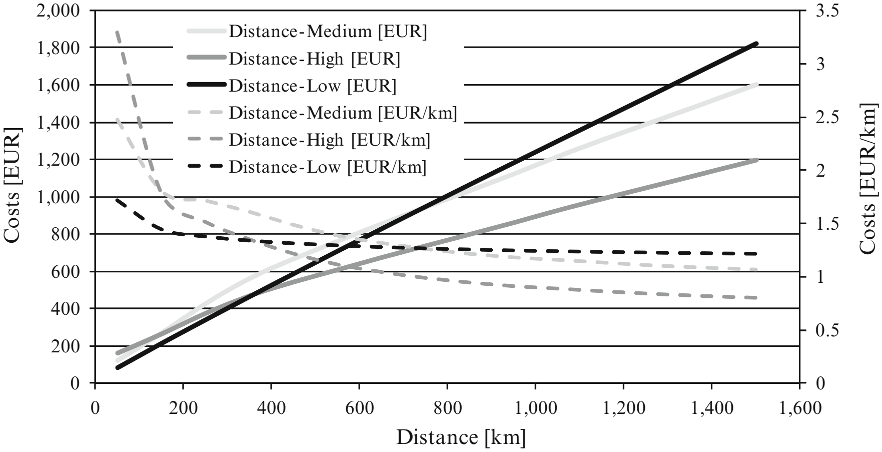

Fig. 6.13 Variation of distance degression in three instances

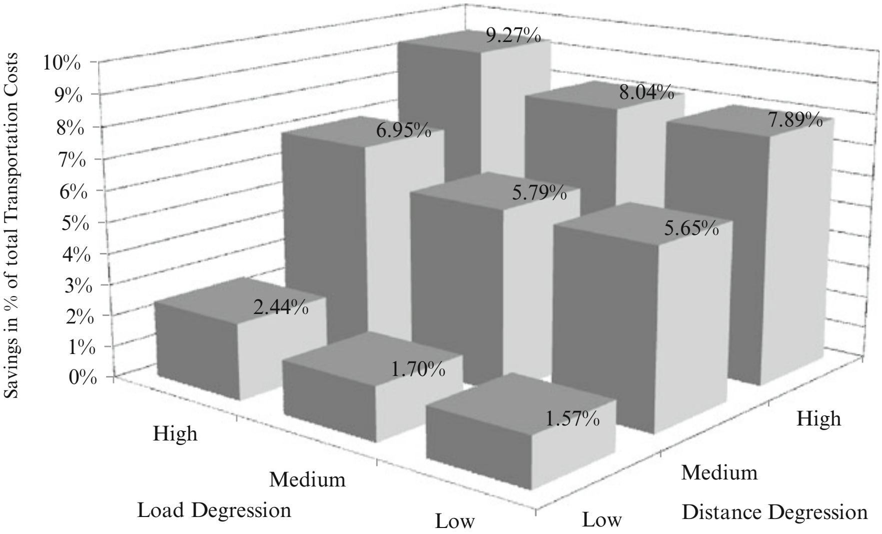

Fig. 6.14 Transportation cost savings averaged over five instances after variation of freight rates

relative savings are clearly rising with increasing degrees of degression in both dimensions (see Fig. 6.14). As for the influence of the two dimensions, distance degression has the stronger influence on the cost savings compared to load degression. The reason can be found in the higher share of FTL shipments that are incorporated in the shipment data. Bigger shipments are much harder to combine with the few smaller shipments existing in the input data – a necessity for load degression to be profitable.

6.2.6 Summary

As shown, the presented approach for operational transportation planning results in considerable savings by combining several shipments to order combinations. It profits from degression effects that have been identified to exist in real life freight rate structures and are in place for outsourced transportation services.

The overall time for the building of combinations, their rating and their selection is sufficiently short to implement the approach in a real life transportation planning environment. The time required to generate the order combinations is by far the longest in comparison to the succeeding process steps. The approach is capable of processing a large number of orders serving many locations. Even though the time required for processing the extended amounts of data is longer, computational time is still acceptable for the required process approach. Solution quality, however, drops significantly with a growing number of orders. The amount of generated combinations is also increased; however, this is hardly substantiated in additional saving prospects. This behavior is largely caused by the chosen implementation approach using a database environment. The generation of combinations using database queries is slowed down drastically when more data is stored. In addition, combinations are generated in batch mode. Once a query for generating combinations is called, the process cannot be interrupted and exit criteria or filter parameters cannot be checked after the query has finished. Any parameter adjustment is only valid for the succeeding queries. Therefore, parameter values have a strong influence on solution quality and speed, an issue that is also addressed in the next subsection.

Critically viewed, a programming approach that is executed only in the RAM should generally be better performing. However, these approaches are very limited with regard to the amount of data that can be processed. As for the system behavior at the limits of the suggested case study, a lack of memory might in many cases have concealed valuable findings.

6.3 Filter Parameter Variation

An adjustment of the filter parameters is suggested to be able to adapt the planning approach to specific implementation environments. Therefore, these are altered and the results are analyzed according to their significance in this subsection. The significant parameters are investigated further in order to suggest guidelines for practical implementation. However, the investigated parameters can only provide an example of possible parameter deployment scenarios. For a real-life implementation it is suggested that filters are specifically designed and customized for the featured problem instances.

6.3.1 Filter Parameter Alteration

The filter parameters are tightened and loosened in relation to their “basic” value. All investigations are performed based on the basic scenario data. Since filters 1 and 2 are only applied to exclude infeasible combinations from being taken into account, these filters are not subject to investigation in this subsection. The details for the filter deployment are described in Sect. 5.2.3 and shown in Fig. 5.2.

Filters 3 and 4: Bundle Propagation Filters

The two filters have to be distinguished with regard to their succeeding combination schemes. While filter 3 controls the propagation of order combinations toward the milk run combinations, filter 4 is responsible for propagation toward the pickup and delivery processes. And while milk run combinations are of a simultaneous nature,

Table 6.2 Parameter variation for filter 3 and 4 (aggregation levels propagated to the next combination schemes)

	Filter 3	Filter 4
Tighter (P+)	1	1
Basic scenario	2	1
Less tight (P−)	4	2

lower load sizes may profit largely from additional, poorly utilized, combination partners. Still, it is generally expected that bundling is the combination scheme with the highest relative savings potential. The basic scenario for filter 3 therefore propagates order combinations with the two highest aggregation levels toward milk run combination. Tightening these restrictions is expressed by propagating only order combinations with the highest aggregation level. In contrast, weakening these restrictions has been implemented by propagating the combinations with the top-four aggregation levels. The parameter values are detailed in Table 6.2.

In contrast to milk run combinations, the pickup and delivery schemes do not increase truck utilization any further, which makes highly utilized order combinations the desirable input data for these combination schemes. As a result, basic scenario parameters propagating only the highest aggregation levels are unchanged for the tightened instances. However, these restrictions are lowered for the weakened scenario allowing the two highest aggregation levels for propagation.

The numerical results of the parameter variation for filters 3 and 4 are largely insignificant. Since only a few bundling combinations are generated, their influence when propagating them to the next level is close to irrelevant with regard to the investigated shipment structure. In some instances, transportation cost savings are lower even though some of the filter criteria have been relaxed. Although this seems illogical at first glance, it is a result of the exit criteria in place for the combinations according to scheme 4. Since a large number of combinations are generated at this stage, the exit criteria always find application limiting the overall number of combinations generated. Due to a higher number of order combinations that are propagated to combination schemes 4a–c, the exit criterion is reached "earlier" and combinations that would have been generated if less orders had found their way into these combination schemes are no longer generated. As a result, overall savings may be lower even though the restrictions are weakened. However, because impact is minimal (below 5‰ of savings), the parameters are assessed as not significant.

Filters 5 and 6: Milk Run Filter

Filters 5 and 6 are controlled using four sets of parameters. The detour factor as well as the relation between overall average utilization and last leg utilization (for inbound milk runs — for outbound milk runs first leg utilization respectively) have been described in Sect. 5.2.3. In addition, maximum overall transit times and minimum buffer time requirements have been implemented. While the former limits the total transit time for re-combination within filter 5, the latter confines combinations without a sufficient time buffer. While the detour factor as well as the

Table 6.3 Parameters for filters 5 and 6

Parameter	Distance	Minimum distance	Tighter (P+)	Basic scenario	Less tight (P−)
Detour factor	≤ 250 km	< 100 km	1	1.5	3
	≤ 250 km	≥ 100 km	1	1	2
	> 250 km	< 100 km	1	1.4	2.8
	> 250 km	≥ 100 km	0.5	0.9	1.8
Utilization diffrence			0.8	0.5	0.25
Utilization threshold			40	80	200
Minimum buffer time	≤ 250 km		8	4	0
	> 250 km		16	8	2

time buffer parameters are distance dependent, the utilization requirements and the transit time parameters are without direct relation to transportation distance. The detour factor is once more specified according to the minimum direct distance.

The detour factor for short distances is chosen less restrictively than for long distances. This choice is justified by decreasing freight rate degression for increasing distances. For the same reason the minimum direct distance has been included in parameter definition. If the minimum distance is very short the savings potential for the respective leg is expected to be greater due to stronger degression effects.

The utilization parameter is subject to the absolute difference between the average utilization and the maximum utilization of a milk run. For tight restrictions only very small differences ($\leq 20\%$) are allowed; for weaker restrictions, larger values are accepted ($\leq 80\%$). The reference is set at 50%.

The maximum transit time reference is set at 20 h. It is lowered to 10 h for the instance with tighter restrictions, and it is raised to 50 h in order to define the instance with weaker restrictions. The minimum required buffer time for combination generation is 1 h for the reference scenario. Tightening the restriction leads to 2 h of minimum required buffer time while loosening it will result in no buffer time requirements. The detailed parameters can be found in Table 6.3.

All the described parameters generate higher transportation cost savings when loosened. The effects are depicted in Fig. 6.15. However, except for an increase of the minimum milk run buffer time, the effects are not significant enough.

Filter 7: Pickup and Delivery Filter

The pickup and delivery filters are controlled using five different parameters. These have already been described in Sects. 5.2.2 and 5.2.3. The maximum empty running distance and the maximum distance for a further processing using the pickup and delivery combination scheme are subject to variation in this section. Furthermore, the maximum number of combinations per iteration has been restricted; also a variation of this parameter is investigated. In addition, the parameter limiting the total number of combinations generated has been varied, as has the maximum number of iterations.

The maximum empty running distance, parameter MD in Sect. 5.2.2, affects the number of regional pickup and delivery combinations being generated. For very small parameters of MD and therefore very short empty running distances only few regional pickup and delivery combinations are generated. However, these are likely to have particularly low transportation costs and therefore high savings, since little inefficiency due to empty transportation is incorporated in these order combinations. High values of MD and therefore the admittance of long empty running distances may generate many more regional pickup and delivery combinations. However, these may often experience little or no transportation cost savings since inefficiency is very high due to long legs of empty transportation. It may furthermore result in longer processing times and in fewer savings due to exit criteria.

The maximum overall distance for orders and order combinations to be admitted according to the schemes 4a–c also limits the overall number of combinations generated by these schemes. Due to the nature of distance degression, it is expected that the consolidation of two short-distance orders is more profitable than combining a long-distance with a short-distance order. The latter is still expected to be more profitable than combining two long-distance orders. A limitation of the maximum overall distance is therefore destined to concentrate on short-distance orders for order combination according to schemes 4a–c.

The parameter limiting the maximum number of combinations per iteration is another means to keep their number controllable. They are generated by matching orders and existing order combinations with very short distances and their potential counterparts first. Step by step, the distance of the first potential partner is increased until the maximum number of combinations per iteration is reached. Since combinations that contain orders destined within a short distance of the origin promise higher transportation cost savings, this approach aims at maximizing the number of short-distance orders to be combined. However, it may dismiss some saving prospects included in long-distance orders.

The total number of combinations generated according to schemes 4a–c is limited by an additional parameter. When a certain number of combinations is exceeded the combination process is stopped. The number of iterations that are performed according to the combination schemes is also limited by a specific parameter. The detailed values can be obtained from Table 6.4.

Two of the five parameters show major significance; namely, the maximum empty running distance and the limitation toward a number of maximum combinations per iteration; the remaining three are insignificant and will therefore

Table 6.4 Parameters for filter 7

	Tighter (P+)	Basic scenario	Less tight (P−)
Maximum empty running distance (MD)	25	50	100
Maximum distance	600	1,200	2,400
Maximum combinations per iteration	25,000	50,000	100,000
Maximum combinations overall	500,000	1,000,000	2,000,000
Maximum number of iterations	2	4	8

not be detailed here any further. As for the minimum empty running distance, the results are most interesting. In both cases — lowering and raising the parameter values — transportation costs savings are lower compared to the reference case. It is particularly surprising that cost savings dropped even when the minimum empty running distance was raised. All the combinations that have been generated within the basic instance are part of the solution, with extended empty running distance, which is why cost savings are expected to be the same or larger. However, this expectation does not take into account that the process of generating combinations is limited by exit criteria. Since more combinations are generated in "early" stages of the combination process, fewer iterations are performed, and overall, approximately the same number of combinations is generated. The extended parameter scenarios therefore do not contain the same combinations as the basic combinations scenarios. The extension of empty running distances has for the investigated case led to a higher number of unpromising combinations versus the basic scenario in which the share of high-savings combinations is bigger.

The second significant parameter is the maximum number of combinations that are generated within an iteration. The findings that tighter restrictions transportation cost savings are higher are as surprising as the above mentioned effect. However, its root-cause is similar. While a large number of combinations generated in "early" iterations lead to a lower number of generations for "later" iterations, the generated combinations are of poorer quality. If the number of combinations is however restricted at the beginning, more high-quality combinations are generated throughout the several iterations. Therefore, limiting the number of combinations per iteration substantiates a suitable means for the generation of "high-quality" combinations, particularly since short-distance orders are combined with priority.

An overview of influences on parameter variation is given in Fig. 6.15. The significant parameters are assessed further toward their relevance for real life implementations.

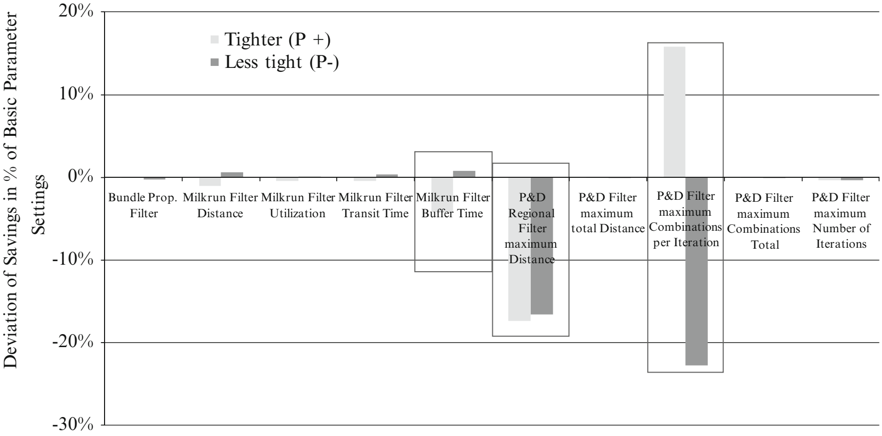

Fig. 6.15 Results from parameter variation

6.3.2 Assessment of Significant Filter Parameters

The three parameters assessed as significant can be used for application within practical implementation in order to control the solution quality as well as the solution time. With regard to the reference data used for this case, different input data may require different parameters and the parameters that have been assessed as not significant may in other deployment scenarios be very well significant.

The milk run combinations filter parameter "minimum required time buffer" has been assessed as significant. The danger for this parameter is the choice of a too conservative value omitting potential results. Since milk runs may combine many different orders involving different locations the risk that delays are propagated throughout the network is large. And in comparison to pickup and delivery combinations, which, if disrupted due to delays may be taken up at short notice by additional vehicles to avoid further delays, milk runs are designed to consolidate many orders within one vehicle, and therefore the effects of delays may be more severe. The parameter choice should therefore be left to a person responsible for both shipping costs and shipping reliability. In practice, it may be helpful to make this parameter more flexible toward selected relations; for example, those requiring ferry use are subject to higher risk (e.g., arriving only a little late for a ferry departure may account for a delay of several hours) and are therefore subject to increased time buffer requirements.

The maximum empty running distance should be left unchanged from the basic parameters for implementations similar to the test environment. Only if very few combinations are generated is a relaxation of these parameters suggested. Within the applied freight rate structures and degrees of degression there is also no reason to tighten this parameter. However, in cases when distance degression is subject to substantial change the parameter should be adjusted.

Finally, the filter parameter limiting the maximum number of combinations per iteration could be made tighter with regard to the basic test-set. This parameter should be subject to constant monitoring. On the one hand, enough combinations need to be generated so they can be propagated to the next iteration. On the other hand, the share of high quality combinations is of major importance. Practical experience with real-life implementations may prove to be the most valuable input for this parameter.

6.3.3 Summary

The investigated parameters represent a set of possible adjustments that may be considered in real life implementations. They are, however, by no means complete. Additional parameters may be developed that can better address the areas in question. Surely, the existing parameters may be also altered toward better scalability and dynamic adjustment during combination. Still, filters for combination and propagation have been identified to constitute a major contribution toward process quality. In a TMS environment filters shall be subject to system customization during a TMS implementation process. They can be defined in a standardized description language; for example, .xml and the according parameters can be held in the TMS' parameter environment. This way, the chosen approach can be easily adjustable for a broad number of implementations making use of the specific restrictions and the overall context.

6.4 Head Scenario Evaluation

The different head scenarios have been described in the introduction to this section. They serve to investigate different network specific attributes that may be subject to distinction in real life implementations. Yet, the variation of input data still serves an additional purpose. It may provide additional measures that, in combination with the presented planning approach, can be used to increase transportation efficiency even more.

The first input parameter that is subject to variation is the time window length. Usually, either dispatching or receiving locations are controlled by the shipper, and time window length is subject to its own definition. In case supplier or customer locations are affected, time windows may become subject to contract negotiations. The second set of head scenarios sees a variation of load sizes. Again, alterations from the basic scenario may be motivated internally as well as externally. The question as to which effect, for instance, increasing transportation load sizes may have due to changed production planning processes is investigated. In the following paragraphs equipment variation is subject to analysis. It has already been addressed that multipurpose equipment and improvements in packaging may have effects on the number of order combinations being generated. The default planning horizon has been identified to account for a 1-week period in the consumer goods industry. However, in order to be more flexible, transportation orders may be assigned to carriers at a later stage leaving room for adjustments. The effects of a prolonged and a shortened planning horizon are also examined. Finally, transportation distance is an additional aspect that is worthwhile investigating. Assumptions taken for the basic scenario represent a regional supplier, manufacturing and distribution footprint. However, due to expansion trends addressed in Sect. 2.3.3, growing transportation distances have been (and still are) subject to increase. The behavior of the presented approach in cases of larger but also of smaller transportation distances is examined.

The presented head scenarios feature both internally driven change processes as well as responses to a changing market environment. The head scenario investigation therefore focuses on the relative transformation of transportation cost savings and not their absolute amount. In many cases, better results can be achieved by a systematic adjustment of control parameters such as the ones described in the previous subsection. The following investigation focuses on the question whether the presented approach is generally capable of operating in these very different environments. Additional fields of application as well as fields for further research are obtained in this investigation.

6.4.1 *Time Window Variation*

Time windows within the initial transportation orders are designed to show a realistic distribution – based on both their occurrence across the working day (see Appendix III) and their length. They average 5 h and are distributed between 2 h and 8 h in Scenario I. Time windows in this investigation have been shortened and prolonged in two scenarios. In Scenario II time windows have been reduced to 0–4 h averaging only 2 h. In contrast to that, Scenario III sees extended time windows between 2 h and 14 h. The distributions are depicted in Fig. 6.16.

A total of 1,215 solution instances based on 135 combination instances have been subject to investigation; that is, 45 instances per scenario. The number of combinations observed fully meets the expected behavior. While shorter time windows result in fewer combinations, longer time windows show a greater number of combinations. Yet, the time required for the combination process is in some cases that feature fewer combinations surprisingly longer than for others featuring more combinations. The same observation holds true with regard to transportation cost savings. For selected cases, shorter time windows generate higher savings compared to time windows incorporated in the basic scenario. However, in most cases an extension of time windows results in higher savings (0.6% points). Yet for shortened time windows, results do not show savings to be considerably lower than for the basic scenario.

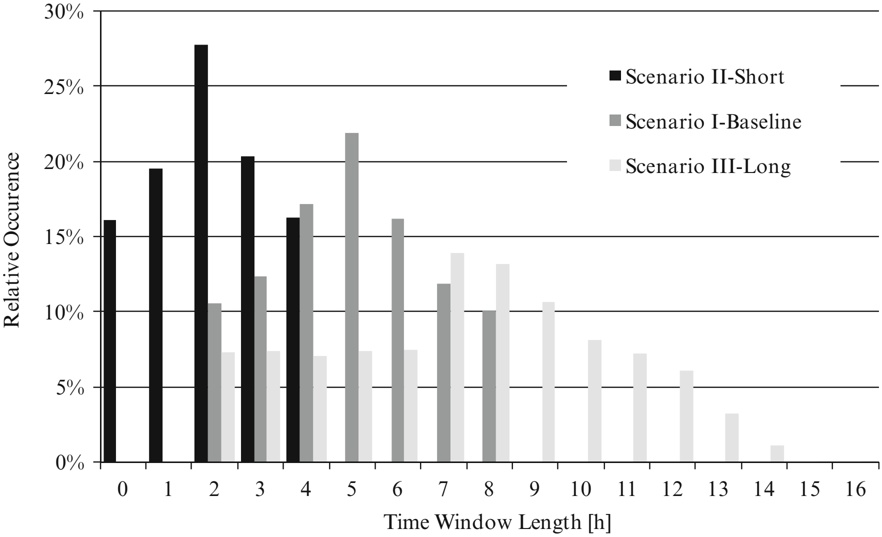

Fig. 6.16 Time window length for Scenarios I–III

Increased time consumption for the generation of fewer combinations can be attributed to combination probability. In all scenarios, roughly the same amount of orders is examined for combination, which is the major driver for processing time. However, for shorter time window, the examination process is far more often unsuccessful in comparison to a scenario incorporating longer time windows due to fewer overlaps. It is therefore very possible that fewer combinations may take a longer time in the event of shortened time windows. Reasons for the effect that transportation cost savings do not significantly decrease when applying shorter time windows can be found in the employment of filters, especially for pickup and delivery combinations. Since fewer combinations are generated for shorter time windows when examining the same amount of orders, the filters limiting the number of combinations are by far less efficient with regard to computational time (see Sect. 6.3). An adjustment of these parameters would shift results toward a more expected outcome. However, regarding the overall time consumption for combination, it must be stated that the filters largely serve their purpose. While the number of combinations between Scenario I and Scenario III has quadrupled, the time required for combination has only increased by little more than 50%.

The suggested approach is applicable to implementation environments characterized by very short time windows. Due to the application of filter criteria, larger time windows can also be covered. However, as stated above, the design of filter criteria significantly influences the results' quality. An adjustment of the applied filter criteria should therefore be taken into account, in order to gain better results, especially for the scenario with stretched time windows.

6.4.2 Load Size Variation

Within Scenarios IV and V, load size has been subject to alteration in comparison to Scenario I. Since average load sizes in the examined consumer goods industry are generally not subject to systematic change, a stronger focus has been put onto the distribution of load sizes. While for Scenario IV load size has only increased by approximately 9%, Scenario V only features a change of load size distribution (see Appendix III). Here, the percentage of shipments utilizing less than 50% is increased.

Again, results require further interpretation. One reason can be found in the distribution of shipments accounting for 51–80% truck utilization. Orders in this range are difficult to be combined according to combination schemes 1–3, and since most of the remaining orders have higher load sizes, they are therefore excluded as combination partners. In addition, most of these orders receive an LTL discount when freight rates are applied. Therefore, the application of sequential combination schemes (4a–c) is also of little prospect, because freight rates are lower compared to a full FTL shipment. In turn, for a combination containing such an order, the savings are lower since LTL discounts do not account for any of the sequential combinations (see Sect. 5.1.1). It must be furthermore expected that a larger amount of small loads (Scenario V) sees more combinations generated according to combination schemes 1–3. This again influences the number of orders propagated to combination schemes 4a–c. Therefore, a largely different filter behavior influences not only the number of combinations but also their quality.

With regard to transportation cost savings, generally higher relative values are obtained for Scenario V compared to Scenario I (approximately 0.9% points). However, these differ largely with regard to the sub-scenarios and a general conclusion that transportation cost savings must be higher cannot be drawn. Scenario IV sees relative transportation cost savings that barely differ from those obtained in Scenario I. Still, the distribution of transportation cost savings between the three considered scenarios meets the expectations. While Scenario V shows a high portion of savings according to combination schemes 1–3 (approximately 30% of total savings for 15,000 orders and 100 locations), this share is substantially lower for Scenario IV (approximately 15% for the same sub-scenario). Furthermore, for rate structures characterized by poor distance degression, savings are significantly higher for Scenario V, almost doubling the obtained figures.

Additional findings are identified with regard to the applicability of the approach for smaller load sizes. The number of combinations as well as the computational time in Scenario V are considerably higher in comparison to Scenarios I and IV. For some sub-scenarios they amounted to a multiple of the time required in the reference instances in Scenario I. Instances with a large number of orders and smaller numbers of locations were especially affected. This emphasizes the necessity for adjusting the filters and their parameters in charge of limiting the combinations for the combination schemes 2 and 3.

Results from the specific alteration of load size distribution have provided valuable insights concerning the practicability of real life implementations. The large increase of combinations and computational time for Scenario V shows a shortcoming of the approach when large amounts of small shipments are covered. An adjustment of filter parameters may be a solution for this outcome. However, an extended filtering process should also be considered. For larger shipment sizes this approach has again been proven very successful. Increasing transportation efficiency and the extensive use of distance degression could contribute toward lower transportation costs even for transport orders that utilize trucks to a great extent.

6.4.3 Equipment Variation

Different equipment specifications have been implemented for Scenarios VI and VII. In Scenario VI, completely homogeneous transportation requirements have been inserted into the test data. The scenario features only one truck type (here: single layer truck) and only one type of transportation temperature requirement (here: ambient). Therefore, no restrictions for combining different vehicle requirements apply. The reference case shows a deployment of three different temperature classes and two different truck types that are unevenly distributed. For Scenario VII the same vehicle requirements find application in an even distribution. The details are depicted

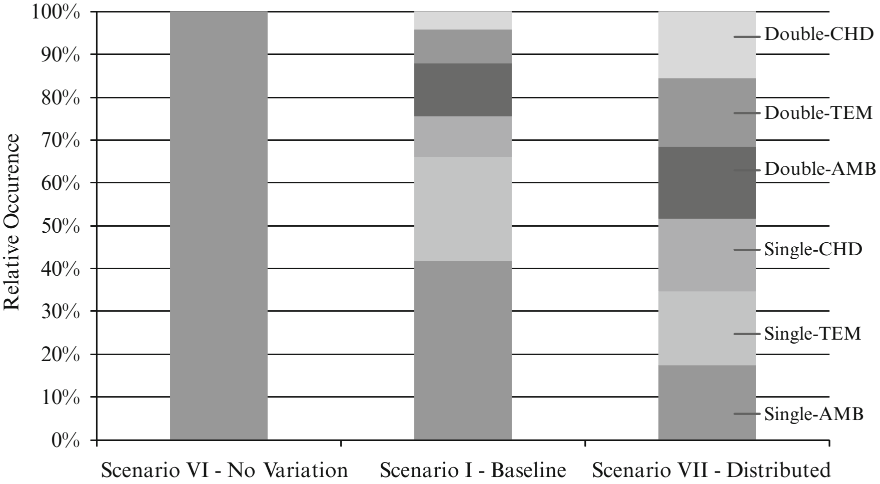

Fig. 6.17 Distribution of vehicle requirements from Scenarios I, VI and VII

in Fig. 6.17. Due to less restrictive combination requirements, more combinations from Scenario VI are expected. Along these lines the even distribution should see fewer combinations being generated in Scenario VII.

With regard to combinations that are generated in the three investigated scenarios, all expectations are met. By far the highest number of combinations is generated for instances related to Scenario VI. Furthermore, the number of combinations generated in Scenario VII is lower compared to those obtained from the reference scenario (Scenario I). However, the difference to the reference case is larger for Scenario VI than for Scenario VII. Computational time consumption behaves analogously.

While relative savings are higher for Scenario VI than for Scenarios I and VII, this behavior does not stand the comparison between Scenarios I and VII. Even though more combinations are obtainable, relative transportation cost savings in Scenario VII are slightly higher than in Scenario I. The advantage of the two approaches varies between the several sub-scenarios and instances. Multiple factors contribute to this behavior: In Scenario I, the average transportation temperature is warmer than in Scenario VII. In cases where two shipments of different temperature levels are combined, the colder one defines the required service level. Since colder temperature levels are usually more expensive, transportation cost savings are lower in a combination of two shipments of different temperature levels than in a combination of two shipments of the same temperature level. This effect may partly explain the results for Scenarios I and VII. Additionally, the deployment of filter criteria with particular regard to combination schemes 4a–c again limits the number of combinations generated in favor of shorter computational time. Here again, an adjustment of parameter values may generate better results with regard to the specific requirements.

The variation of vehicle requirements with particular focus on the distribution thereof has once more underlined the broad applicability of the suggested approach. Across all scenarios, including the variations between the affected sub-scenarios, computational effort has remained within a very acceptable timeframe. Also the reported transportation cost savings have remained steady in the ranges that have been observed beforehand. However, filter criteria have once more been crucial with regard to their influence on results quality. A specific adjustment of the criteria themselves may not be necessary for the amount of restrictions that are covered within the underlying study. However, for a broadened scope toward multitude shipping attributes in the consumer goods industry (e.g., with regard to scent) a re-evaluation of the criteria is suggested.

6.4.4 Variation of the Planning Horizon

In Scenarios VIII and IX the planning horizon has been varied. For the reference scenario (Scenario I) the standard approach covering one week has been chosen. Within this week, transportation orders are concentrated in the period from Monday to Friday; only a few orders have pickup operations or deliveries scheduled for the weekend (see Appendix III). In Scenario VIII, the 1-week planning horizon is split into two sections, the first ranging from Sunday to Wednesday and the second from Wednesday to Saturday. Orders that have a pickup or delivery operation scheduled for Wednesday are subject to combination in two combination runs. The selection however takes place in a joint process. This approach of splitting the planning horizon with an overlap has been chosen to avoid omitting too many combinations by simply dividing the planning horizon in two exclusive sections. That way, an order contained in one section of the week would be impossible to form a combination with an order in another section of the same week. For Scenario IX, the orders of two consecutive weeks have been subject to combination and selection within one run. While for Scenarios I and VIII the number of orders that are subject to investigation is the same, for Scenario IX this figure is twice as large due to the extended planning horizon. The partitioning of the planning horizon is shown in Fig. 6.18. Since transportation cost savings are subject to relative investigation they are not flawed by the additional orders in Scenario IX.

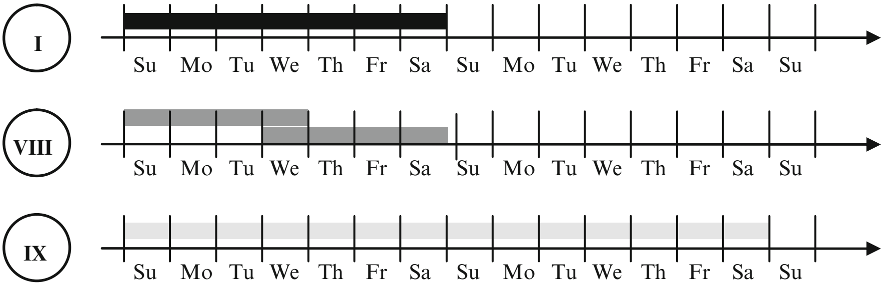

Fig. 6.18 Planning Horizon for Scenarios I, VIII and IX

In Scenario VIII, the number of combinations generated in two combination runs by far exceeds the combinations generated in Scenarios I and IX (approximately 350% to Scenario I and approximately 280% to Scenario IX). The latter scenarios are very similar with regard to the number of combinations that are generated, with Scenario IX only slightly exceeding Scenario I by an average of 25%. This is very notable since in Scenario IX twice as many orders are subject to combination than in Scenario I. With respect to computational time, however, Scenario IX requires about 80% more time for all instances than Scenario I. The computational time consumption for combining transportation orders in Scenario VIII, however, takes about 150% longer than for Scenario I.

When investigating the transportation cost savings for the three scenarios, the picture changes. Transportation cost savings observed for Scenario VIII are by far the highest and exceed those for the reference Scenario I by about 60% or 3% points. Scenario I, however, outmatches Scenario IX by about 0.8% points.

Since the number of generated combinations is limited by filters, the observations show their influence on results' quality and computational time. The generation of combinations is limited for each combination run. The division of the planning horizon in Scenario VIII has raised the number of combinations generated, since they have been generated in two independent runs. As a result, the potential lack of prospects for combining transportation orders between the two sections of the planning horizon is overcompensated. The effects for Scenario IX are similar, yet inverse. Since the number of combinations is generally limited per combination run, it is considerably lower for a single week in comparison to Scenario I. The result is a lower transportation cost saving.

The application of different planning horizons has demonstrated the applicability of the approach with the given filter criteria and parameters for an again different planning environment. Yet, the investigations regarding the length of the planning horizon will need to take place in relation to average transit time as well as time window length. For transportation orders covering much longer transit times the suggested planning horizons may be subject to further adjustment to achieve feasible planning results. It is therefore of great importance that the planning horizon as well as any planning lead times suit the necessary planning and communication process. The determination of a suitable planning horizon and the definition of suitable filter parameters should therefore be subject to the availability of high quality planning data within the overall process design.

6.4.5 Distance Variation

The influence of the average distance and thereby the average transit time of the transportation orders are subject to investigation in the Scenarios X and XI. For the reference scenario the locations that serve as origins and destinations have been scattered randomly over a 1,000 km × 1,000 km square. This results in an average transportation distance for Scenario I of 470 km. In Scenario X the average distance is halved also resulting in substantially lower transit times. In Scenario XI the distance is doubled and as a result it averages 940 km in this scenario.

It is expected that for shorter distances between all locations, a larger number of combinations is generated. The closer proximity makes it more likely that transportation orders may be combined using the scheme of regional pickup and delivery. In contrast to that, Scenario X is expected to deliver fewer combinations due to fewer possibilities of applying the above mentioned scheme. The results of the investigation support the thesis. However, the amount of combinations created in some single instances of Scenario XI has exceeded expectations. For Scenario XI more than three times as many combinations are generated in comparison to Scenario I. However, some instances show a tenfold increase when comparing Scenario I to Scenario XI. Instances with longer distances that are implemented in Scenario XI show similarly lower results in comparison to Scenario I. The time required to generate the combinations largely reflects the number of combinations that are created. However, differences between the scenarios are not as big; for Scenario XI the computational time is about twice as long as for Scenario I. Scenario X takes about 70% of the computational time of Scenario I.

With regard to transportation cost savings, results show the lowest values for longer distances incorporated in Scenario X. This is in line with expectations for two reasons. On the one hand, fewer combinations that may contribute to savings have been found. On the other hand, long transportation distances for the considered transportation orders will experience a larger share of distance degression already incorporated in the transportation costs of the individual order. A reduction of transportation distances in Scenario XI, however, does not automatically lead to additional transportation cost savings in comparison to Scenario I. Here further differentiation with regard to the number of locations is required. Instances comprising a few locations and a large amount of orders mostly show larger transportation cost savings for Scenario XI versus Scenario I. However, for instances with 1,000 locations, Scenario I shows bigger saving prospects. For a smaller number of locations in a given geographic area, the number of locations in proximity to each other is very limited. In these cases, reducing the distance has a great effect and additional order combinations become feasible. However, when the same geographic area is covered by more locations, the likelihood of two locations being in proximity with regard to scheme 4a is much higher. Therefore, the advantage of Scenario XI no longer exists for larger amounts of locations.

In this regard, special attention should be paid to the filter parameter defining the maximum empty running distance for combination scheme 4a. Since this figure is an absolute distance in kilometers or miles and is equal for all scenarios, its value relative to the average distance is different in each scenario. Adjusting it accordingly would produce very different results. This underlines the importance of parameter choice as already pointed out above.

With regard to freight rate structure, Scenario X has shown substantially lower savings than Scenario I for rates that show high and medium distance degression. Scenario XI has in terms of transportation cost savings outperformed Scenario I and X, respectively, for freight rates that show low distance degression.

For different transportation distances and location proximities, the investigation of these scenarios gives a good example of the boundaries of the implemented approach. Since it largely benefits from a limited and easily identifiable set of order combinations, the concentration of many locations within a defined region leads to new dimensions of reasonable combinations. The influence of the developed filter criteria is limited and does not necessarily lead to the desired outcome of achieving quality results within limited time. Adjusting filter parameters may in some cases improve solution quality and help to control computational time. However, the parameter defining the minimum empty running distance is usually not a parameter that is limited to the shipper's part of the transportation network. Rather, it references the repositioning requirements of the carrier. In addition, the relation between transit time and time windows has been shifted within the investigated scenarios, as already mentioned in the previous subsection. Since the problem instances that are relevant for real-life implementations in Europe as well as in North America usually span larger distances than the ones investigated in Scenarios I and XI and sometimes even exceed the ones in Scenario X, effects for real-life implementations are not expected to be critical.

6.5 Summary and Conclusion

Numerical investigations for the presented approach have covered many aspects of network layout and order process that may be relevant to the practical implementation of the designed processes. Multitudinous findings have been presented and not every detail can be discussed in full length in a research of this nature because, in reality, no two transportation networks are alike. The investigation has given an indication toward expected transportation cost savings that can result from the implementation of such an approach. Some studies of this approach based on real life transportation data have been performed and solutions from the above investigations are compared with real life results.

6.5.1 Summary of Key Findings of the Numerical Investigation

The numerical investigations have produced findings in many different areas relevant to real-life implementations. It has been discovered by running the approach on randomized instances of the same problem type that the achievable transportation cost savings may vary more significantly than the underlying transportation costs. While the mean deviation was 0.6% in transportation costs among the randomly generated instances, the standard deviation for cost savings amounted to 8.3%. With regard to real life implementations, frequently observed deviations larger than the reported standard deviations may hint at systematic process errors.

With regard to computational time it was observed that the greatest share of time is consumed by the generation of combinations. Therefore, any approach to accelerate the planning process should be aimed at reducing the time required for the creation of combinations. Since time consumption largely correlates with the number of combinations that are generated, their limitation may contribute toward faster combination processing. In order to control computational time as well as the number of combinations generated, filter parameters have been introduced. Some of them have proved to be very successful; however it was observed that parameter choice is a task with highest priority within any implementation process.

The selection of order combination, in contrast, is a comparably rapid process. It is ideally performed by standard software solving the resulting binary optimization problem since solution speed and quality significantly exceed those of the presented greedy heuristic approach.

A variation of the number of locations and the number of orders has shown the general applicability of the presented approach to a multitude of different network layouts and dimensions. However when implementing networks spanning large geographical areas and comprising many different locations, computational time may increase due to the processing of additional geographic data. The variation of the degree of freight rate degression in the dimensions “load degression” and “distance degression” is of an academic quality.

The length of the time windows has been thoroughly investigated and it has been argued that the prolongation of time windows may, together with the required filter parameter adjustments, lead to better transportation cost saving prospects. However, this comes at the price of longer computational time requirements. On the other hand, even for stricter time window requirements, good quality solutions were generated. With regard to practical implementations the importance of “correct” time windows cannot be underestimated and it may require intense harmonization between different planning processes (e.g., production, warehousing, sales) and the involved parties in order to obtain high input data quality.

The investigation of load sizes has shown their great influence on processing time and solution quality. Again, the importance of well-adjusted filter parameters has been emphasized. Since transportation volumes in the consumer goods industry are usually large, findings do not affect implementation prospects within this focus area. However, for implementation scenarios with different shipment structures a general redesign of the filter criteria for combination schemes 1–3 may be considered.

Very instructive results have also been obtained for a variation of the planning horizon and for different transportation equipment requirements. The former investigation has shown that a separation of the planning horizon may open additional combination prospects. The variation of transportation equipment gives an idea of how transportation costs are influenced by vehicle requirements.

Finally, the assessment of the average transportation distance and location geography has shown the significant influence of location proximity on the solution time and quality. Here, the boundaries of this approach became transparent. However, they were also identified to lie beyond the requirements of the underlying case study, and again, an adjustment of the way filter parameters are applied may push these boundaries further.

6.5.2 Comparison to Real Life Results

In real life cases taken from the European consumer goods industry the approach has been assessed in feasibility studies based on historic shipment data. Overall, results are generally similar to the ones presented above. However, some major differences were detected:

- *Freight rate availability:* While for the original transportation orders freight rates are usually available in the form of carrier contracts, rates for non-recurring tours as generated by the combination process are usually not directly available. Freight benchmarks can be chosen to rate these tours; in cases where a combination is chosen for implementation the load is sourced at the spot market. Real life results will in this case depend on the chosen benchmarking approach as well as on a broad participation of carriers in spot sourcing tenders. Overall results may nevertheless be flawed due to inaccurate rates and unsteady spot sourcing performance.
- *Transportation distance:* Transportation distances may vary widely and their distribution is usually not random due to the complex geography of Europe, the demographic distribution and possibly a historic development of consumer goods corporations within certain regions. A deviation toward very long, highly frequented, and therefore costly transportation lanes can result in a lower proportional share of savings compared to total transportation costs and a very different distribution of savings according to combination schemes.
- *Network structure:* It was not possible within the conducted real life studies to cover complete networks containing every truck movement. Some exceptions had to be made concerning special organizational units (responsible for special categories), special processes and other specific network characteristics. Therefore, the conducted studies had to focus on those subsections where cost savings could be implemented with a reasonable effort.

Overall, in real life cases transportation cost savings of 3–5% are regarded as realistic by supply chain executives in the consumer goods industry when using the introduced planning approach. These savings usually justify the necessary investment in IT and organizational restructuring with an approximate amortization-period of less than 1 year.

6.5.3 Conclusion

The conclusion for the conducted numerical investigations primarily aims at the implications for practical implementations. Investigations have revealed that the presented approach for operational transportation planning is generally able to contribute to considerable cost savings in a TMS implementation. The key requirements for a practical implementation as addressed in Sect. 4.1.1 are as follows:

- Suitability for application in an environment where transportation is outsourced to external carriers.
- Accuracy in freight cost representation.
- Ability to consider real life restrictions such as time windows and different temperature levels.

The presented approach for operational transportation planning has met these requirements in various instances, which have been subject to investigation in this section. Furthermore, results have been generated in reasonable computational time and in most cases with savings that are sufficient to justify investment as well as running costs for IT and organizational resources.

With considerable savings prospects, decision making should be straightforward on an economic basis. On the downside, however, the presented approach shows very demanding requirements toward process stability. The risk for delayed shipments is increased in case of complex order combinations. Whereas previously only one transport order may have been affected, now multiple shipments may be subject to irregularities. A realistic risk assessment and the allocation of profit and risk between different organizational units are keys for successful implementation. And while practical implementation was assessed thoroughly in this section and opportunities for transportation cost savings have been discussed all through this research, their actual implementation is subject to decisions made by people. It may be easy to assess the mathematical advantageousness of one alternative over the other. Reasons that lie beyond this model formulation may, however, change the picture. Therefore, implementation of this planning approach should be supported by a powerful graphical user interface (GUI) that supplies the user with the required information regarding potential order combinations and may also quickly show alternative combinations dismissed by the selection process.

The planning support perspective of this approach is, however, not only vital for practical implementation of the measures identified using the combination schemes. Supporting the planner performing the everyday job efficiently will disclose the possibilities for additional saving prospects. Better time window information, adjusted planning horizons and optimized filter parameters are only a few examples. The skillful implementation of additional measures may easily exceed the presented transportation cost savings directly attributed to the presented approach.

Chapter 7
Summary and Conclusion

An operational transportation planning problem from the perspective of the consumer goods industry was analyzed in this text. It has been pointed out how efficiency gains can be obtained in a transportation network run by third party logistics service providers, and how they can lead to a reduction in freight costs. Since many of the very specific algorithms in Operations Research literature are lacking the practical aspects of operational transportation planning in the consumer goods industry, further attention has been paid to the development of a specific approach for planning support. Such an approach has been presented and numerically assessed. Case studies on real life data have underlined its practical value. One key characteristic of the presented approach is the independence of predetermined freight rate structures. TMS functionality is used for any cost based assessment of combinations in an integrated, service-oriented system architecture.

7.1 Summary of Key Findings

The presented approach has been assessed as feasible for practical implementation, generating substantial savings in a real life environment. Since transportation activities are outsourced to carriers, these savings are cash-effective. However, in order to access the described savings potential, transportation management processes, organization and IT will need to be harmonically tuned toward a central transportation management approach. A TMS implementation is required to run the process efficiently and to provide central access to the transportation order data. In addition, experience from practical implementations has shown that the presented operative transportation planning approach raises awareness of transportation order parameters that had been of little interest previously.

Against the background of rising importance and awareness regarding transportation processes, this text has emphasized the significance of transportation management for modern industrial value creation using the example of the consumer goods supply chain. Special attention was paid to pricing mechanisms on transportation markets.

T. Seiler, *Operative Transportation Planning*, Contributions to Management Science, DOI 10.1007/978-3-7908-2792-7_7,

Not only have pricing mechanisms on these markets been assessed in detail, they have also been structured to form a pricing model that may be generally applied to outsourced transportation services.

In Chap. 4, current transportation management was assessed with regard to a case study from the consumer goods industry that had been previously discussed. An evaluation of transportation management was conducted using the dimensions of process, IT and organization. In the subsections focusing on transportation management processes, prevalent academic approaches were subject to a critical review. The approaches were found to show major shortcomings, especially with regard to freight rate representation and accuracy as well as with regard to some of the specific restrictions required to be met along the consumer goods supply chain. The subsection on IT systems focused on the definition and description of TMS. Since only very few contributions in academic literature feature TMS, processes and functionalities were described in greater detail. Today's TMS suites have been assessed. Although some show very extensive support for transportation order management, they are of little help exploiting freight rate structures to increase transportation efficiency. Furthermore, approaches that may serve as a structure for decision making in transportation management have been introduced and discussed. Throughout the respective section the requirements of transportation management in the consumer goods industry were addressed in different dimensions.

Based on these requirements, Chap. 5 discusses the development of a systematic approach for operational transportation planning in the consumer goods industry. The section directly addresses the identified pricing mechanism on outsourced transportation markets, and with the help of combination schemes identifies prospects for increasing transportation efficiency expressed by lower transportation costs. The developed combination schemes are related to one another and are completed by mechanisms that select the most advantageous combinations. The chapter concluded with implementation guidelines for this approach in a real life transportation management environment.

The developed approach is thoroughly investigated in Chap. 6. A multitude of parameters and different sets of transportation order data is applied in a realistic test-environment. The results show substantial transportation cost savings in the region of 5% of total transportation costs. In addition, the approach proves to be rather robust toward variations in input data, especially with regard to computational time. The application of this approach to real life data shows similar savings prospects and has emphasized its applicability to today's consumer goods industry.

7.2 Fields of Further Research

A broad overview on transportation management and a detailed description on operational transportation planning were given in this research. Still, some fields may be subject to further academic research in the future in order to increase transportation efficiency even more.

The term transportation cost savings has been used in order to express increased transportation efficiency in the second half of this research. Even though this may in most cases be a reasonable equivalent with regard to the underlying case study, it reveals a major shortcoming in transportation markets. Shippers know very little about true operational efficiency when it comes to the transport orders they place with their carriers. For LTL modes the involved shippers are ignorant of the total utilization of the vehicle that has been assigned to serve their orders. For FTL orders shippers do not know where the vehicle comes from when approaching the dispatching location and where it moves on to after delivery (McKinnon and Ge 2006). Efficiency indicators, such as empty running distance or vehicle utilization, are largely unknown to shippers and pricing schemes may only hint at an efficiency context. A sound model that integrates transportation efficiency and freight rates and helps to assess efficiency gains beyond cost savings – for example, with regard to emissions or other environmental aspects — is required. This may help to convince supply chain executives of the suggested planning approach.

For the purpose of practical implementation, a sustainable approach for the generation and application of reference freight rates to new tours should be devised, taking the specific forces prevailing at transportation spot markets into account. Within the given approach, it is suggested that unavailable rates be rated using a freight rate benchmark. Afterwards, the selection process takes place based on the costs calculated with the rate benchmark. Only if the combination in question is selected, is it subsequently tendered at the spot market. Consequently, there is a remaining risk that the benchmark rate cannot be achieved at the spot market and hence the combination is disintegrated. An improved approach may address this risk upfront, for example, by developing risk markups for combinations that have to be sourced on the spot market due to poor freight rate availability.

Additionally, the extension of this approach to fields of business with similar applicability should be investigated — potential industries could include the production of household appliances or the paper industry. In industrial environments the integration of production planning and scheduling with transportation planning promises additional savings prospects potentially exceeding the dimensions described in this research.

In terms of mathematical approaches to the described planning problem, additional work may be performed to find model formulations that provide increased speed and quality. In order to be able to measure solution quality, the determination of advanced quality criteria is indispensible.

Contributions to transportation planning and scheduling problems have been manifold in the past and show no sign of diminishing with the increasing importance of transportation in today’s society. However, many of these contributions lack relevance for some of the currently dominant questions in transportation management. Software companies as well as industrial corporations have multitudinous case studies from real life that require systematic research in order to develop solution approaches. Jointly accepting these challenges may constitute a first step to a necessary and sustainable increase of transportation efficiency.

7.3 Conclusion

In today’s consumer goods industry, efficient transportation (management) is very valuable and is a key factor for achieving high product availability, but it is often perceived as a non-value creating lump of supply chain costs. The prevailing transportation networks, organizations and shipment structures leave only little space for operational improvement. The presented proposal as described in this text has proven to be able to fill part of this space with a dedicated planning approach.

The approach has been described in detail and numerically assessed. More importantly, it has been integrated into modern transportation management with clear recommendations toward process, IT and organizational implementation. Due to the broad integration approach, the planner making transportation decisions has been moved to the center of this approach. The deployment of combination schemes is a measure that is easily comprehensible. Being limited to transportation processes, further opportunities are expected to become accessible when simultaneously considering production planning and replenishment. However, the transportation process will need to regain acceptance as a key link in any supply chain operation rather than being considered an undesirable driver of supply chain costs. Mature transportation management organizations empowered with suitable IT solutions may be an initial step in this direction.

Still, the dimension of transportation cost savings suggests that the larger part of transportation efficiency potential is not accessible (see Sect. 3.1.3). In order to achieve efficiency levels that are usually realized in the production process of consumer goods, further extensions of the approach will need development and implementation. However, it is necessary to jointly tackle the numerous challenges in conjunction with transportation management today; namely, congestion and environmental pollution, as well as the expansion of free trade and global competition, in order to achieve sustainable efficiency.

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Appendix I: Freight Rates

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Table I.1 Freight rates GVE (Stolletz and Stolletz 2008)

All Prices in EUR/Shipment	Until 100 km	Until 200 km	Until 300 km	Until 400 km	Until 500 km	Until 600 km	Until 700 km	Uxntil 800 km	Until 900 km	Until 1000 km	Until 1100 km	Until 1200 km	Until 1300 km	Until 1400 km	Until 1500 km
Until 1.5 m^3	29.53	38.90	46.46	50.37	51.26	51.34	51.51	56.34	61.52	66.58	72.28	76.57	81.78	86.34	91.33
Until 3 m^3	46.34	90.91	110.32	121.04	123.46	124.19	124.92	136.64	149.19	161.47	175.29	185.69	198.32	209.38	221.49
Until 4.5 m^3	69.47	135.60	164.18	180.04	183.52	184.45	185.41	202.81	221.44	239.66	260.18	275.60	294.36	310.78	328.75
Until 6 m^3	90.64	175.25	211.53	231.40	235.64	236.83	238.02	260.36	284.27	307.66	334.01	353.81	377.89	398.87	422.04
Until 7.5 m^3	108.00	207.44	249.60	272.57	277.27	278.52	279.76	306.02	334.13	361.62	392.59	415.86	444.16	468.94	496.06
Until 9 m^3	125.58	235.48	280.60	304.70	308.89	309.62	310.96	340.14	371.38	401.94	436.36	462.22	493.68	521.22	551.60
Until 10.5 m^3	129.59	246.79	295.98	322.57	327.80	329.14	330.49	361.50	394.71	427.18	463.77	491.26	524.69	553.96	585.99
Until 12 m^3	130.93	253.65	306.39	335.27	341.46	343.22	344.98	377.35	412.02	445.92	484.10	512.80	547.70	578.25	611.69
Until 13.5 m^3	131.91	257.64	314.12	345.46	352.90	355.19	357.98	390.96	426.88	462.00	501.57	531.30	567.45	599.11	633.76
Until 15 m^3	140.35	261.18	321.20	354.99	363.71	366.40	369.08	403.72	440.80	477.07	517.92	548.63	585.96	618.65	654.42
Until 18.8 m^3	161.52	283.42	352.93	392.63	403.91	407.45	410.98	449.55	490.85	531.23	576.72	610.92	652.48	688.88	728.72
Until 22.5 m^3	176.35	324.58	404.18	449.66	462.54	466.61	470.69	514.85	562.15	608.40	660.50	699.66	747.27	788.96	834.58
Until 30 m^3	176.70	329.02	418.99	481.78	515.93	527.80	539.68	590.32	644.55	697.58	757.32	802.22	856.81	904.60	956.92
Until 37.5 m^3	178.39	329.48	420.70	485.32	521.81	534.60	547.40	598.77	653.77	707.56	768.16	813.69	869.06	917.54	970.60
Until 45 m^3	178.67	333.77	435.18	516.71	574.08	594.53	614.98	672.69	734.48	794.91	862.99	914.15	976.35	1,030.82	1,090.43
Until 52.5 m^3	178.95	337.24	446.98	542.18	587.60	600.13	669.64	732.48	799.77	865.57	939.69	995.40	1,061.13	1,122.44	1,187.35
Until 60 m^3	181.56	338.49	459.18	564.80	616.35	639.57	724.47	780.31	853.87	921.87	988.79	1,039.21	1,130.00	1,192.40	1,282.80
Until 67.5 m^3	182.33	339.65	469.92	587.21	651.88	695.70	776.29	849.13	927.14	1,003.41	1,089.34	1,153.92	1,232.44	1,301.20	1,376.44
Until 75 m^3	185.42	340.93	482.12	602.25	666.95	746.95	833.47	911.68	995.43	1,077.33	1,169.58	1,238.92	1,323.23	1,397.04	1,477.83
Until 82.5 m^3	185.99	341.99	492.45	607.24	694.10	790.29	881.83	964.58	1,053.19	1,139.84	1,237.45	1,310.81	1,400.00	1,478.10	1,563.58
Until 90 m^3	186.97	351.56	495.22	609.73	713.37	801.72	894.59	978.53	1,068.42	1,156.33	1,255.35	1,329.78	1,420.26	1,499.49	1,586.20
Until 100 m^3	187.74	354.28	504.41	623.41	716.61	810.34	904.20	989.04	1,079.90	1,168.75	1,268.84	1,344.06	1,435.52	1,515.60	1,603.24

Table I.2 Freight rates GVE in EUR per m^3 and 100 km

All Prices in EUR per m^3 and 100 km	Until 100 km	Until 200 km	Until 300 km	Until 400 km	Until 500 km	Until 600 km	Until 700 km	Until 800 km	Until 900 km	Until 1000 km	Until 1100 km	Until 1200 km	Until 1300 km	Until 1400 km	Until 1500 km
Until 1.5 m^3	19.69	12.97	10.32	8.40	6.83	5.70	4.91	4.70	4.56	4.44	4.38	4.25	4.19	4.11	4.06
Until 3 m^3	15.45	15.15	12.26	10.09	8.23	6.90	5.95	5.69	5.53	5.38	5.31	5.16	5.09	4.99	4.92
Until 4.5 m^3	15.44	15.07	12.16	10.00	8.16	6.83	5.89	5.63	5.47	5.33	5.26	5.10	5.03	4.93	4.87
Until 6 m^3	15.11	14.60	11.75	9.64	7.85	6.58	5.67	5.42	5.26	5.13	5.06	4.91	4.84	4.75	4.69
Until 7.5 m^3	14.40	13.83	11.09	9.09	7.39	6.19	5.33	5.10	4.95	4.82	4.76	4.62	4.56	4.47	4.41
Until 9 m^3	13.95	13.08	10.39	8.46	6.86	5.74	4.94	4.72	4.58	4.47	4.41	4.28	4.22	4.14	4.09
Until 10.5 m^3	12.34	11.75	9.40	7.68	6.24	5.22	4.50	4.30	4.18	4.07	4.02	3.90	3.84	3.77	3.72
Until 12 m^3	10.91	10.57	8.51	6.98	5.69	4.77	4.11	3.93	3.82	3.72	3.67	3.56	3.51	3.44	3.40
Until 13.5 m^3	9.77	9.54	7.76	6.40	5.23	4.39	3.78	3.62	3.51	3.42	3.38	3.28	3.23	3.17	3.13
Until 15 m^3	9.36	8.71	7.14	5.92	4.85	4.07	3.52	3.36	3.27	3.18	3.14	3.05	3.00	2.95	2.91
Until 18.8 m^3	8.59	7.54	6.26	5.22	4.30	3.61	3.12	2.99	2.90	2.83	2.79	2.71	2.67	2.62	2.58
Until 22.5 m^3	7.84	7.21	5.99	5.00	4.11	3.46	2.99	2.86	2.78	2.70	2.67	2.59	2.55	2.50	2.47
Until 30 m^3	5.89	5.48	4.66	4.01	3.44	2.93	2.57	2.46	2.39	2.33	2.29	2.23	2.20	2.15	2.13
Until 37.5 m^3	4.76	4.39	3.74	3.24	2.78	2.38	2.09	2.00	1.94	1.89	1.86	1.81	1.78	1.75	1.73
Until 45 m^3	3.97	3.71	3.22	2.87	2.55	2.20	1.95	1.87	1.81	1.77	1.74	1.69	1.67	1.64	1.62
Until 52.5 m^3	3.41	3.21	2.84	2.58	2.24	1.91	1.82	1.74	1.69	1.65	1.63	1.58	1.55	1.53	1.51
Until 60 m^3	3.03	2.82	2.55	2.35	2.05	1.78	1.72	1.63	1.58	1.54	1.50	1.44	1.45	1.42	1.43
Until 67.5 m^3	2.70	2.52	2.32	2.17	1.93	1.72	1.64	1.57	1.53	1.49	1.47	1.42	1.40	1.38	1.36
Until 75 m^3	2.47	2.27	2.14	2.01	1.78	1.66	1.59	1.52	1.47	1.44	1.42	1.38	1.36	1.33	1.31
Until 82.5 m^3	2.25	2.07	1.99	1.84	1.68	1.60	1.53	1.46	1.42	1.38	1.36	1.32	1.31	1.28	1.26
Until 90 m^3	2.08	1.95	1.83	1.69	1.59	1.48	1.42	1.36	1.32	1.28	1.27	1.23	1.21	1.19	1.17
Until 100 m^3	1.88	1.77	1.68	1.56	1.43	1.35	1.29	1.24	1.20	1.17	1.15	1.12	1.10	1.08	1.07

Appendix II: Transportation Management Systems

Vendor	Acteos	Active Logistics	AEB	AXIT	CAL Consult	Cargosoft	GreenCat
Product	Acteos Transportation Management	L-wiS	ASSIST4	AX4 Transport	CALtms	CargoSoft SCM	TMS
Transport Order Management	◑	○	◑	◑	◑	◔	◔
Order Entry	◑	○	●	●	●	◑	◑
Transport Order Specification	○	○	○	◑	◑	○	○
Assignment of Service Providers & Communication	●	○	○	○	○	○	○
Status Tracking	●	●	○	◑	◑	○	○
Invoicing	○	○	◑	○	○	○	○
Controlling	○	○	◑	○	○	○	○
Freight Cost Controlling	○	○	◕	○	○	○	○
Service Provider Controlling	○	○	◑	○	○	○	○
Location Controlling	○	○	○	○	○	○	○
Network Controlling	○	○	○	○	○	○	○
General Planning Support	○	○	○	○	○	○	○
Material Flow Analysis	○	○	○	○	○	○	○
Budgeting	○	○	○	○	○	○	○
Transportation Costing	○	○	○	○	○	○	○
Transportation Planning	○	○	○	○	○	○	○
Strategic Planning	○	○	○	○	○	○	○
Tactical Planning	○	○	○	○	○	○	○
Operational Consolidation	◔	○	○	○	○	○	○
Operational Dock Scheduling and Yard Management	○	○	○	○	○	○	○
Freight Rate Management	◑	○	◑	○	○	○	○

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Vendor	Central Line	CSD Management Consulting	DDS Logistics	Descartes	Four Soft	High Jump	i2
Product	LP/2	TransWareOne	TMS	Descartes Delivery Management Suite	4S Shipper Logistics	HighJump Transportation Advantage	i2 Transportation Manager
Transport Order Management	◔	◔	●	●	◕	◕	●
Order Entry	●	◑	●	●	●	●	●
Transport Order Specification	○	○	◑	◑	◑	◑	◕
Assignment of Service Providers & Communication	○	○	●	●	◑	◑	●
Status Tracking	○	○	◑	◑	◑	◕	◕
Invoicing	○	○	◑	○	◕	○	◕
Controlling	○	○	◔	◔	◔	◑	◔
Freight Cost Controlling	○	○	◑	◑	◑	◕	◑
Service Provider Controlling	○	○	○	○	○	○	○
Location Controlling	○	○	○	○	○	○	○
Network Controlling	○	○	○	○	○	○	○
General Planning Support	◑	○	◔	○	○	○	◑
Material Flow Analysis	○	○	○	○	○	○	◑
Budgeting	○	○	◑	○	○	○	○
Transportation Costing	○	○	●	○	○	○	◑
Transportation Planning	◔	○	○	○	○	○	◑
Strategic Planning	○	○	○	○	○	○	●
Tactical Planning	○	○	○	○	○	○	○
Operational Consolidation	◔	○	○	○	○	○	◔
Operational Dock Scheduling and Yard Management	○	○	○	○	○	○	◔
Freight Rate Management	◔	○	◑	◔	○	○	◑

◑	○	◷	○	○	◔	○	○	○	○	○	○	◐	◍	◑	●	◑	◍	◍	◍	●	inet TMS	inet-logistics
○	○	◷	○	◍	◔	○	○	○	◑	○	○	○	○	○	○	○	○	○	○	○	Transportation Management	Infor
○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	◐	◔	TRIS	Intris NV
◑	○	○	○	○	○	○	○	○	○	○	○	○	◍	◑	◕	◕	◍	◐	◍	●	Transportation & Logistics Management	JDA Software Group
○	○	○	○	○	○	○	○	○	○	○	○	○	◐	◔	◕	◑	◍	◐	◐	◕	Kewill Transport	Kewill
●	◷	◷	○	○	◔	○	◐	○	◔	○	○	◐	◍	◑	◕	◕	◍	◐	◍	◕	On-Demand TMS	Lean Logistics
◑	○	◷	○	○	◔	○	◐	○	◔	○	○	○	◍	◑	◕	◕	◍	◐	◍	●	Voyager Transportation Planning & Management	Logility
◑	○	○	○	○	○	○	○	○	○	○	○	○	◐	◔	○	○	○	○	○	○	International Transportation Management solution	Management Dynamics
◑	○	◷	○	○	◔	○	○	○	○	○	○	○	◍	◔	●	◕	◍	◐	◍	◕	Transportation Planning & Execution	Manhattan Associates
○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	◑	◑	○	○	◐	◔	Sterling Transportation Management System	Sterling Commerce
○	○	○	○	◐	◔	○	○	○	○	○	○	○	○	○	○	●	○	○	◍	◑	Optrak Routing & Scheduling	Optrak Distribution Limited
●	○	◶	○	○	◔	○	○	○	○	○	○	○	◐	◔	●	◕	◍	◍	◍	●	Oracle Transportation Management	Oracle
○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	◕	○	◍	◍	◕	ORTEC Transport and Distribution	ORTEC International
○	○	◐	○	◐	◔	○	○	◐	◔	○	○	○	○	○	○	◑	○	◐	◐	◑	PTV Intertour	PTV

Vendor	Quintiq	RedPrairie	Replica Sisterni	Routing International	SAP	ShipitSmarter.com	Tesi
Product	Logistics Planning Solutions	Transportation Management	Show Trip, Controller	WinRoute	SAP TM	shipitsmarter.com	NetMover
Transport Order Management	◔	◕	◔	○	◕	◕	◔
Order Entry	◔	●	◑	○	●	◑	◑
Transport Order Specification	◑	○	○	○	◑	●	○
Assignment of Service Providers & Communication	○	◑	○	○	●	●	○
Status Tracking	◑	◑	○	○	◕	◑	●
Invoicing	○	○	○	○	◕	◑	◕
Controlling	◔	◔	◑	○	○	◔	◔
Freight Cost Controlling	◑	◑	◕	○	○	◑	◑
Service Provider Controlling	○	○	○	○	○	○	○
Location Controlling	○	○	○	○	○	○	○
Network Controlling	○	○	○	○	○	○	○
General Planning Support	○	○	○	○	○	○	○
Material Flow Analysis	○	○	○	○	○	○	○
Budgeting	○	○	○	○	○	○	○
Transportation Costing	○	○	○	○	○	○	○
Transportation Planning	○	○	○	○	○	○	○
Strategic Planning	○	○	○	○	○	○	○
Tactical Planning	○	○	○	○	○	○	○
Operational Consolidation	○	○	○	○	○	○	○
Operational Dock Scheduling and Yard Management	○	○	○	○	○	○	○
Freight Rate Management	○	○	○	○	○	◑	○

Table II.1 Findings from system assessment TMS

◑	○	○	○	○	○	○	◒	○	◔	○	○	○	○	○	◑	◑	●	○	●	◕	LBASE TMS	Transflow Informationslogistik
○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	◒	◒	◔	PRA Car 3000	Wanko
○	○	○	○	○	○	○	○	○	○	○	○	○	◒	◔	◕	◑	◒	○	●	◕	Wex vs tms	Wexlog Technologies
○	○	◒	○	○	◔	○	○	○	○	○	○	○	○	○	○	○	○	○	◒	◔	LS/ATN	Whitestein Technologies

Table II.2 Overview on transportation solution by Acteos (Based on Acteos 2009, 2010; Cap Gemini Nederland 2007)

Vendor:	Acteos
Product:	Acteos Transportation Management
Website:	www.acteos.com

Turnover (2008):	12,266 thsd. EUR	**Functional Assessment:**	
Profit (2008):	377 thsd. EUR	Transport Order Management	◑
Number of Employees (2008):	92	Status Tracking	●
		Invoicing	○
Home Region / Country:	EU / FR	Controlling	○
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	600 (2010)	Transportation Planning	○
		Freight Rate Management	◑

Comment:	Planning and optimization only partially covered, sold together with WMS and telematics solutions

Table II.3 Overview on transportation solution by active logistics (Based on active logistics GmbH 2010; Cap Gemini Nederland B.V. 2007)

Vendor:	Active Logistics
Product:	L-wiS
Website:	www.active-logistics.com

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	○
Number of Employees (2010):	>250	Status Tracking	●
		Invoicing	○
Home Region / Country:	EU / DE	Controlling	○
Number of Implementations:	>1,500 (2010)	General Planning Support	○
Number of Users:	>13,000 (2010)	Transportation Planning	○
		Freight Rate Management	○

Comment:	Broad telematic support, no real TMS

Table II.4 Overview on transportation solution by AEB (Based on AEB GmbH 2010)

Vendor:	AEB
Product:	ASSIST4
Website:	www.aeb.de

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◑
Number of Employees:	N/A	Status Tracking	○
		Invoicing	◑
Home Region / Country:	EU / DE	Controlling	◑
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	>999(2010)	Transportation Planning	○
		Freight Rate Management	◑

Comment:	Solution with a focus on customs processes, only basic transportation functionalities are covered

Table II.5 Overview on transportation solution by AXIT (Based on AXIT AG 2010)

Vendor:	AXIT
Product:	AX4 Transport
Website:	www.axit.de

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◑
Number of Employees (2010):	70	Status Tracking	◑
		Invoicing	○
Home Region / Country:	EU / DE	Controlling	○
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	40,000 (2010)	Transportation Planning	○
		Freight Rate Management	○

Comment:	Order management software, strong integrational focus, however, mere data management with only little logistics focus

Table II.6 Overview on transportation solution by CAL Consult (Based on CAL Consult 2010; Cap Gemini Nederland B.V. 2007)

Vendor:	CAL Consult
Product:	CALtms
Website:	www.cal-consult.nl

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◑
Number of Employees (2010):	120	Status Tracking	◑
		Invoicing	○
Home Region / Country:	EU / NL	Controlling	○
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	N/A	Transportation Planning	○
		Freight Rate Management	○

Comment:	Carrier software for order management and quotations

Table II.7 Overview on transportation solution by Cargosoft (Based on CargoSoft 2010; Morningstar 2010)

Vendor:	Cargosoft
Product:	CargoSoft SCM
Website:	www.cargosoft.de

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◔
Number of Employees (2007):	25	Status Tracking	○
		Invoicing	○
Home Region / Country:	EU / DE	Controlling	○
Number of Implementations:	130 (2010)	General Planning Support	○
Number of Users:	750 (2010)	Transportation Planning	○
		Freight Rate Management	○

Comment:	Carrier software (customer portfolio) with a strong regional focus on northern Germany

Table II.8 Overview on transportation solution by GreenCat (Based on Cap Gemini Nederland 2007)

Vendor:	GreenCat
Product:	TMS
Website:	www.greencat-it.com

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◔
Number of Employees:	N/A	Status Tracking	○
		Invoicing	○
Home Region / Country:	EU / NL	Controlling	○
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	N/A	Transportation Planning	○
		Freight Rate Management	○

Comment:	Carrier software mainly for vehicle routing

Table II.9 Overview on transportation solution by Central Line (Based on Cap Gemini Nederland 2007)

Vendor:	Central Line
Product:	LP/2
Website:	www.centralline.eu

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◔
Number of Employees:	N/A	Status Tracking	○
		Invoicing	○
Home Region / Country:	EU / BE	Controlling	○
Number of Implementations:	N/A	General Planning Support	◐
Number of Users:	N/A	Transportation Planning	◔
		Freight Rate Management	◔

Comment:	Logistics planning software, inhomogenous product portfolio

Table II.10 Overview on transportation solution by CSD (Based on Management Consulting 2010; Cap Gemini Nederland 2007)

Vendor:	CSD Management Consulting
Product:	TransWareOne
Website:	www.csd-management.de

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◔
Number of Employees:	N/A	Status Tracking	○
		Invoicing	○
Home Region / Country:	EU / DE	Controlling	○
Number of Implementations:	300 (2010)	General Planning Support	○
Number of Users:	N/A	Transportation Planning	○
		Freight Rate Management	○

Comment:	Document management software for freight documentation, quotations and customs declaration

Table II.11 Overview on transportation solution by DDS (Based on DDS 2007b, 2009; Cap Gemini Nederland B.V. 2007)

Vendor:	DDS Logistics
Product:	TMS
Website:	www.ddslogistics.com

Turnover (2006):	4,500thsd. EUR	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	●
Number of Employees (2007):	52	Status Tracking	◑
		Invoicing	◑
Home Region / Country:	EU / FR	Controlling	◔
Number of Implementations:	50 (2007)	General Planning Support	◔
Number of Users:	N/A	Transportation Planning	○
		Freight Rate Management	◑

Comment:	TMS with broad implementation scope, however, lacking planning and optimization functionality

Table II.12 Overview on transportation solution by Descartes (Based on Descartes 2010a, 2010b)

Vendor:	Descartes
Product:	Descartes Delivery Management Suite
Website:	www.descartes.com

Turnover (FY 2010):	73,800thsd. USD	**Functional Assessment:**	
Profit (FY 2010):	14,300thsd. USD	Transport Order Management	●
Number of Employees:	400	Status Tracking	◑
		Invoicing	○
Home Region / Country:	AMS / CA	Controlling	◔
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	N/A	Transportation Planning	○
		Freight Rate Management	◔

Comment:	Process oriented TMS suite with little planning and optimization support

Table II.13 Overview on transportation solution by FourSoft (Based on Four Soft Ltd 2008a, 2008b, 2009)

Vendor:	Four Soft
Product :	4S Shipper Logistics
Website :	www.four-soft.com

Turnover (FY 2008):	17,273thsd. lacs	**Functional Assessment:**	
Profit (FY 2008):	868 thsd. lacs	Transport Order Management	◕
Number of Employees (2009):	600	Status Tracking	◑
		Invoicing	◕
Home Region / Country:	ASIA / IN	Controlling	◔
Number of Implementations:	300 (2009)	General Planning Support	○
Number of Users:	50,000(2009)	Transportation Planning	○
		Freight Rate Management	○

Comment:	Software suite focussing on distribution and warehouse management extention, customer focus on LSP

Table II.14 Overview on transportation solution by High Jump (Based on BNET 2010a; Woods 2006)

Vendor:	High Jump
Product:	HighJump Transportation Advantage
Website:	www.highjump.com

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◕
Number of Employees (2010):	350	Status Tracking	◕
		Invoicing	○
Home Region / Country:	AMS / US	Controlling	◑
Number of Implementations:	1,500(2010)	General Planning Support	○
Number of Users:	N/A	Transportation Planning	○
		Freight Rate Management	○

Comment:	TMS with a focus on controlling, very limited planning and optimization functionality

Table II.15 Overview on transportation solution by i2 (Based on i2 technologies 2009; Woods 2006; Connaughton 2008)

Vendor:	i2
Product:	i2 Transportation Manager
Website:	www.i2.com

Turnover (2008):	255,813thsd. USD	**Functional Assessment:**	
Profit:	109,843thsd. USD	Transport Order Management	●
Number of Employees (2008):	1,280	Status Tracking	◕
		Invoicing	◕
Home Region / Country:	AMS / US	Controlling	◔
Number of Implementations:	N/A	General Planning Support	◑
Number of Users:	N/A	Transportation Planning	◑
		Freight Rate Management	◑

Comment:	Very broad TMS application, however, customer base mainly in the US

Table II.16 Overview on transportation solution by inet-logitics (Based on Top1001.at 2010)

Vendor:	inet-logitics
Product:	inet TMS
Website:	www.inet-logistics.com

Turnover (2008):	8,100 thsd. EUR	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	●
Number of Employees (2008):	44	Status Tracking	◑
		Invoicing	●
Home Region / Country:	EU / AT	Controlling	◑
Number of Implementations:	30 (2005)	General Planning Support	○
Number of Users:	N/A	Transportation Planning	◔
		Freight Rate Management	◑

Comment:	Software suite with a strong process focus for efficient order management

Table II.17 Overview on transportation solution by Infor (Based on Infor 2010; Connaughton 2008)

Vendor:	Infor
Product:	Transportation Management
Website:	www.infor.com

Turnover (2010):	2,100,000thsd. USD	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	○
Number of Employees (2010):	8,000	Status Tracking	○
		Invoicing	○
Home Region / Country:	AMS / US	Controlling	○
Number of Implementations:	N/A	General Planning Support	◑
Number of Users:	70,000 (2010)	Transportation Planning	◔
		Freight Rate Management	○

Comment:	Logistics planning software suite, no order management coverage

Table II.18 Overview on transportation solution by Intris (Based on Intris 2010; Cap Gemini Nederland B.V. 2007)

Vendor:	Intris NV
Product:	TRIS
Website:	www.intris-group.com

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◔
Number of Employees:	N/A	Status Tracking	○
		Invoicing	○
Home Region / Country:	EU / BE	Controlling	○
Number of Implementations:	250 (2008)	General Planning Support	○
Number of Users:	4,500 (2008)	Transportation Planning	○
		Freight Rate Management	○

Comment:	Carrier software for route planning and fleet management

Table II.19 Overview on transportation solution by JDA (Based on JDA Software Group I 2010a, 2010b; Cap Gemini Nederland 2007; Woods 2006; Connaughton 2008)

Vendor:	JDA Software Group
Product:	Transportation & Logistics Management
Website:	www.jda.com

Turnover (2009):	385,000 thsd. USD	**Functional Assessment:**	
Profit (2009):	96,800 thsd. USD	Transport Order Management	●
Number of Employees (2009):	1,846	Status Tracking	◕
		Invoicing	◕
Home Region / Country:	AMS / US	Controlling	◑
Number of Implementations:	6,000 (2010)	General Planning Support	○
Number of Users:	N/A	Transportation Planning	○
		Freight Rate Management	◑

Comment:	TMS with a focus on order management, lacking planning and optimization functionality

Table II.20 Overview on transportation solution by Kewill (Based on Kewill plc 2009, 2010; Cap Gemini Nederland B.V. 2007)

Vendor:	Kewill
Product:	Kewill Transport
Website:	www.kewill.com

Turnover (FY2009):	53,300 thsd. GBP	**Functional Assessment:**	
Profit (FY2009):	2,000 thsd. GBP	Transport Order Management	◕
Number of Employees (2009):	603	Status Tracking	◑
		Invoicing	◕
Home Region / Country:	EU / UK	Controlling	◔
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	40,000(2010)	Transportation Planning	○
		Freight Rate Management	○

Comment:	TMS based on trading platform with a strong focus on status tracking

Table II.21 Overview on transportation solution by lean logistics (Based on Lean 2010; Cap Gemini Nederland B.V. 2007; Woods 2006; Connaughton 2008)

Vendor:	Lean Logistics
Product:	On-Demand TMS
Website:	www.leanlogistics.com

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◕
Number of Employees:	50	Status Tracking	◕
		Invoicing	◕
Home Region / Country:	AMS / US	Controlling	◑
Number of Implementations:	45 (2010)	General Planning Support	◔
Number of Users:	24,000(2010)	Transportation Planning	◔
		Freight Rate Management	●

Comment:	Full-scale TMS, yet lacking planning and optimization features, customer footprint US-based

Table II.22 Overview on transportation solution by logility (Based on LinkedIn 2010a, 2010b; Woods 2006)

Vendor:	Logility
Product:	Voyager Transportation Planning & Management
Website:	www.logility.com

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	●
Number of Employees (2010):	143	Status Tracking	◕
		Invoicing	◕
Home Region / Country:	AMS / US	Controlling	◑
Number of Implementations:	1,250(2010)	General Planning Support	◔
Number of Users:	N/A	Transportation Planning	◔
		Freight Rate Management	◑

Comment:	Broad TMS-process support, limited planning and optimization features, customer footprint US-based

Table II.23 Overview on transportation solution by management dynamics (Based on Management 2010; BNET 2010b; Wikipedia 2010a)

Vendor:	Management Dynamics
Product	International Transportation Management solution
Website:	www.managementdynamics.com

Turnover (2009):	17,500 thsd. USD	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	○
Number of Employees (2010):	350	Status Tracking	○
		Invoicing	○
Home Region / Country:	AMS / US	Controlling	◔
Number of Implementations:	300 (2010)	General Planning Support	○
Number of Users:	13,000(2010)	Transportation Planning	○
		Freight Rate Management	◑

Comment:	Documentation tool for LSP contracts

Table II.24 Overview on transportation solution by Manhattan Associates (Based on Manhattan Associates 2010; Cap Gemini Nederland B.V. 2007; Woods 2006; Connaughton 2008)

Vendor:	Manhattan Associates
Product:	Transportation Planning & Execution
Website:	www.manh.com

Turnover (2009):	246,000 thsd. USD	**Functional Assessment:**	
Profit (2009):	33,100 thsd. USD	Transport Order Management	◕
Number of Employees (2010):	2,000	Status Tracking	◕
		Invoicing	●
Home Region / Country:	AMS / US	Controlling	◔
Number of Implementations:	1,200 (2010)	General Planning Support	○
Number of Users:	N/A	Transportation Planning	◔
		Freight Rate Management	◑

Comment:	Full-scale TMS, yet limited planning and optimization features

Table II.25 Overview on transportation solution by Sterling Commerce (Based on Sterling 2010; Wikipedia 2010c; Woods 2006; Connaughton 2008)

Vendor:	Sterling Commerce
Product:	Sterling Transportation Management System
Website:	www.sterlingcommerce.com

Turnover (2007):	634,000 thsd. USD	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◔
Number of Employees (2010):	2,700	Status Tracking	◑
		Invoicing	◑
Home Region / Country:	AMS / US	Controlling	○
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	18,000(2010)	Transportation Planning	○
		Freight Rate Management	○

Comment:	TMS exclusively offered as on-demand services with basic functionality

Table II.26 Overview on transportation solution by Optrak (Based on LinkedIn 2010c; Cap Gemini Nederland B.V. 2007)

Vendor:	Optrak Distribution Limited
Product:	Optrak Routing & Scheduling
Website:	www.optrak.co.uk

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◑
Number of Employees (2010):	15	Status Tracking	●
		Invoicing	○
Home Region / Country:	EU / UK	Controlling	○
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	N/A	Transportation Planning	◔
		Freight Rate Management	○

Comment:	Carrier software for route planning and fleet management with a strong focus on telematics integration

Table II.27 Overview on transportation solution by Oracle (Based on Oracle 2009a, 2009b; Cap Gemini Ernst & Young 2002; Woods 2006; Connaughton 2008)

Vendor:	Oracle
Product:	Oracle Transportation Management
Website:	www.oracle.com

Turnover (FY2009):	23,000,000 thsd. USD	**Functional Assessment:**	
Profit (FY2009):	10,900,000 thsd. USD	Transport Order Management	●
Number of Employees (2009):	86,000	Status Tracking	◕
		Invoicing	●
Home Region / Country:	AMS / US	Controlling	◔
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	N/A	Transportation Planning	◔
		Freight Rate Management	●

Comment:	Full-scale TMS suite, however, lacking planning and optimization functionality with a strong focus on the North American market

Table II.28 Overview on transportation solution by ORTEC (Based on Ortec 2010a, 2010b; Cap Gemini Nederland B.V. 2007)

Vendor:	ORTEC International
Product:	ORTEC Transport and Distribution
Website:	www.ortec.com

Turnover (2008):	65,000 thsd. EUR	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◕
Number of Employees (2010):	700	Status Tracking	◕
		Invoicing	○
Home Region / Country:	EU / NL	Controlling	○
Number of Implementations:	1,250 (2010)	General Planning Support	○
Number of Users:	N/A	Transportation Planning	○
		Freight Rate Management	○

Comment:	Carrier software focusing on vehicle routing of own fleet

Table II.29 Overview on transportation solution by PTV (Based on PTV 2010; Cap Gemini Nederland B.V. 2007)

Vendor:	PTV
Product:	PTV Intertour
Website:	www.ptv.de

Turnover (FY2008):	83,400 thsd. EUR	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◑
Number of Employees (2008):	494	Status Tracking	◑
		Invoicing	○
Home Region / Country:	EU / DE	Controlling	○
Number of Implementations:	N/A	General Planning Support	◔
Number of Users:	N/A	Transportation Planning	◔
		Freight Rate Management	○

Comment:	Logistics planning suite with a focus on vehicle routing and GIS

Table II.30 Overview on transportation solution by Quintiq (Based on Quintiq 2010; Cap Gemini Nederland B.V. 2007)

Vendor:	Quintiq
Product:	Logistics Planning Solutions
Website:	www.quintiq.com

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◔
Number of Employees	N/A	Status Tracking	◑
		Invoicing	○
Home Region / Country:	EU / NL	Controlling	◔
Number of Implementations:	500 (2010)	General Planning Support	○
Number of Users:	N/A	Transportation Planning	○
		Freight Rate Management	○

Comment:	TMS mainly extends given product portfolio of ERP/APS

Table II.31 Overview on transportation solution by RedPrairie (Based on RedPrairie 2010; Wikipedia 2010b; Cap Gemini Nederland B.V. 2007; Woods 2006; Connaughton 2008)

Vendor :	RedPrairie
Product:	Transportation Management
Website:	www.redprairie.com

Turnover (2008):	292,900 thsd. USD	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◕
Number of Employees (2010):	1,100	Status Tracking	◑
		Invoicing	○
Home Region / Country:	AMS / US	Controlling	◔
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	34,000 (2010)	Transportation Planning	○
		Freight Rate Management	○

Comment:	TMS extends the functionality of the very popular WM, lacking planning support and freight rate coverage

Table II.32 Overview on transportation solution by Replica Sistemi (Based on Replica 2010; Cap Gemini Nederland B.V. 2007)

Vendor :	Replica Sisterni
Product:	Show Trip, Controller
Website:	www.replica.it

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◔
Number of Employees (2010):	140	Status Tracking	○
		Invoicing	○
Home Region / Country:	EU / IT	Controlling	◑
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	N/A	Transportation Planning	○
		Freight Rate Management	○

Comment:	Vehicle routing software also supporting the LSP with tender processes

Table II.33 Overview on transportation solution by Routing International (Based on Routing 2010; Cap Gemini Nederland B.V. 2007)

Vendor :	Routing International
Product:	WinRoute
Website:	www.routing-international.com

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	○
Number of Employees:	N/A	Status Tracking	○
		Invoicing	○
Home Region / Country:	EU / BE	Controlling	○
Number of Implementations:	200 (2010)	General Planning Support	○
Number of Users:	N/A	Transportation Planning	○
		Freight Rate Management	○

Comment:	Software package exclusively used for route planning, no real TMS

Table II.34 Overview on transportation solution by SAP (Based on SAP 2010a, 2010b; Cap Gemini Nederland B.V. 2007; Woods 2006; Connaughton 2008)

Vendor :	SAP
Product:	SAP TM
Website:	www.sap.com

Turnover (2009):	10,670,000 thsd. EUR	**Functional Assessment:**	
Profit (2009):	2,640,000 thsd. EUR	Transport Order Management	◕
Number of Employees (2010):	47,500	Status Tracking	◕
		Invoicing	◕
Home Region / Country:	EU / DE	Controlling	○
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	95,000 (2010)	Transportation Planning	○
		Freight Rate Management	○

Comment:	TMS is designed to be the industry solution for LSPs, market presence with TMS still poor

Table II.35 Overview on transportation solution by ShipitSmarter.com (Based on LinkedIn 2010d; Cap Gemini Nederland B.V. 2007)

Vendor :	ShipitSmarter.com
Product:	shipitsmarter.com
Website:	www.shipitsmarter.com

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◕
Number of Employees (2010):	20	Status Tracking	◑
		Invoicing	◑
Home Region / Country:	EU / NL	Controlling	◔
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	N/A	Transportation Planning	○
		Freight Rate Management	◑

Comment:	Integrational platform for shippers and carriers for easy order management, only basic functionality

Table II.36 Overview on transportation solution by Tesi (Based on Gruppo 2010; Cap Gemini Nederland B.V. 2007)

Vendor :	Tesi
Product:	NetMover
Website:	www.gruppotesi.com

Turnover (2009):	17,500 thsd. EUR	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◔
Number of Employees (2010):	160	Status Tracking	●
		Invoicing	◕
Home Region / Country:	EU / IT	Controlling	◔
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	N/A	Transportation Planning	○
		Freight Rate Management	○

Comment:	TMS integrates the existing product portfolio of WMS and telematics systems

Table II.37 Overview on transportation solution by Transflow (Based on Transflow 2010; Cap Gemini Nederland B.V. 2007)

Vendor :	Transflow Informationslogistik
Product:	LBASE TMS
Website:	www.transflow.com

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◕
Number of Employees (2010):	70	Status Tracking	◑
		Invoicing	◑
Home Region / Country:	EU / AT	Controlling	○
Number of Implementations:	N/A	General Planning Support	◔
Number of Users:	N/A	Transportation Planning	○
		Freight Rate Management	◑

Comment:	Full-scale TMS suite, however, limited planning and optimization functionality

Table II.38 Overview on transportation solution by Wanko (Based on Wanko 2010; Cap Gemini Nederland B.V. 2007; ten Hompel 2006)

Vendor :	Wanko
Product:	PRA Car 3000
Website:	www.wanko.de

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◔
Number of Employees (2010):	31	Status Tracking	○
		Invoicing	○
Home Region / Country:	EU / DE	Controlling	○
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	N/A	Transportation Planning	○
		Freight Rate Management	○

Comment:	Carrier software with focus on tour planning, no real TMS

Table II.39 Overview on transportation solution by Wexlog (Based on Cap Gemini Nederland B.V. 2007)

Vendor :	Wexlog Technologies
Product:	Wex vs tms
Website:	www.wexlog.com

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◕
Number of Employees:	N/A	Status Tracking	◑
		Invoicing	◕
Home Region / Country:	EU / FR	Controlling	◔
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	N/A	Transportation Planning	○
		Freight Rate Management	○

Comment:	Basic TMS suite extending the ERP solution portfolio

Table II.40 Overview on transportation solution by Whitestein (Based on Whitestein 2010; ten Hompel 2006; Cap Gemini Nederland B.V. 2007)

Vendor :	Whitestein Technologies
Product:	LS/ATN
Website:	www.whitestein.com

Turnover:	N/A	**Functional Assessment:**	
Profit:	N/A	Transport Order Management	◔
Number of Employees (2010):	70	Status Tracking	○
		Invoicing	○
Home Region / Country:	EU / DE	Controlling	○
Number of Implementations:	N/A	General Planning Support	○
Number of Users:	N/A	Transportation Planning	◔
		Freight Rate Management	○

Comment:	Tour planning software using advanced optimization algorithms for fleet operators

Appendix III: Determination of Test Data

Deduction of Network Size

Table III.1 Approximation of a consumer goods manufacturer's transportation network

Consumer goods manufacturer turnover for one continent	10,000	mn. EUR p.a.	Approximation from turnover (Unilever 2009; Nestlé 2009b; Kraft Foods Inc. 2008)
Turnover in retail prices	12,500	mn. EUR p.a.	Thonemann et al. (2004), also depicted in Fig. 2.6, p. 22
Operations cost	2,500	mn. EUR p.a.	Thonemann et al. (2004), also depicted in Fig. 2.6, p. 22
Logistics costs	625	mn. EUR p.a.	Thonemann et al. (2004), also depicted in Fig. 2.6, p. 22
Transportation costs	400	mn. EUR p.a.	Grocery Manufacturers Association and IBM (2008b), also depicted in Fig. 2.8, p. 25
Transportation costs per week	8	mn. EUR per week	
Average distance per shipment	500	km	
Costs per FTL km	1.507	EUR/km	717.61 EUR divided by 500 km + 5% Markup for Distance Variation (Stolletz and Stolletz 2008), also depicted in Table I.2, p. 187
Average shipment size	12	tons	
Costs per Ton km	0.132	EUR/(ton km)	+5% markup for load variation
Shipments per week	10,112		
Tons per year	6,067	thsd.	
Pallet places per year	14,156	thsd.	

T. Seiler, *Operative Transportation Planning*, Contributions to Management Science,
DOI 10.1007/978-3-7908-2792-7, © Springer-Verlag Berlin Heidelberg 2012

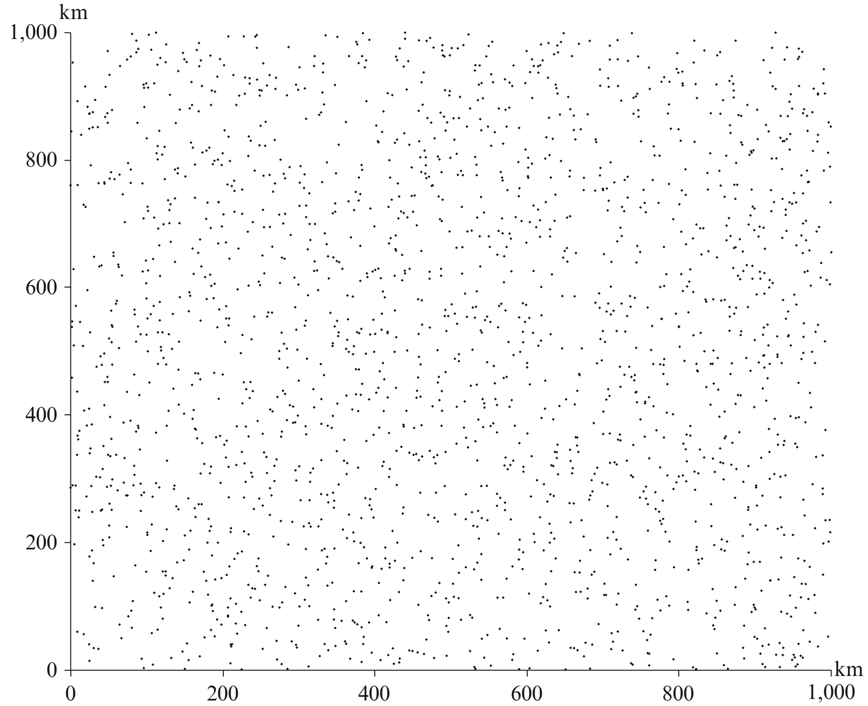

Figure III.1 Randomized distribution of 2,000 locations in a 1,000 × 1,000 km^2 area

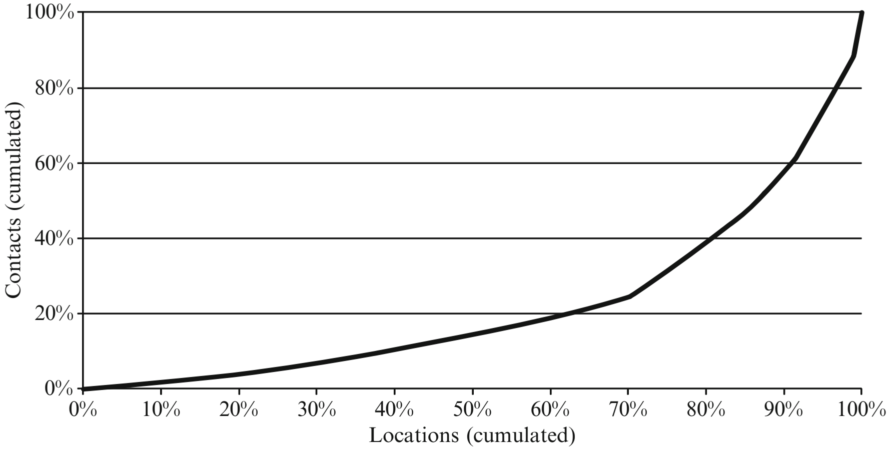

Figure III.2 Distribution of contacts per location

The applied freight rates for the test cases are based on the GVE table of rates (Stolletz and Stolletz 2008). The construction of the applied rates is performed in a two-step manner. First, a distance dependent rate was built based on the GVE input representing standard equipment (single layer trucks) without any form of temperature control. Based on this, markups were chosen to reflect differing rates for different equipment.

Table III.2 Freight rate markups for different truck types and temperature levels

Distance	Single AMB	Single TEM	Single CHD	Double AMB	Double TEM	Double CHD
Until 100 km	100%	122%	128%	108%	128%	132%
Until 200 km	100%	120%	126%	108%	126%	128%
Until 300 km	100%	120%	125%	108%	125%	127%
Until 400 km	100%	119%	125%	108%	125%	126%
Until 500 km	100%	119%	124%	108%	124%	125%
Until 600 km	100%	119%	124%	108%	124%	125%
Until 700 km	100%	119%	124%	108%	124%	125%
Until 800 km	100%	118%	124%	108%	124%	124%
Until 900 km	100%	118%	124%	108%	124%	124%
Until 1000 km	100%	118%	123%	108%	123%	124%
Until 1100 km	100%	118%	123%	108%	123%	124%
Until 1200 km	100%	118%	123%	108%	123%	124%
Until 1300 km	100%	118%	123%	108%	123%	124%
Until 1400 km	100%	118%	123%	108%	123%	124%
Until ∞ km	100%	118%	123%	108%	123%	123%

The basic set of rates was then varied in two steps, one increasing the distance degressivity (distance degression high) and another one decreasing distance degressivity (distance degression low). Therefore, for short distances, the rate with the smallest distance degression is the least expensive one (due to its almost linear shape) and the rate with the highest degression turns out to be the most expensive. For great distances, the highly degressive rate is least expensive while the rate with low degressivity is most expensive — given a fixed distance.

Table III.3 FTL rates featuring different degrees of distance degression

Distance degression medium												
Distance	Single – AMB		Single TEM		Single – CHD		Double – AMB		Double – TEM		Doube – CHD	
	Fixed [EUR/trip]	Variable [EUR/km]	Fixed [EUR/trip]	Variable [EUR/km]	Fixed [EUR/trip]	Variable [EUR/km]	Fixed [EUR/trip]	Variable [EUR/km]	Fixed [EUR/trip]	Variable [EUR/km]	Fixed [EUR/trip]	Variable [EUR/km]
Until 100 km	60.00	1.28	73.20	1.56	76.85	1.64	65.06	1.39	76.85	1.64	78.94	1.68
Until 200 km	21.20	1.67	25.51	2.00	26.72	2.10	22.96	1.80	26.72	2.10	27.22	2.14
Until 300 km	54.02	1.50	64.60	1.80	67.60	1.88	58.46	1.62	67.60	1.88	68.58	1.91
Until 400 km	147.41	1.19	175.60	1.42	183.65	1.48	159.47	1.29	183.65	1.48	185.82	1.50
Until 500 km	250.61	0.93	297.74	1.11	311.25	1.16	271.05	1.01	311.25	1.16	314.40	1.17
Until 600 km	247.96	0.94	294.02	1.11	307.27	1.16	268.14	1.01	307.27	1.16	309.98	1.17
Until 700 km	247.18	0.94	293.09	1.11	306.30	1.16	267.29	1.01	306.30	1.16	309.01	1.17
Until 800 km	310.32	0.85	367.00	1.00	383.36	1.05	335.49	0.92	383.36	1.05	386.09	1.06
Until 900 km	262.16	0.91	310.04	1.07	323.87	1.12	283.42	0.98	323.87	1.12	326.17	1.13
Until 1000 km	280.25	0.89	330.87	1.05	345.52	1.10	302.93	0.96	345.52	1.10	347.59	1.10
Until 1100 km	167.85	1.00	198.17	1.18	206.94	1.23	181.43	1.08	206.94	1.23	208.18	1.24
Until 1200 km	441.42	0.75	520.51	0.89	543.46	0.93	477.09	0.81	543.46	0.93	546.28	0.93
Until 1300 km	246.54	0.91	290.71	1.08	303.53	1.13	266.46	0.99	303.53	1.13	305.10	1.13
Until 1400 km	394.48	0.80	465.16	0.94	485.67	0.99	426.35	0.87	485.67	0.99	488.19	0.99
Until ∞ km	288.64	0.88	339.93	1.03	354.84	1.08	311.92	0.95	354.84	1.08	356.38	1.08
Distance degression high												
Until 100 km	120.00	0.89	146.40	1.09	153.70	1.15	130.12	0.97	153.70	1.15	157.88	1.18
Until 200 km	92.84	1.17	111.72	1.40	117.03	1.47	100.54	1.26	117.03	1.47	119.19	1.50
Until 300 km	115.81	1.05	138.50	1.26	144.94	1.32	125.34	1.14	144.94	1.32	147.02	1.33
Until 400 km	181.19	0.83	215.83	0.99	225.73	1.04	196.02	0.90	225.73	1.04	228.40	1.05
Until 500 km	253.43	0.65	301.08	0.78	314.75	0.81	274.10	0.71	314.75	0.81	317.93	0.82
Until 600 km	251.57	0.66	298.30	0.78	311.74	0.81	272.04	0.71	311.74	0.81	314.50	0.82
Until 700 km	251.03	0.66	297.65	0.78	311.07	0.81	271.45	0.71	311.07	0.81	313.82	0.82

Until 800 km	295.22	0.59	349.14	0.70	364.72	0.73	319.17	0.64	364.72	0.73	367.31	0.74
Until 900 km	261.51	0.64	309.27	0.75	323.07	0.79	282.72	0.69	323.07	0.79	325.37	0.79
Until 1000 km	274.18	0.62	323.69	0.73	338.03	0.77	296.36	0.67	338.03	0.77	340.06	0.77
Until 1100 km	195.50	0.70	230.80	0.83	241.03	0.86	211.31	0.76	241.03	0.86	242.47	0.87
Until 1200 km	386.99	0.53	456.33	0.62	476.45	0.65	418.26	0.57	476.45	0.65	478.92	0.65
Until 1300 km	250.58	0.64	295.47	0.75	308.50	0.79	270.82	0.69	308.50	0.79	310.10	0.79
Until 1400 km	354.14	0.56	417.59	0.66	436.00	0.69	382.75	0.61	436.00	0.69	438.26	0.69
Until ∞ km	286.05	0.61	329.81	0.72	344.28	0.75	302.64	0.66	344.28	0.75	345.77	0.76
Distance degression low												
Until 100 km	20.00	1.32	24.40	1.61	25.62	1.69	21.69	1.43	25.62	1.69	26.31	1.74
Until 200 km	22.20	1.30	26.71	1.56	27.98	1.64	24.04	1.41	27.98	1.64	28.50	1.67
Until 300 km	31.00	1.25	37.07	1.50	38.80	1.57	33.55	1.36	38.80	1.57	39.35	1.59
Until 400 km	37.60	1.23	44.79	1.47	46.84	1.53	40.68	1.33	46.84	1.53	47.40	1.55
Until 500 km	46.40	1.21	55.13	1.44	57.63	1.50	50.18	1.31	57.63	1.50	58.21	1.52
Until 600 km	51.90	1.20	61.54	1.42	64.31	1.49	56.12	1.30	64.31	1.49	64.88	1.50
Until 700 km	58.50	1.19	69.37	1.41	72.49	1.47	63.26	1.28	72.49	1.47	73.13	1.49
Until 800 km	66.20	1.18	78.29	1.39	81.78	1.45	71.57	1.27	81.78	1.45	82.36	1.46
Until 900 km	66.20	1.18	78.29	1.39	81.78	1.45	71.57	1.27	81.78	1.45	82.36	1.46
Until 1000 km	76.10	1.17	89.84	1.38	93.82	1.44	82.26	1.26	93.82	1.44	94.39	1.45
Until 1100 km	76.10	1.17	89.84	1.38	93.82	1.44	82.26	1.26	93.82	1.44	94.39	1.45
Until 1200 km	76.10	1.17	89.73	1.37	93.69	1.44	82.25	1.26	93.69	1.44	94.18	1.44
Until 1300 km	89.30	1.16	105.30	1.36	109.94	1.42	96.52	1.25	109.94	1.42	110.51	1.43
Until 1400 km	89.30	1.16	105.30	1.36	109.94	1.42	96.52	1.25	109.94	1.42	110.51	1.43
Until ∞ km	89.36	1.16	105.17	1.36	109.78	1.42	96.50	1.25	109.78	1.42	110.26	1.43

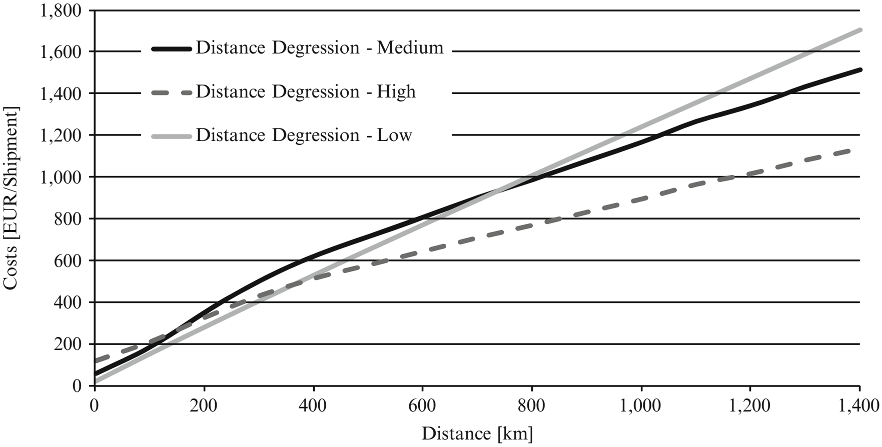

Figure III.3 Different degrees of distance degression

Based on the developed FTL rates, LTL rates are generated. Once again, the basis is a depiction of the GVE suggested rates (Load Degression — Medium), and from there load degression is in one case increased (Load Degression — High) and in another case decreased (Load Degression — Low). The LTL rate is given in a percentage of the FTL rate for the given distance at the necessary resulting truck utilization. The percentage varies for different distances for a very practical reason: For short distances classical LTL services are usually not offered by carriers – the transfer costs to the origin and onwards from the destination, which are the same as for the FTL case, usually dominate the total costs for such a trip. Therefore, these orders can sometimes be served by smaller equipment (literally speaking as an FTL service) resulting in only slightly smaller costs than for the FTL service. For greater distances, in contrast, LTL services will be available only for a fraction of the costs of FTL services due to carrier networks that allow trunk lining with highly utilized equipment. In contrast to above described process for the development of FTL rates, the lower degression type always comes out to be the least expensive rate for a given distance and shipment size.

Table III.4 LTL rates in % of FTL costs featuring different degrees of load degression

Truck utilization Distance	Until 1.5%	Until 3%	Until 4.5%	Until 6%	Until 7.5%	Until 9%	Until 10.5%	Until 12%	Until 13.5%	Until 15%	Until 18.8%	Until 22.5%	Until 30%	Until 37.5%	Until 45%	Until 52.5%	Until 60%	Until 67%	Uuntil 75%	Until 82.5%	Until 90%	Until 100%
Load degression medium																						
Until 100 km	16%	25%	37%	48%	58%	67%	69%	70%	70%	75%	86%	94%	94%	95%	95%	95%	97%	97%	99%	99%	100%	100%
Until 200 km	11%	26%	38%	49%	59%	66%	70%	72%	73%	74%	80%	92%	93%	93%	94%	95%	96%	96%	96%	97%	99%	100%
Until 300 km	9%	22%	33%	42%	49%	56%	59%	61%	62%	64%	70%	80%	83%	83%	86%	89%	91%	93%	96%	98%	98%	100%
Until 400 km	8%	19%	29%	37%	44%	49%	52%	54%	55%	57%	63%	72%	77%	78%	83%	87%	91%	94%	97%	97%	98%	100%
Until 500 km	7%	17%	26%	33%	39%	43%	46%	48%	49%	51%	56%	65%	72%	73%	80%	82%	86%	91%	93%	97%	99%	100%
Until 600 km	6%	15%	23%	29%	34%	38%	41%	42%	44%	45%	50%	58%	65%	66%	73%	74%	79%	86%	92%	98%	99%	100%
Until 700 km	6%	14%	21%	26%	31%	34%	37%	38%	40%	41%	45%	52%	60%	61%	68%	74%	80%	86%	92%	98%	99%	100%
Until 800 km	6%	14%	21%	26%	31%	34%	37%	38%	40%	41%	45%	52%	60%	61%	68%	74%	79%	86%	92%	98%	99%	100%
Until 900 km	6%	14%	21%	26%	31%	34%	37%	38%	40%	41%	45%	52%	60%	61%	68%	74%	79%	86%	92%	98%	99%	100%
Until 1000 km	6%	14%	21%	26%	31%	34%	37%	38%	40%	41%	45%	52%	60%	61%	68%	74%	79%	86%	92%	98%	99%	100%
Until 1100 km	6%	14%	21%	26%	31%	34%	37%	38%	40%	41%	45%	52%	60%	61%	68%	74%	78%	86%	92%	98%	99%	100%
Until 1200 km	6%	14%	21%	26%	31%	34%	37%	38%	40%	41%	45%	52%	60%	61%	68%	74%	77%	86%	92%	98%	99%	100%
Until 1300 km	6%	14%	21%	26%	31%	34%	37%	38%	40%	41%	45%	52%	60%	61%	68%	74%	79%	86%	92%	98%	99%	100%
Until 1400 km	6%	14%	21%	26%	31%	34%	37%	38%	40%	41%	45%	52%	60%	61%	68%	74%	79%	86%	92%	98%	99%	100%
Until ∞ km	6%	14%	21%	26%	31%	34%	37%	38%	40%	41%	45%	52%	60%	61%	68%	74%	80%	86%	92%	98%	99%	100%
Load degression high																						
Until 100 km	60%	70%	75%	80%	85%	90%	91%	92%	93%	94%	95%	96%	97%	98%	99%	100%	100%	100%	100%	100%	100%	100%
Until 200 km	50%	55%	62%	69%	74%	78%	82%	85%	88%	90%	92%	94%	96%	97%	98%	99%	100%	100%	100%	100%	100%	100%
Until 300 km	40%	45%	50%	55%	60%	65%	70%	75%	77%	80%	83%	88%	91%	95%	97%	98%	99%	100%	100%	100%	100%	100%
Until 400 km	30%	35%	40%	43%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	92%	94%	96%	98%	100%	100%	100%	100%
Until 500 km	27%	32%	37%	41%	43%	46%	49%	53%	60%	64%	69%	74%	80%	84%	87%	89%	91%	94%	100%	100%	100%	100%
Until 600 km	27%	32%	37%	40%	42%	46%	49%	53%	59%	63%	68%	73%	79%	83%	86%	88%	91%	94%	100%	100%	100%	100%
Until 700 km	27%	31%	37%	40%	42%	45%	48%	52%	59%	63%	68%	73%	79%	83%	85%	88%	91%	93%	100%	100%	100%	100%
Until 800 km	27%	31%	37%	40%	42%	45%	49%	51%	58%	62%	67%	72%	78%	82%	85%	87%	90%	93%	94%	100%	100%	100%
Until 900 km	27%	31%	37%	39%	42%	44%	47%	51%	58%	62%	67%	72%	78%	82%	84%	87%	90%	93%	94%	100%	100%	100%
Until 1000 km	24%	29%	34%	38%	41%	44%	47%	50%	57%	61%	66%	71%	77%	81%	84%	87%	90%	93%	94%	100%	100%	100%
Until 1100 km	24%	29%	34%	38%	41%	43%	46%	49%	57%	61%	66%	71%	77%	81%	84%	86%	90%	93%	94%	100%	100%	100%
Until 1200 km	24%	28%	34%	37%	40%	42%	46%	49%	56%	60%	65%	70%	76%	80%	83%	86%	89%	92%	94%	99%	100%	100%
Until 1300 km	24%	28%	34%	37%	38%	41%	45%	48%	56%	60%	65%	70%	76%	80%	83%	86%	89%	92%	94%	99%	100%	100%

(continued)

Table III.4 (continued)

Truck utilization Distance	Until 1.5%	Until 3%	Until 4.5%	Until 6%	Until 7.5%	Until 9%	Until 10.5%	Until 12%	Until 13.5%	Until 15%	Until 18.8%	Until 22.5%	Until 30%	Until 37.5%	Until 45%	Until 52.5%	Until 60%	Until 67%	Uuntil 75%	Until 82.5%	Until 90%	Until 100%
Until 1400 km	21%	26%	32%	36%	39%	41%	44%	47%	54%	58%	64%	69%	75%	79%	82%	85%	89%	92%	94%	99%	100%	100%
Until ∞ km	21%	26%	32%	35%	37%	40%	43%	46%	53%	56%	63%	68%	74%	79%	82%	85%	88%	92%	94%	99%	100%	100%
Distance degression low																						
Until 100 km	6%	11%	16%	20%	245	27%	30%	34%	36%	39%	47%	54%	66%	75%	82%	88%	93%	97%	100%	100%	100%	100%
Until 200 km	5%	11%	16%	20%	23%	26%	29%	33%	35%	38%	46%	52%	64%	73%	80%	86%	91%	96%	99%	99%	99%	100%
Until 300 km	5%	11%	15%	19%	23%	25%	29%	32%	34%	37%	44%	51%	63%	72%	79%	85%	90%	94%	98%	98%	99%	100%
Until 400 km	4%	10%	15%	19%	22%	25%	28%	31%	33%	36%	43%	50%	61%	70%	77%	84%	89%	93%	97%	98%	99%	100%
Until 500 km	4%	10%	14%	18%	21%	24%	27%	30%	33%	35%	42%	49%	60%	69%	76%	82%	87%	92%	96%	97%	98%	100%
Until 600 km	3%	10%	14%	17%	21%	23%	26%	29%	32%	34%	41%	47%	58%	67%	74%	81%	86%	91%	95%	96%	98%	100%
Until 700 km	3%	9%	13%	17%	20%	23%	25%	28%	31%	33%	40%	46%	57%	66%	73%	79%	85%	90%	94%	96%	97%	100%
Until 800 km	3%	9%	13%	16%	19%	22%	25%	27%	30%	32%	39%	45%	56%	64%	71%	78%	83%	88%	93%	95%	97%	100%
Until 900 km	3%	9%	12%	16%	19%	21%	24%	26%	29%	31%	38%	44%	54%	63%	70%	76%	82%	87%	92%	94%	97%	100%
Until 1000 km	3%	8%	12%	15%	18%	20%	23%	26%	28%	30%	37%	42%	53%	61%	68%	75%	81%	86%	91%	94%	96%	100%
Until 1100 km	3%	8%	11%	14%	17%	20%	22%	25%	27%	29%	35%	41%	51%	60%	67%	74%	79%	85%	90%	93%	96%	100%
Until 1200 km	3%	8%	11%	14%	17%	19%	21%	24%	26%	28%	34%	40%	50%	58%	65%	72%	78%	84%	89%	92%	95%	100%
Until 1300 km	3%	7%	10%	13%	16%	18%	21%	23%	25%	27%	33%	39%	48%	57%	64%	71%	77%	82%	88%	91%	95%	100%
Until 1400 km	3%	7%	10%	13%	15%	17%	20%	22%	24%	26%	32%	37%	47%	55%	62%	69%	76%	81%	87%	91%	95%	100%
Until ∞ km	3%	7%	10%	12%	15%	17%	19%	21%	23%	25%	31%	36%	45%	54%	61%	68%	74%	80%	86%	90%	94%	100%

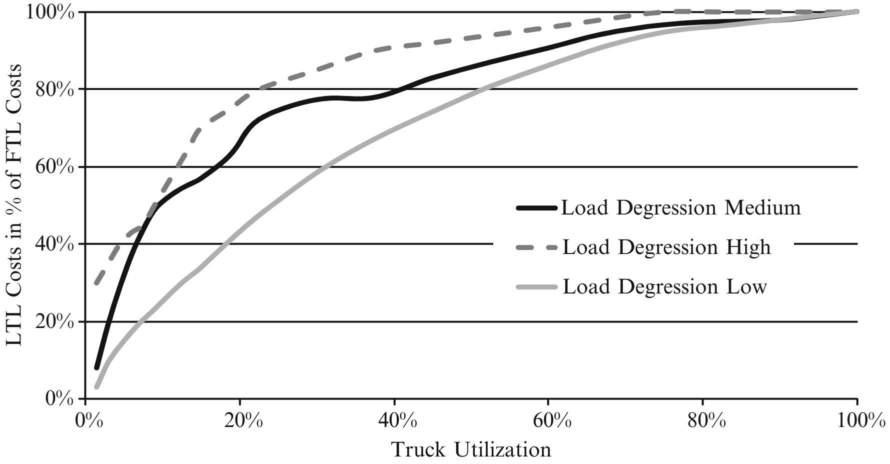

Figure III.4 Different degrees of load degression

Time Windows

The distribution of time window length has taken place in a randomized process. Within this process, time window length had to be adjusted to match transit times in order to generate a realistic pickup and delivery schedule. In this schedule the vast majority of pickup operations take place in the early morning due to regular

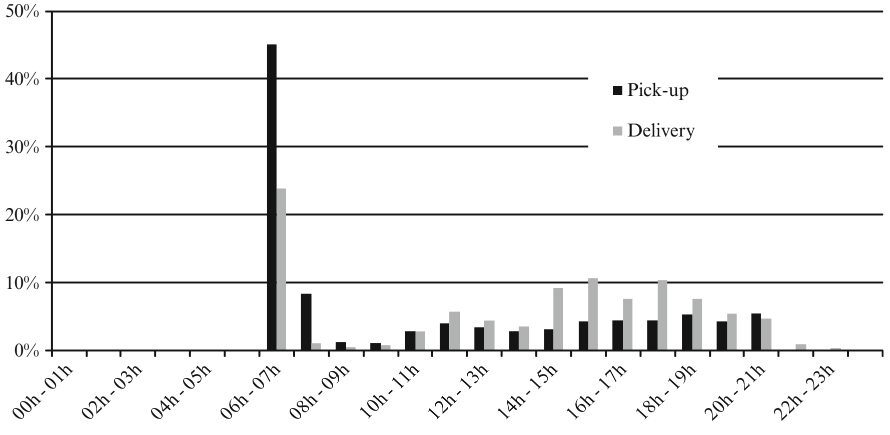

Figure III.5 Distribution of pickup and delivery time windows over 24 h

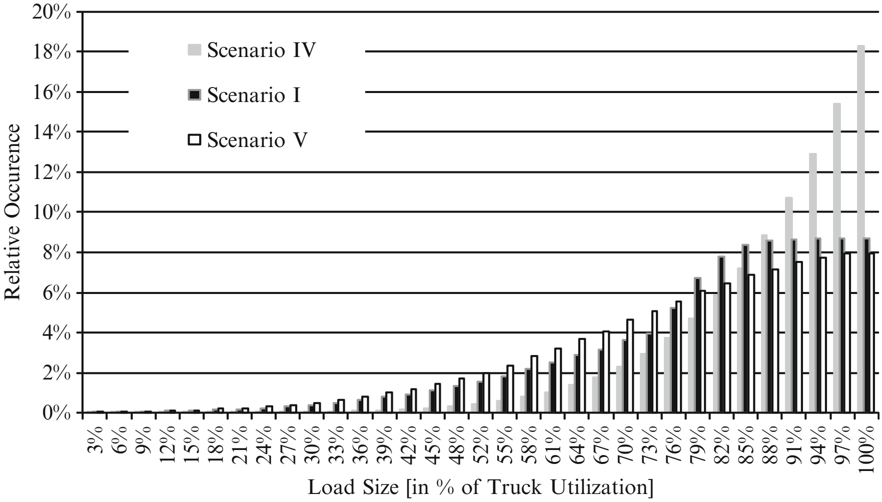

Figure III.6 Load Size variation for Scenarios IV and V

overnight production taking place in most production sites. Early morning deliveries also have their peaks due to overnight transportation. Although overnight production is very common in consumer goods industry, shipping docks are not commonly operated at this time, which is reflected in very limited contacts between 21 h and 06 h.

Shipment Size

In three different scenarios the structure and the distribution of the shipment size has been varied as follows. All three scenarios are characterized by a high overall utilization due to the described case study background; however, the distribution differs between the scenarios. All scenarios are based on a manipulated right skewed Gaussian distribution.

The generation of required pallet places has taken place using randomly generated numbers according to the proposed distribution. In order to generate loading weight W_i (which is expected to have a very strong correlation with the amount of pallet spaces required PS_i), the following formula has been used (z: random number between −0.5 and 0.5 equally distributed):

$$W_i = MAX\left(WC_{p\in P(i)}; 750 * PS_i * (0,4z + 1)\right)$$

Index

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