GOR
PUBLICATIONS

Jörn Schönberger

Operational Freight Carrier Planning

Basic Concepts,
Optimization Models
and Advanced
Memetic Algorithms

Springer

GOR ■ Publications

Titles in the Series

H.-O. Günther and *P. v. Beek* (Eds.)
Advanced Planning and Scheduling
Solutions in Process Industry
VI, 426 pages. 2003. ISBN 3-540-00222-7

Jörn Schönberger

Operational Freight Carrier Planning

Basic Concepts, Optimization Models and Advanced Memetic Algorithms

With 43 Figures
and 24 Tables

Springer

Dr. Jörn Schönberger

University of Bremen
Lehrstuhl für Logistik
Fachbereich 07
Wilhelm-Herbst-Straße 5
28359 Bremen
Germany
E-mail: sberger@logistik.uni-bremen.de

Library of Congress Control Number: 2005922933

ISBN 3-540-25318-1 Springer Berlin Heidelberg New York

Springer is a part of Springer Science+Business Media
springeronline.com

Printed in Germany

Cover design: Erich Kirchner
Production: Helmut Petri
Printing: Strauss Offsetdruck

SPIN 11407584 Printed on acid-free paper – 42/3153 – 5 4 3 2 1 0

Preface

This book represents the compilation of several research approaches on operational freight carrier planning carried out at the Chair of Logistics, University of Bremen. It took nearly three years from the first ideas to the final version, now in your hands. During this time, several persons helped me all the time to keep on going and to re-start when I got stuck in a dead end or when I could not see the wood for the trees. I am deeply indebted to them for their encouragement and comments.

Prof. Dr. Herbert Kopfer, holder of the Chair of Logistics, introduced me into the field of operational transport planning. He motivated and supervised me. Furthermore, he supported me constantly and allowed me to be as free as possible in my research and encouraged me to be as creative as necessary. In addition, I have to thank Prof. Dr. Hans-Dietrich Haasis, Prof. Dr. Martin G. Möhrle and Prof. Dr. Thorsten Poddig.

On behalf of all my colleagues, who supported me in numerous ways, I have to say thank you to Prof. Dr. Dirk C. Mattfeld, Prof. Dr. Christian Bierwirth, Henner Gratz, Prof. Dr. Elmar Erkens, Nadja Shigo and Katrin Dorow. They all helped me even with my most obscure and dubious problems.

My family supported me all the time. They always showed me their trust and encouraged me continuously. Special thanks are dedicated to my parents Monika and Heinz-Jürgen.

However, there is somebody who helped and supported me much more than any other person. It's my beloved wife Ilka. She believes in me more often than I believe in myself. But more importantly, she periodically rescues me from the *jungle of science* and guides my attention to other wonderful aspects of life. Thank you very much.

Bremen,
January 2005

Jörn Schönberger

Contents

1

Transport in Freight Carrier Networks

The division of labor among the continents, countries or regions over the world enables the production of goods in the most efficient manner. Goods are produced at different locations so that the overall costs are minimized. The manufacture of a certain product often concentrates on few places in a region, a country, a continent or even in the world. However, the demand for the products manufactured at certain locations in an economic zone is typically scattered over the complete zone. In order to satisfy this demand with the centrally produced goods, extensive transport is needed. Transport describes the spatial transformation of goods or persons with the goal of balancing supply and demand. The increase of goods transport is accompanied by a significant extension of passenger transport. The movement of manpower to the centralized production facilities becomes necessary and additionally, the enlarged incomes are used for private travel.

In Sect. 1.1 of this chapter, the economic importance of freight transport is explored. Some current trends, from which the demand for a reinforced planning arises, are shown by means of the examples European Union (EU) and United States (US). In Sect. 1.2 the structure of a freight carrier network and the transport processes in such a network are analyzed. Planning problems regarding the design, configuration and deployment of the transport system are discussed in Sect. 1.3. The distribution and collection of freight from providers or suppliers to a consolidation facility, and in the reverse direction, is identified as a very critical phase of the transport and the need for additional planning support is emphasized in Sect. 1.4. The goals and the organization of this thesis are given in Sect. 1.5.

1.1 Recent Trends in Freight Transportation

The commonly used indicator for the performance of the goods transport sector is the amount of realized ton-kilometers (tkm) expressing the product of the quantities moved and the sum of traveled distances. For passenger transport the number of passenger-kilometers (pkm) gives an adequate measure for the quantity of passengers moved and the bridged distances.

From 1990 to 2000, the performance of the transport sector has grown significantly in the US as well as in the EU. For the United States a growth of more than 20% (goods) and 24% (passengers) is reported (Fenn, 2004). The European rates show an increase of 29% for goods and 17% more passengers (Eurostat, 2002).

At the same time, the Gross Domestic Product (GDP) of the US has expanded by 39% (Fenn, 2004) and the EU-GDP has improved by 21% in the observed decade(Eurostat, 2002). The absolute values of the performance indicators have increased from 5.76 billion tkm to 6.93 billion tkm, from 6.23 billion pkm to 7.72 billion pkm (US), from 2.33 billion tkm to 3.08 billion tkm and from 4.041 billion pkm to 4.839 billion pkm (EU).

Different studies forecast a further significant increase in required transport (Eurostat, 2002; Arendt and Achermann, 2002; ICF, 2002). An annual growth of around 3.4% (US) and 3.0% (EU) is expected in the transport of goods. Relative to 2000, a growth of 40% (US) and 34% (EU) in goods transport will be achieved by 2010.

This thesis is about problems in planning the transport of goods, often called freight transport (Crainic and Laporte, 1997). Freight transport is performed by different means of transport: road transport by trucks and vans, rail transport by trains, waterway transport by inland navigation (barges) and vessels and pipeline transport of fluid products. The contributions of each mode (the modal split) have changed during the last decade. In both economies, the contribution of pipeline transport remains on a approximately unchanged level. Waterway transport's part has lost significantly in the US as well as in the EU. Different directions are observed for rail transport: in the US it has grown but in the EU it has declined.

In both economic zones, the main share of the internal freight transport is performed on the roads. Trucks and vans make up 32% of the US-domestic freight transport (Moore, 2002) and 44% of the intra-EU transport of goods (Eurostat, 2002).

The domain of road transport mostly takes place in the short or medium size quantity field with shipments of less than 45 tons and distances of typically not more than 500 km (Eurostat, 2002; Moore, 2002).

Two modes of road transport are performed. In the *own account (AC)* mode, the owner of the vehicles and of the moved goods are identical. Typically, such a company requires transport in order to manage the flow of their goods along their supply chain from the suppliers, through production stages and warehouses to the customers. The contribution of AC transports to the performance of the transport sector in the US has decreased slightly from 28% to 24% (Moore, 2004) in the nineties. A significant performance loss for AC has been observed in the EU-zone. For example, in Germany it has fallen from 42% down to 30%, and in France the value has dropped from 28% down to 18% (Oberhausen, 2003). An increasing number of enterprises outsource their transport departments, basically to reduce their overhead costs. They hire independent logistics service providers to execute the necessary transport. Such a transport company is called a (freight) carrier: it operates in the so-called *hire or reward (HR)* mode. This sector's contribution to the overall performance varies from 50% (in Portugal) to over 76% (in the US) and nearly 90% (in Spain) with an average value of nearly 70%. In both modes, AC and HR, short-distance (max. 50km) and medium-distance transport operations (max. 150km) are the most often demanded services (Oberhausen, 2003) in the EU. In the United States the average haul distance is 730km, all other modes operate at longer average haul lengths (Moore, 2002).

The environmental impacts of road transport are significant: 19% (US) and 24% (EU) of the annual carbon dioxide emission is produced by this mode of transport (Eurostat, 2002; Fenn, 2004). An increase of nearly 16% (US) and 20% (EU) during the nineties of the last century has been observed. Besides the emissions, several other negative impacts to the environment are observed: intensified traffic congestion lowers the performance of the road transport, large surfaces are sealed by roads, parking lots and transshipment areas and noise emissions lower the quality of residential areas. Regulations and laws have been announced in order to alleviate the pollution and to maintain several standards of life quality (European Commission, 2001).

For the EU some additional current developments are observed which are expected to have significant impacts on road transport and the companies involved.

The transport enterprises in the current EU member countries expect the complete integration of the accession countries, e.g. Poland or the Czech Republic. These new competitors can offer lower transport costs since their labor costs are low and the regulations are not as restrictive as the laws in the current full member countries of the EU. The low cost structure in the pre-accession countries will lead to a new wave of competitors intruding onto the EU transport market. Therefore, the existing transport sector in the current EU now has to improve the efficiency of their business.

Roads are free of charge in most EU countries. The construction and maintenance of the expressways, highways and other roads is under the responsibility of public authorities. For some special connections (typically including large bridges or tunnels) the payment of a toll is required. Recently, several member countries like Germany, Austria and the Netherlands announced their intention to establish a toll system for using their national roads, and in most of the pre-accession countries road pricing has been established for years. The consideration of this additional kind of costs cannot be avoided in the future. The public authorities are not able anymore to provide the necessary funding in inter-urban transport infrastructure (roads, bridges, tunnels). Private investors are sought for funding, constructing and maintaining these facilities. They are allowed to collect a toll from the users.

Several urban governments (e.g. such as the municipality of the City of London, UK) have recently either introduced or plan to introduce a toll for driving on the urban roads. The urban-toll has been introduced mainly for the reason of preventing traffic congestion caused by private road transport with the goal of improving the speed of business transport in the urban areas (Nash and Niskanen, 2003).

As mentioned above, road transport is an important player in the US and European economy with a significant contribution to the overall performance of the economic zone. However, it is faced with several challenges in the near future, which make it unconditionally necessary to strive for an improvement in the efficiency of the freight transport operations on the roads. Carrier companies, which only operate in HR-mode, will be most affected by the challenges due to the increasing importance of road transport in the United States and in the EU, and their unconditional need of external customers.

1.2 Carrier Transport Networks

A customer request describes a single transport demand. The location of the pickup and the location of the delivery are specified as well as the quantity to be moved. Typically, additional requirements like time limits for the loading or unloading operation or special handling requirements are stipulated. A transport department or a carrier company derives internal processes from the requests in order to satisfy the customer demands using the available resources in an efficient manner. Several independent requests with coinciding or adjacent origins and coinciding or adjacent destinations are bundled to shipments or truckloads of larger quantity. A significant decrease of the relative price for the movement of one single request is achieved, because overhead costs are split into small amounts that are assigned to each request. The realization of maximum economies of scale requires consolidation processes, which both support as well as depend upon the operation mode of a transport company.

Firstly, the AC-mode is analyzed. This mode is typically selected for the distribution of finished goods in industrial productions. From a small number of factories, large quantities of different goods are moved over relatively long distances to regional distribution centers (DCs) in order to replenish the DCs with goods. From a DC, the goods are distributed to customers, who are situated relatively near to the DC. Typically, the distance from a DC to a customer is less than 100 km, whereas the distance between a production facility and a DC is often more than several 100 km. The links between the production facilities, DCs and the customers defines a distribution network. In a distribution network, the flow of goods is uni-directional from few sources (the production facilities) to many sinks (the customers). Since the quantities moved for replenishment are large, this network topology supports the realization of economies of scale. In Fig. 1.1, a distribution network with two production facilities F_1 and F_2 is shown. These two factories produce goods that are used to replenish the three distribution centers DC_1, DC_2 and DC_3. Each customer is assigned to one of the DC from which he is supplied. The traveled distance and the moved quantities in the distribution are different from those observed in the replenishment. In distribution tasks, the distances to travel are significantly reduced and the quantities moved along a link are significantly smaller.

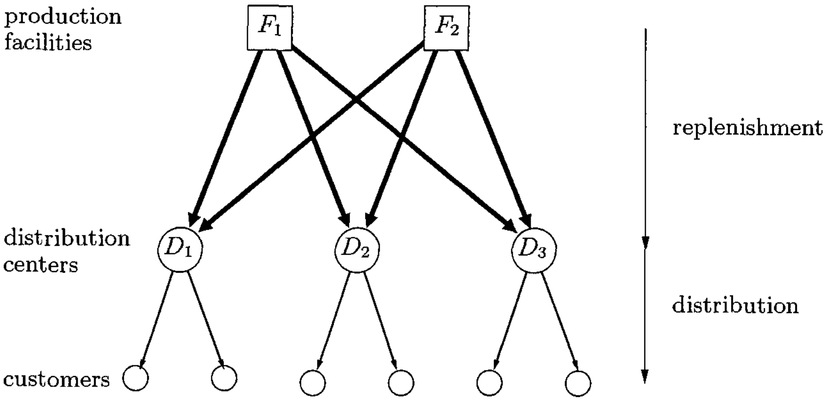

Fig. 1.1. Structure of a distribution network

The strict uni-directional flow of goods from the factories to the DCs or customers leads to an inefficient use of the deployed vehicles. They drive fully loaded from the production facilities to the DCs, from a DC to customers or directly from the factory to a customer (if enough load is available). However, they have to travel back to the DC or production facilities. If no back-freight is available, which is carried on the way back to the DC or to the production facility, half of the traveled distance consists of empty miles.

Often, the transport of finished goods cannot be combined with back-freights flowing in the reverse direction. National laws in several countries (e.g. Germany) do not allow vehicles operating in the AC-mode to transport goods that are owned by another company. In order to use the existing network and equipment also for moving goods of third parties, several manufacturing enterprises decided to outsource their distribution systems and let them operate (at own responsibility) as freight carriers in the HR-mode.

A freight carrier transports goods for different customer companies. Particular batches of different customers are combined in one vehicle if the origins and the destinations match. A vehicle of a carrier picks up goods of one customer at a certain place and moves it either directly to the final destination or with intermediate loading, unloading or transshipment stops belonging to other requests. Afterwards, it continues to a new pickup location situated near the destination of the former transport task and loads new goods that are then moved towards the specified destination.

Typically, a carrier company operates for several customers. The flow of the goods is not limited to a small number of relations and it is not unidirectional, but rather bi-directional (Fleischmann, 1998). There are many sources and many sinks of flow spread over the whole operational area. The quantity of goods associated to a certain pair of origin and destination is small, and the particular flows are numerous. Long-distance transport demands and medium-distance demands must be satisfied as well as short-distance bridging. Exclusive origin-destination transport is typically not achievable (Trip and Bontekoning, 2002). Due to the small quantities of particular requests, an efficient consolidation strategy is necessary in order to reduce the part of the overhead costs that have to be assigned to each single request. The consolidation of small flows from a huge number of locations into large long-distance flows has to be supported as well as the deconsolidation into flows to the particular customer destinations.

Therefore, the operations area of a carrier is hierarchically organized and the origin-to-destination transport process is partitioned in sub-processes according to the partition of the area. Few large regions form the operations area, and each region is divided into several small zones. A hierarchically organized network of transshipment facilities and connections between these facilities is maintained. The network structure permits a successive aggregation of flows from customer origins into high quantity flows and a subsequent resolution from bundled flows into deliveries to the several destinations. Whenever a single transport demand requires the crossing of an organizational border, the goods of a request are combined with goods of other requests or extracted from a large volume flow.

Transport between different regions takes place only between hubs (H). A hub is a transshipment facility where all inbound flows from other regions are received and where all outbound flows are released. In each region, the hub receives the goods from different transshipment points (TP) situated in the zones and forwards incoming goods into the right destination zones. In each zone, the goods are distributed from the TP to the customer locations by vehicles within several tours. The same vehicles are used to collect goods from customer locations. These goods are delivered to the destinations in the same tour if the location is situated in the same zone. Otherwise, they are brought to the TP, where they are merged with other collected goods and forwarded to the regional hub. A typical layout of such a hierarchically structured freight transport network is given in Fig. 1.2. The overall operations area is partitioned into four regions. The thin continuous lines mark the borders. In each region one hub (H_1, H_2, H_3 and H_4) is available. All extra-regional flows of goods out of a region are realized through this transshipment facility as well as all inbound flows. Each region is separated into several zones. Their borders are given by the thin dotted lines. In each zone one TP is maintained where the goods flowing out of the zone are bundled and forwarded and where the

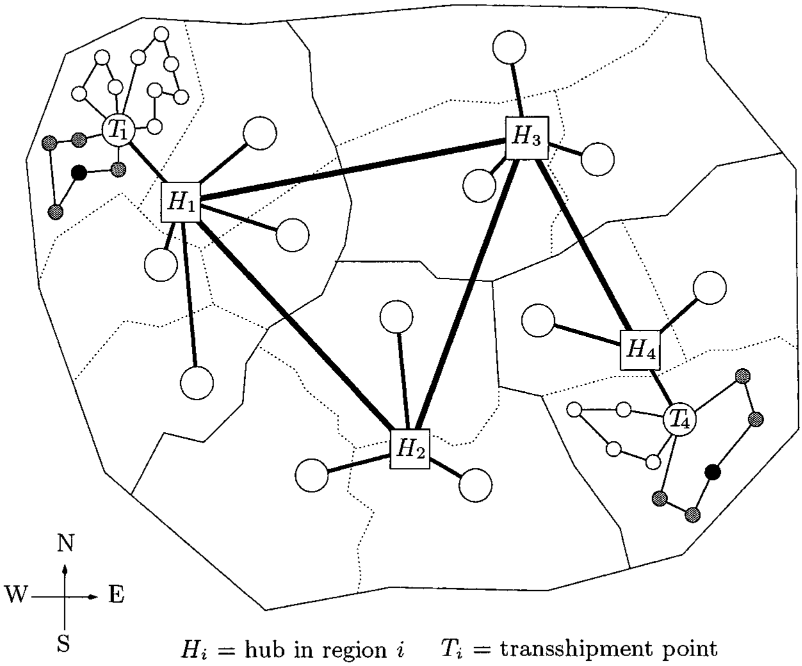

Fig. 1.2. Hierarchical network structure of a carrier network

flow of goods destined for this particular zone is received. The distance from the customer location to a TP in a zone is typically less than the distance between the TP and the corresponding regional hub. However, the distance between the hubs often causes the main part of the distance necessary for moving a packet from its origin to its destination.

The hierarchically organization is typical for a freight transport network operated by a carrier. It permits the economically reasonable service of geographically scattered locations with averagely low flow between particular origins and destinations (Fleischmann, 1998). However, the described original structure is often modified adapted to meet the special requirements (Wlcek, 1998). A hub serves as the TP for a zone or a complete region, if the quantity of the flow of goods does not require the strong tree structure in a region. Direct origin-to-destination shipments among different regions or zones are offered in the event that the quantity of goods to be moved and the associated revenues are sufficiently large.

In the following, the transport process for carrying the less-than-truckload (LTL) packet p_r of the request r is analyzed in detail. Figure 1.3 shows the five phases of the process from an origin $\mathcal{O}$ to the destination $\mathcal{D}$.

Initially, the packet p_r is collected. This phase is called *collection*. Typically, a vehicle of small or medium capacity is deployed for the fulfilment of this task. This vehicle collects packets from several requests with origins in one selected zone and carries them to the transshipment point (TP) of the zone. A TP is a special facility, in which the packets of a zone, collected by several vehicles, are consolidated into larger quantities (*truckloads*). A truckload consists of all quantities belonging to requests originating out of a *zone* with destinations in zones embedded in different regions. Requests in which both the origin and the destination are included in the same zone are served without involving a TP.

In the *forward feeding* phase, the truckload is carried from the TP of the origin zone to the regional hub. All truckloads of a region arrive synchronized at this large and high-performance transshipment facility (Fleischmann, 1998). In contrast to a TP, incoming and outgoing goods are merged while passing a hub. Bundled truckloads from different TPs are resolved before the packets are re-consolidated into shipments so that all packets in a shipment have to be carried to customer locations in the same destination region.

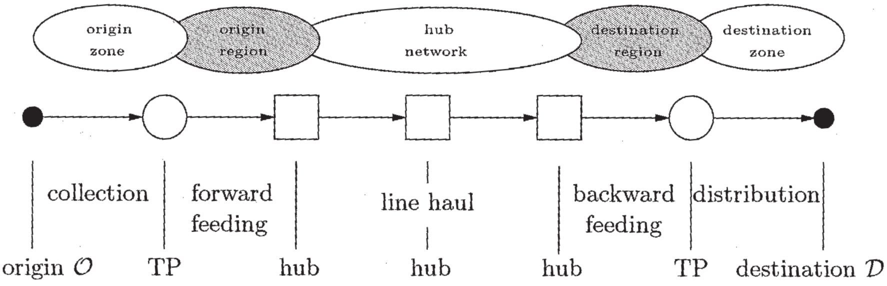

Fig. 1.3. Process-chain of an origin-destination carrier transport

The complete shipment containing p_r is now carried to the hub of the destination region, which includes the final customer location. If the hubs are fully connected, then no intermediate stop at any other hub is necessary because there is a direct connection between each two hubs. Otherwise the shipment is moved to one or several intermediate hubs, reconsolidated if necessary, and then finally transferred to the hub of the destination region. In this *line haul* phase (Daganzo, 1999), large distances are traveled. The means of transport is often different to those in the previous phases. Since the flow of goods is continuous and of balanced quantity, the inter-hub connections are often served in a regular way following a fixed schedule (Crainic, 2000). For this reason, it is necessary that the feeder transport schedule be synchronized with the departures from the hub. All feeder truckloads should arrive in time so that they can be considered for the inter-hub transport departures. A synchronized arrival enables the most effective re-consolidation of the incoming truckloads from other hubs and from the TPs.

At the destination hub, the shipment containing p_r is resolved and merged with other incoming shipments into truckloads, so that each truckload comprises packets for different customers who are situated in the same distribution zone of the considered region. Each truckload is transported to the TP of the corresponding zone. This phase is denoted as *backward feeding*.

At the TP of the zone, which contains the destination of r, the truckload is broken into the packets and the packets are distributed to the customers that are situated scattered over the *destination zone*. Delivering p_r to the customer specified delivery location completes the request r.

The first two phases of the transport process are subsumed under the name *pickup* and the last two phases are referred to as *delivery*. The pickup in an origin region is typically combined with the delivery of back-freight destined for this region. Thereby, the flows of goods in both directions are combined in an effective and efficient way.

The correspondence of the five-phase transport process and the hierarchically organized network is shown by means of a transport of a packet from a customer situated at the small black point in the north-western zone to the location marked by the small black point in the south-eastern zone in Fig. 1.2. A vehicle following the route that visits all customer locations in the origin zone, shaded in grey, picks up the considered packet. At T_1, the TP of the origin zone, the packet is consolidated with all other packets originating from this zone into a truckload and it is fed to the regional hub H_1. With an intermediate stop at H_3, the packet is carried to H_4, the hub in the destination region. There, it is transshipped and fed to T_4, the TP in the destination zone. From T_4 it is delivered on the route visiting all grey shaded locations, including the particular delivery site.

1.3 Network Design, Configuration and Deployment

The construction, the management and the usage of an effective and efficient freight carrier transport network require the solution of numerous often interdependent decision problems.

Logistics System Design. The design of a freight transportation network affects several problems related to the location and the layout of the network components such as the TPs, hubs or traffic routes. Three main classes of design problems are distinguished (Crainic and Laporte, 1997):

- How many hubs and TPs are needed? Where should they be installed? How large should they be? (*location and layout*)
- How should the hubs and TPs be linked? Which means of transport should be used for the connections? How should the flow of goods be distributed over the connections between the hubs? (*network design*)
- How can the network be protected against disadvantageous external influences and evolutions arising from infrastructure modifications, the evolu-

tion of demand and from new governmental or industrial policies? (*regional multi modal planning*)

Network design problems are strategic. The necessary funding and the necessary time for the construction or modification of an existing infrastructure do not allow short or medium-time changes. Design problems are solved using estimated data expressing the expected flows of goods. The decision for a certain network architecture is based upon the costs for installing, maintaining and using the facilities and the traffic links between them.

Logistics System Configuration comprises three main mid-term planning categories (Crainic, 2000): service selection, traffic distribution and terminal policies. A service describes a repeated transport operation connecting hubs or hubs and TPs. In a service selection problem, the offered services in a network are determined. Typically, the repetition of a service follows a regular schedule. The departure and the arrival times at the first, the last and the intermediate stops are defined and announced. The necessary work power and transport capacity to offer the intended services is procured.

Several services are compiled into closed routes (itineraries). For each itinerary, a vehicle is allocated and the corresponding necessary terminal operations are fixed. Services are determined only for connections of hubs with TPs or other hubs. The derived schedule is valid for up to several months in the future, but exact long-term planning data are not available. The quantities of goods have to be estimated, e.g. based on observations from the past. However, reliable estimates need reliable input data, which is typically available only for the feeder or line haul connections. The consolidation of packets from the customers ensures a predictable and balanced flow of goods between the hubs.

A terminal policy describes the offered activities at a given hub or TP. The type of performed consolidation tasks at a certain hub or TP is specified and defines the available throughput that can be handled. Additional resources have to be maintained in order to compensate for peaks in the demanded services.

Logistics System Configuration aims at establishing services that allow efficient operations to answer customer demands and to ensure the profitability of the operations (Crainic, 2003). Efficiency is typically measured in terms of costs for fulfilling the customer demands at a predicted quality that allows the customers to maintain complex and reliable production systems (Rodrigue, 1999).

Logistics System Deployment comprises short-term planning problems in a freight carrier network. In contrast to the design and configuration of the network, deployment decisions are mainly based on known problem data. These data are derived from the known or declared flows of goods extracted from the customer demands. The goal is to allocate labor and capacities in order to support the efficient fulfilment of known customer demands with respect to the policies and services determined in the configuration step. These planning problems are solved following the rolling horizon planning paradigm in order to handle the continuously updated information about additional, cancelled or modified customer requests. The necessary operations for the next period are definitively determined together with a tentative determination of the operations planned for the subsequent planning periods. The following short-term planning problems occur (Crainic and Laporte, 1997):

- Assignment of crews, reserve crews or maintenance teams to vehicles or transshipment facilities in order to support the planned operations (*crew scheduling*)
- Preparation of the operations for the next planning period (*empty balancing*)
- Scheduling of the services for the pickup and the delivery phases (*vehicle routing and scheduling*)

Logistics System Deployment mainly impacts the short-term planning of pickup and delivery operations. The operations during the long haul phase are determined by the valid regular schedules. For two reasons the determination of a long-term schedule for the pickup and the delivery operations is not achievable:

1. The locations that have to be visited are typically not known in advance.
2. There is no balanced flow of goods that permits the prediction of necessary services and/or necessary capacities in a zone.

The costs for the operations in the first and in the last phase of the carrier transport process are, expressed in terms of money units per tkm, the most expensive part in the complete transport from the pickup location to the final delivery location. Herry (2001) states that the costs per tkm in short-distance transport are at least three times larger than the costs per tkm in the middle or long distance case. The reason for this extreme increase of the costs can be seen in the relatively small quantities that are delivered or picked up at a customer site stop, and in the lack of consolidation options due to the scattered locations of customer sites that requires a visit. Furthermore, the unconditional need for the consideration of tight time windows for the pickup and the delivery visits confines the realization of economies of scale that are otherwise achieved by the bundling of several requests (Punakivi et al., 2001). The consideration of time windows is necessary in order to synchronize the transport processes performed by the carrier company with the internal processes of the customers.

1.4 Distribution and Collection Planning

Each customer request is split into five internal requests according to the subprocesses described in Sect. 1.2. A collection task is necessary to carry the