Serieuze mensen schrijven niet, zeker niet over serieuze zaken.
Plato (vrij vertaald uit 7^{e} brief, 344$^{c\ 1\text{-}3}$, 353/352 v. Chr.)

Διὸ δὴ πᾶς ἀνὴρ σπουδαῖος τῶν
ὄντως σπουδαίων πέρι πολλοῦ
δεῖ μὴ γράψασ ποτὲ ἐν ἀνθρώποις
εἰς φθόνον καὶ ἀπορίαν καταβαλη.

Preface

The subject of this thesis is highly relevant to many business managers today. Most certainly in the Netherlands (synonymous for distribution land) where it is on the agenda of many boards of directors. Borders that are disappearing, development of global markets, increasing demand for flexible services, shifting competitive positions, growing impact of information technology - these are but a few of the ingredients of a highly complex matter. Add to that the decision-making procedures that are often far from simple but must lead to sound decisions of which the impact in time and money is often all but insignificant.
It is clear there is plenty of food for thought here.
The unique character of this thesis is that it not only presents a theoretical framework for approaching this matter. A sound and carefully thought-out mathematical base provides a reliable set of instruments. At the same time, the presented approach is full of the pragmatism which is the result of the issue having been addressed so often in practice. That did not only occur in the environments of trade and industry with their traditional focus on logistical optimization. It also occurred at financial institutions and in the service sector where the whole range of tools proved applicable. BSO/Advies, the consultancy organization of BSO/Origin, that specializes in matters of strategy, organization and information technology, was able to advise in a number of situations for which it was happy to be able to make use of the knowledge and

experience of Lorike Hagdorn. It is exactly the goal of providing practical advice that makes the approach presented here so useful.
Over the past few years, it was a pleasure for many colleagues at BSO/Origin to work together with the author of this thesis. Many inspiring discussions on logistics issues had a valuable effect on the eventual proposals and implementations. It is therefor with great pleasure that I have agreed to writing the preface to this publication.

Drs A. Kornaat
Managing Partner Consulting group, Origin/IT Services Netherlands
March 1996

DECISION SUPPORT
for Strategic Planning in Logistics
— concepts, tools and applications —

BESLISSINGSONDERSTEUNING
voor Strategische Planning in de Logistiek
— concepten, hulpmiddelen en toepassingen —

Proefschrift ter verkrijging van de graad van doctor
aan de Erasmus Universiteit Rotterdam, op gezag van
de Rector Magnificus Prof. dr P.W.C. Akkermans M.A.
en volgens besluit van het College voor Promoties.

De openbare verdediging zal plaatsvinden op
donderdag 9 mei 1996 om 16.00 uur

door

LORIKE HAGDORN-VAN DER MEIJDEN
geboren te 's Gravenhage.

PROMOTIE-COMMISSIE

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Prof. dr ir J.J.M. Evers
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Acknowledgements

This thesis deals with strategic planning in logistics and more particularly with the design of logistics networks. It was completed at the Rotterdam School of Management at the Erasmus University, Rotterdam, under the supervision of Professor Jo van Nunen.

After working for several years in projects on strategic planning in logistics for a number of national and international firms, I needed the challenge of translating this experience into a structured and validated method. I sincerely hope that the results presented in this thesis will contribute to the effectiveness and the efficiency of future projects in strategic planning in logistics.
The pleasant and fruitful cooperation with the people involved in the consulting projects in which I participated added much to my enthusiasm for the topic of this thesis.

Jo van Nunen not only supervised my thesis. When I was still one of his students, he picked me for a research assistant post in Business Administration. It was he who, a few years later, encouraged me to leave my academic pursuits to deal with problems in 'real-life' situations; it was also he who encouraged my subsequent return to university to write my doctoral thesis. His innovative and critical views have always been a strong support to me.

Dear Jo, I enjoyed our discussions, both professional and personal, and I hope we will continue to work together for many years. Thank you for all the support you gave me.
Dear Marleen, thank you for your hospitality and for all the hours with Jo you gave up for me.

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To my colleague Leo Kroon, I would like to express my appreciation for his companionship and his cooperation, especially on the quantitative aspects of this thesis. I hope we will have the opportunity to further explore the significance of the results presented in this thesis in the near future.

Peter Boumans, Diederic van Wanrooij, Michael van Wetering and Marianne Wigmans assisted in designing and building the DSS SLAM, which played an important role in the research. Moreover, they were always ready to help whenever a hardware or software problem arose. Thank you for all the work you have done.

Kees Broekhof, linguistic editor, and Brenda Renssen, designer, worked many hours under high time pressure to polish the final draft of this thesis. Dear Kees and Brenda, thank you both for your dedication, your conscientiousness and your creative contributions.

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Furthermore, I thank my colleagues of the Rotterdam School of Management, especially those in the department of decision and information sciences, and my colleagues of Origin for the pleasant working atmosphere they have provided. Together they create the opportunity for me to do research in business administration and at the same time to investigate the real-life problems companies are having to deal with in practical situations.

Many colleagues and friends have supported me in many different ways. Although not all are mentioned by name, I am indebted to all for encouraging me to complete this thesis and for accepting my absence from some meetings and social gatherings.

I could never have managed to be absent from home so often, without the wonderful manner in which Letty Hulst took charge of the care of Ties and Ewout and of our household. For this, I owe her a particular debt of gratitude.

It was the foundations laid by my parents and my sister Marinke that fostered the attitude of mind and the skills required for conducting research and writing a thesis: patience, perseverance, discipline and precision.
Dear mom and dad, dear Rink, thank you for the solid basis you gave me.

Although many people contributed to this dissertation, my major source of inspiration and energy were - and are - my 'three men': my husband Adriaan and our twin-sons Ties and Ewout.

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Dear Daan, thank you for all those cups of coffee you brought me, for changing all those diapers and most of all for your inspiring role in my life, your patience, support, friendship and love.
Dear Ties and Ewout, thank you both for being there and showing us how rich life is.

Rotterdam, March 1996

Lorike Hagdorn

Lorike Hagdorn - van der Meijden

Comments, suggestions and questions concerning this thesis are welcomed. Kindly send them to:

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Summary

Decision Support for Strategic Planning in Logistics
- concepts, tools and applications -

This thesis is concerned with the analysis and design of logistics networks for industrial firms. A logistics network is comprised of suppliers, plants and warehouses which, by a systematic transfer of raw materials, semi-finished and finished products, accomplish the delivery of the final product to the customer at the right time and in the right place.

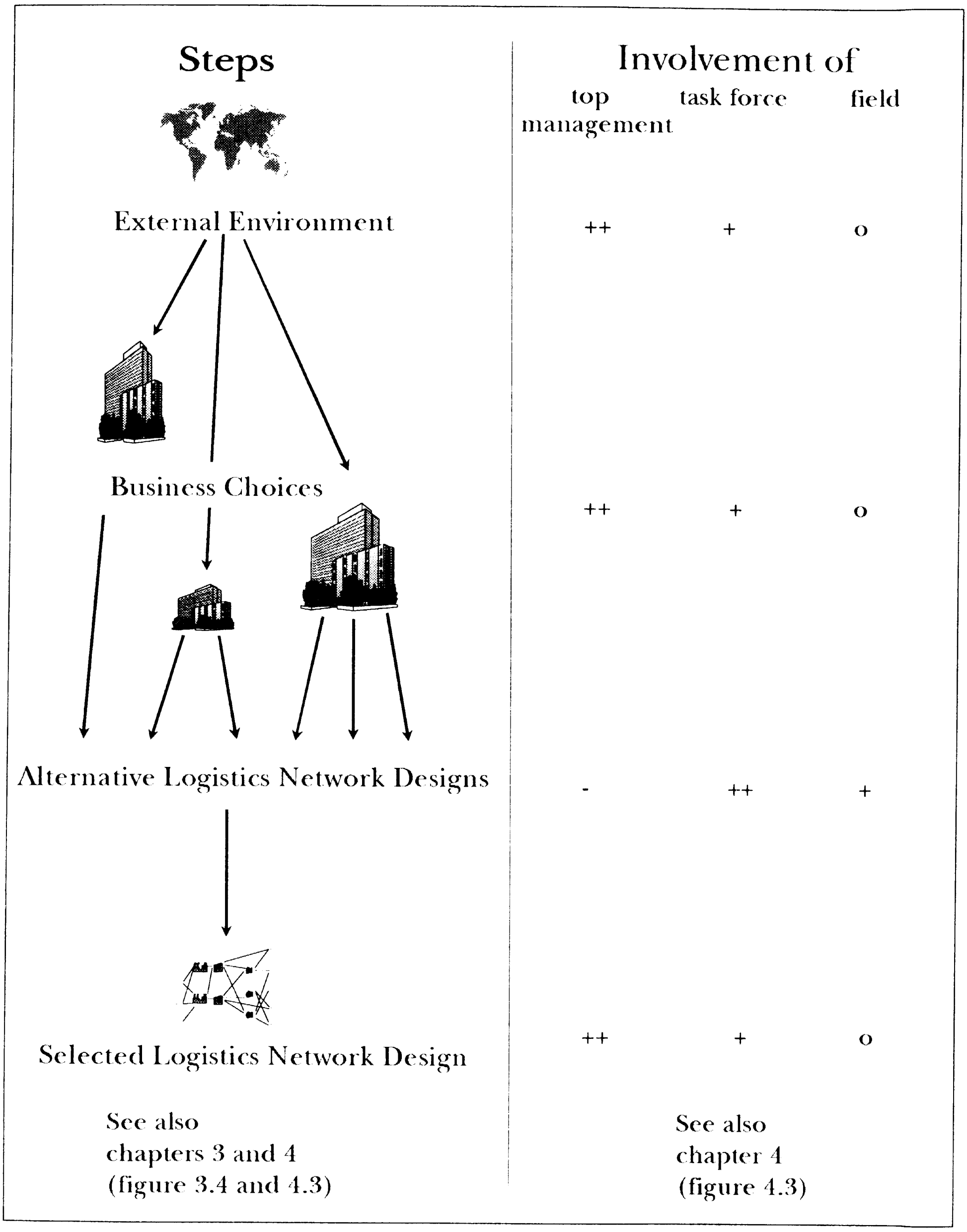
In the turbulent environment of today, in which new markets are emerging and customers are asking for high quality products, produced according to customer specifications and delivered within short lead-times with high reliability; in which technologies are evolving fast; and in which environmental issues cannot be ignored, companies are looking for new opportunities to enhance their competitive advantage. In this context, a major contribution can be made by a logistics network that provides flexibility under rapidly changing circumstances and that enables swift delivery of products at the lowest possible cost.
This takes us to the central problem of this thesis: *"How to design a competitive logistics network for a specific industrial company?"* In addressing this question, special attention is paid to the selection of the locations, the number and size of plants and warehouses, the choice

of suppliers and the product flows from suppliers via plants and warehouses to the customers.
The author has practical experience with several cases in which this strategic and complex decision problem had to be solved. On the basis of this experience, a case of a fictitious company is described in chapter 2.

In logistics network design processes, often a large number of alternatives is developed, analyzed and compared. In selecting the most appropriate logistics network a wide range of quantitative and qualitative decision criteria play a role. Moreover, a large number of company divisions and individual staff with differing functional backgrounds are involved in the decision-making process. This results in a complicated and often time-consuming process with many interruptions and feedback delays.
The aim of this thesis is to make this complexity manageable and, thus, to enhance the efficiency and the effectiveness of the decision-making process, which should ultimately result in improved logistics networks. To this end, a framework is developed for designing logistics networks. In this framework, the often applied concept of scenario planning (chapter 3) is refined and strengthened by integrating it with the use of a Decision Support System (SLAM) in which a quantitative optimisation (MILP) model is incorporated (chapters 2 and 4). Also an analysis is made of the stages in the decision-making process and the roles played by the different participants. The framework is described in general terms and applied to two real-life situations (chapter 4). Figure 1 presents a simplified overview of the framework.

In view of the strategic importance of the logistics network, the initiative for redesigning the existing network is usually taken by a company's top management. Often a project team (or 'task force') is established to develop alternative logistics networks and to communicate and co-ordinate this process with other internal and external parties involved. The first step in the framework consists of analyzing relevant developments and uncertainties in the external environment. These are divided into four categories: market developments; technological developments; new organizational methods and techniques; and developments in the labour market. The values of these external factors are combined into consistent sets. Each set of consistent values represents a view of the future and is defined as an external scenario. The top management team and the task force are particularly involved in the development of external scenarios, but often experts from company divisions or from outside the company are also asked to bring in their specific know-how.

The external scenarios provide the basis for the top management's strategic choices concerning the logistics network. The task force supports the management team by elaborating these choices into alternative company scenarios. These are sets of mutually consistent values of company factors, which are related to the external factors and which can also be classified into four categories: entrepreneurial elements, technological elements, administrative elements and human resource elements in the logistics network.
In practice sometimes a many as 20 external scenarios are selected as a starting point for company scenarios. On the basis of each external scenario, several company scenarios are developed, which may result in over 60 alternative company scenarios. Each company scenario includes an outline of the corresponding logistics network is outlined. A valuable tool in the development of such large numbers of logistics networks is SLAM. Starting from the strategic choices made with respect to the market, products and service levels, SLAM calculates a logistics network that fulfils the market requirements against lowest possible variable logistics costs.



Steps	top management	task force	field
External Environment	++	+	o
Business Choices	++	+	o
Alternative Logistics Network Designs	-	++	+
Selected Logistics Network Design	++	+	o

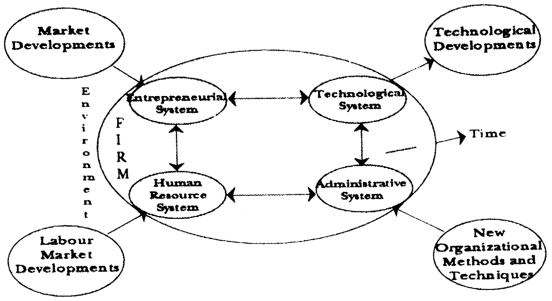
See also
chapters 3 and 4
(figure 3.4 and 4.3)

See also
chapter 4
(figure 4.3)

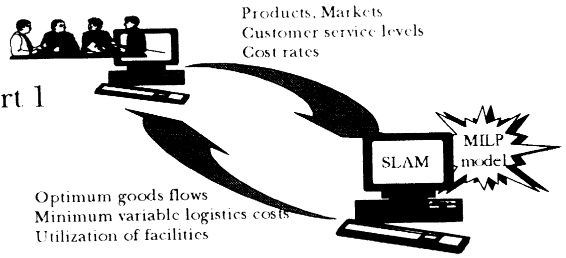
Figure 1: Overview of the framework and the corresponding concepts

Concepts and Tools

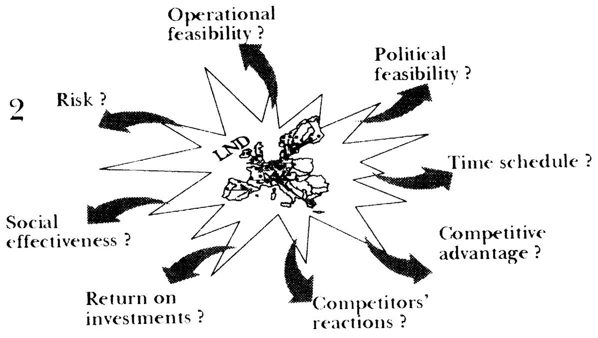
External scenarios



Company scenarios, part 1



Company scenarios, part 2



See also
chapters 3
(figure 3.4)

See also
chapter 3 (figure 3.2)
chapters 2 and 3 (figure 3.6)
chapter 4 (figure 4.4)

and tools for the design of a logistics network.

This part of the development of company scenarios is usually coordinated by the task force, which cooperates with the business units. SLAM proves its added value by swiftly providing insight into the consequences of changes in the logistics network for the logistics costs, the customer service level and the utilization of plants and warehouses.
Groups of four, five of six alternative logistics networks are analyzed and evaluated in terms of financial aspects, operational feasibility, time schedule for reorganization, staffing consequences, political feasibility and their flexibility to adapt to changing external circumstances. These analyses show the competitive advantage of each of the alternative logistics networks.
Finally, a selection of the two, tree or four most promising logistics networks is presented to the top management team, which makes the final choice. The logistics network that is selected is often one that produces satisfactory results under most external scenarios.
During the process from external scenario to logistics network, it is not uncommon to return to a previous phase in the framework, for instance to elaborate a particular external trend in greater detail or to reconsider a particular market strategy. The framework helps structure this stepwise process.

The framework is not only useful for large-scale restructuring processes, involving a complete redesign of a company's logistics network; it can also be used for the regular evaluation of the existing network and the elaboration of small adjustments to the logistics network. In these projects, SLAM is particularly a powerful tool.

Redesigning a logistics network requires large quantities of data concerning markets, products, costs, etc. Often it is a very time-consuming process to gather these data at a detailed level. Moreover, in many situations detailed data are not desirable. In these cases, often use is

made of aggregated data, especially where the input data for SLAM are concerned. Options for data aggregation and the inaccuracy that may be the result are discussed in chapter 5.
A description is given of experimental findings, showing the impact of increasing levels of customer data aggregation on the outcomes of the MILP model of SLAM.
The choice of a particular level of aggregation depends on the stage in the design process. It may be based on the experimental findings referred to above, but also on upper bounds on the errors in the outcomes of the MILP model caused by different aggregation levels. Since the total variable logistics costs are an important decision criterion, several types of upper bound on the total cost error are derived. Two existing bounds are extended and two new types of bound are introduced.
These upper bounds are not only used to select the appropriate aggregation level at an early stage in the design process, but also to check whether the error does not increase too much in the course of this process. They are also valuable to check whether errors do not differ too widely across scenarios, for this may lead to incomparable results and finally to a wrong decision!

The relevance of this dissertation lies in its contribution to improvements of logistics networks that enhance a company's competitive advantage. More generally, it contributes to the effectiveness and the efficiency of decision-making processes that are taking place in a rapidly changing environment.
The thesis presents various new elements in the concepts and tools that are used for these purposes:

- integration of the use of quantitative models and DSSs into strategic decision-making processes through the use of scenarios,
- extension of existing structured approaches to strategic decision

making, resulting in an approach involving multiple participants,

- deepened insight into the possibilities of aggregating unwieldy numbers of detailed data into more easily managable sets of aggregated data.

The thesis concludes by suggesting some interesting areas for further research, aimed at improving the framework, further clarifying the effects of data aggregation and advancing the integration of goods flows and information flows into the design of logistics networks.

Contents

Chapter 1

Introduction

1.1 Problem description

This thesis is concerned with the analysis and design of logistics networks for industrial firms. A logistics network comprises the facilities (plants, warehouses, suppliers, etc.) and the goods flows that enable the primary process (from the supply of raw materials to the delivery of final products to the market), as well as the return flows used for recycling, repair, remanufacturing, etc. Various trends and developments are challenging companies to reconsider the structure of their logistics network:

New markets are emerging, both in the unified European market and in other parts of the world. Companies are eager to serve these international and intercontinental markets. Some develop their own international activities, others expand their business through mergers and takeovers. In both cases, the new international logistics network is of vital importance for successful expansion.

Current and prospective customers are asking for high quality products, produced according to customer specifications and delivered within short lead times with a high level of reliability. The logistics network should enable the company to adapt flexibly to these *high customer service requirements.* The goods flows are related to transportation, production and storage processes (see figure 1.1).

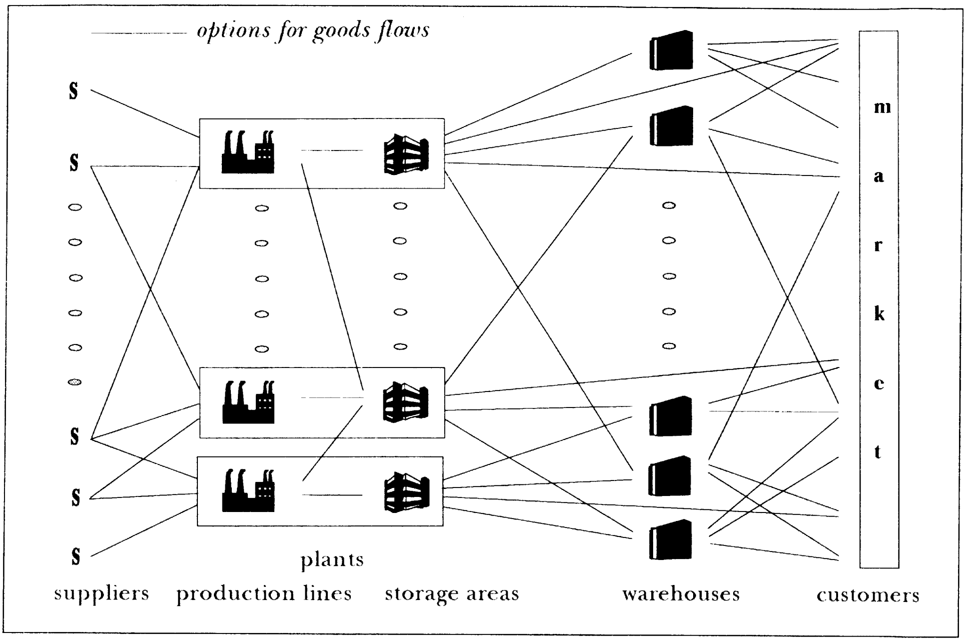


Figure 1.1: Diagram of a logistics network.

Strong competition with regard to the above-mentioned aspects of customer service, in combination with price battles in several branches, compel companies not only to anticipate their customers' wishes, but at the same time to *reduce their costs.*

Besides customer service levels for existing products, the *rapid introduction of new products* is also an important area of competition. Computer-aided product design, combined with advanced marketing technologies and flexible automated production technologies, enable companies to introduce new products at short intervals. This creates

short product life cycles. The structure of the logistics network should be adaptable to these rapidly changing flows of new products.
Other *technological developments*, such as automated warehousing and transportation systems, computer-integrated manufacturing and advances in telecommunications, such as Electronic Data Interchange (EDI) and multimedia communication, enable faster and more reliable flows of goods and information. Moreover, with the help of these new technologies, new products can be introduced and new customers reached. The logistics network should enable the company to capitalise on these powerful technological developments. Advanced technological production processes drive companies towards cooperation in so-called 'Global Network Corporations' (see Maljers, 1995). These corporations cooperate in the production of parts of technologically complex products, such as cars, electrical appliances, robots etc. A competitive logistics network is a key element for their success.
In addition to improving quality and efficiency, technological innovations may also contribute to the *environmental improvements* desired by companies and customers. The use of clean production methods and the recycling and remanufacturing of components and materials are not only enforced by legislation, but also constitute a major issue in competition: e.g. the image of the so-called 'green company' (see Cairncross, 1992).

The above-mentioned developments are creating opportunities that challenge industrial companies to enhance the structure of their logistics network in order to improve their competitive advantage (see also Bowersox, 1992, 1995). It will be clear that support in the complex process of creating competitive logistics networks is of vital importance, both for industrial companies and for research in the field of business administration.

When designing a competitive logistics network for a specific company, the first question that needs to be answered is to determine the number of echelons and the type of facilities needed. In addition, the number, location and role of each type of facility has to be decided on (see also Geoffrion and Powers, 1995). For example, if a logistics network is considered that fits into the structure presented in figure 1.1, one is forced to address several questions of the following type:

- How many plants and warehouses are needed?
- What are the best locations for the plants and the warehouses?
- What should be the size of the plants and the warehouses?
- Which suppliers are needed and which parts should be purchased from which supplier?
- Which products should be produced by which plants?
- Through which warehouses should the products flow from the plants to the customers?

To answer these questions, one has to take account of trends and developments such as the ones described above, which inevitably lead to a complex design process. The vital importance of the logistics network that is designed during this process brings us to the central problem of this thesis: "*How to design a competitive logistics network for a specific industrial company?*"

1.2 Research objectives

In the logistics network design (LND) processes in which we have been involved, a range of alternative networks needed to be developed, analyzed and compared. This comparison was based on a wide variety

of quantitative and qualitative criteria, in order to arrive at the most suitable logistics network for a specific company. Moreover, several parties with differing functional backgrounds (board members, staff departments, operational managers, etc.) and from differing disciplines (logistics, marketing, finance, etc.) were involved in the design process. The result was a complex and often time-consuming process with many interruptions and feed-back loops. We have experienced that the use of a framework for LND enhances the quality of the design process as well as the quality of the resulting network. Such a framework can provide a sound basis for structuring the decision process, developing scenarios and gaining insight into relevant decision criteria. One of the main objectives of this thesis is "*to construct a framework for the design of a competitive logistics network for a specific industrial company*".
In the literature several authors have described a framework for LND, often with a specific focus (see table 1.1). If we combine our experience gained from real-life cases with the descriptions found in the literature, we can make a number of observations:

- *Logistics focus*
  In the classical logistics approach, production and distribution are considered separately. From the point of view of an integrated supply chain, production and distribution are closely connected. Table 1.1 shows that in most existing frameworks the main emphasis is either on production or on distribution.

- *Organization of the design process*
  The design of a logistics network is a complex process. Looking at the design process as a decision-making process may offer additional insights that may improve the design of the logistics network. Table 1.1 shows that existing frameworks do not provide a detailed explanation of the LND in terms of the decision-making

	Bender (1985)	Cohen, Fisher, Jaikumar (1989)	Cook, Burley (1985)	Fine, hax (1985)	Rushton, Saw (1992)	Ven, Ribbers (1993)	Vos (1993)	Mourits (1995)
Logistics focus								
Production	no	yes	yes	yes	yes	**yes**	**yes**	yes
Distribution	**yes**	yes	yes	yes	**yes**	yes	yes	yes
Organization of the design process								
Considered as a decision process	no	no	no	no	no	yes; not in detail	yes; not in detail	yes; not in detail
Different parties and disciplines distinguished	no	no	no	no	no	yes; not in detail	no	yes; not in detail
Development of alternatives								
	yes; not in detail	no	no	no	yes; not in detail	yes; not in detail	no	yes; not in detail
Evaluation criteria								
Qualitative aspects	some	no	yes	yes	yes	yes	some	some
Quantitative aspects	yes; focus on costs	yes; focus on costs	yes; focus on costs	no	yes	yes	yes	yes; focus on costs
Support by DSS								
Models	yes; optimization and simulation	**yes; optimization**	**yes; simulation**	no	yes; simulation, but not in detail	yes; simulation	yes; not in detail	**yes; optimization**
DSS	yes; not a specific one	no	no	no	no	no	no	yes
Use of aggregated data								
	yes; only mentioned as a topic	no	no	no	no	no	no	yes; in case-example
Framework based on cases								
	a small one	no	no	yes	yes	yes	yes	one on distribution

A shaded area shows the main topic of the corresponding framework

Table 1.1: Comparison of frameworks for LND.

process.
As mentioned earlier, there are many parties, with different types of functional backgrounds, involved in the LND process. Incorporating this aspect into the LND framework may also produce additional insights. Van de Ven and Ribbers (1993) and Mourits (1995) comment briefly on this aspect.

- *Development of alternatives*
  In each of the LND processes in which we were involved, several alternative networks were designed, analyzed and compared. The need for a structured approach to developing these alternatives and integrating them in scenario development is reflected by four of the frameworks in table 1.1, but is not worked out in detail.

- *Evaluation criteria*
  During the LND process, a range of evaluation criteria, both quantitative and qualitative, are applied. Nearly all frameworks in table 1.1 take some criteria of both types into consideration.

- *Support by DSS*
  A Decision Support System (DSS) is very helpful in specifying the values of the quantitative evaluation criteria. Although the frameworks in table 1.1 enable the development of several quantitative models for simulating or optimizing logistics networks, only Bender (1985) considers how these can be incorporated in a DSS and how a DSS can support the decision-making process. Although most of the frameworks in table 1.1 pay little attention to the potential role of DSSs in the design of logistics networks, several DSSs for LND exist (see appendix A for an overview).

- *Use of aggregated data*
  Often huge amounts of data on markets, products, production

and distribution facilities are needed in order to develop accurate alternative logistics networks. Gathering all this information is often a time-consuming and costly process. Little is known about the quality of LNDs that are based on less detailed, aggregated data. Bender (1985) and Mourits (1995) refer to this problem, but they do not provide a solution.

It will be clear that there are many questions in the field of LND that are waiting to be answered. In this thesis we hope to provide an answer to some of them or to improve the solutions proposed by other authors. In our framework, we will try to:

- Focus simultaneously on production and distribution.
- Analyze the design process as a strategic decision-making process.
- Take account of the involvement of different parties and disciplines.
- Structure the process of scenario development, in which both qualitative and quantitative evaluation criteria are used.
- Specify the valuable role of a DSS in the design process.

Additionally, we will offer an insight into the effects of the use of aggregated data on the quality of the logistics network. As customers often constitute the largest set of data in an LND problem, we will focus on the effects of the use of customer groups, instead of individual customers.

1.3 Outline of the thesis

The framework for LND presented in this thesis is developed step by step. In chapter 2 we describe a case of a fictitious international European company which manufactures, sells and distributes consumer electronics products. This case description is based on a combination of several real-life situations in which we participated over the years. We describe the LND problem as a problem concerning both production and distribution. With the help of a specially designed mathematical programing model we specify what exactly we mean by an LND problem. Of course, this mathematical model only covers quantitative aspects of the design problem. Nevertheless, it is a useful instrument to illustrate the type of decisions that must be made. Moreover, it provides a basis for the DSS which is discussed in chapters 3, 4 and 5. Chapter 3 focuses on the development of alternative logistics networks with the help of scenarios. We use Broekstra's Consistency Model for Organizational Assessment and Change (1984, 1989) to structure scenario elements and to classify scenarios. For the evaluation of scenarios and the selection of the scenario which yields the most competitive logistics network for a specific company, we consider both qualitative and quantitative criteria. The support of a DSS in the development and evaluation of scenarios is also described in chapter 3.
Chapter 4 describes our framework for the design of a logistics network. The frameworks for strategic decision-making problems of Mintzberg et al. (1976) and Simon (1977) serve as guidelines for our description of the design of a logistics network as a strategic decision-making problem. We take account of the different parties and disciplines involved in the decision process by incorporating into our model elements of the framework for strategic planning proposed by Chakravarthy and Lorange (1991). Our framework also includes the use of scenarios and the support of the DSS developed in chapter 3.

In the framework developed in chapter 4, reference is made to the issue of data gathering and the necessary level of detail of data. This issue is the main concern of chapter 5. Building on the findings of Geoffrion (1975, 1976, 1977) and Zipkin (1980a, 1980b, 1980c, 1982) on the effects of customer aggregation, we derive upper bounds on the error in total costs that is introduced by using aggregated data on customer groups instead of data on individual customers. These upper bounds are defined for solutions of the mathematical programing model developed in chapter 2. Several experimental results show that these new upper bounds work well in practice and that they give decision makers confidence as to the level of detail needed for the data they use in their scenarios and analyses.

Chapter 6 presents the main conclusions of this thesis and suggests some interesting topics for further research.

Chapter 2

A Logistics Network Design problem

2.1 Introduction

In this chapter we introduce a case description of a multinational European company that manufactures, sells and distributes consumer electronics products, such as faxes, printers, copiers, personal computers, etc. Within its logistics network, the company wishes to reorganize the supply of semi-finished products, the manufacturing of final products, warehousing, transshipment and delivery to customers. The case is a combination of several real-life situations in which we participated over the years.

The goal of this case description is to illustrate the challenges in LND and to show the complexity of the problem. Another aim is to offer some guidelines on how best to structure the decision process and how to support decision-making from a quantitative point of view. In chapters 3 and 4 these guidelines are elaborated into a framework for LND.

The case concerns the logistics network of a manufacturing company in Europe which consists of four echelons. The limitations of a four-layer network, a particular geographical area and a manufacturing company do not limit the scope of the LND problem. The framework, the models and the DSS we will discuss can also be applied to logistics networks with more or fewer than four layers and in other geographical areas. The restriction to a manufacturing company is also artificial, since similar approaches can be used for designing networks for other types of companies, for instance, logistics service providers.

Table 2.1 gives an overview of the dimensions of the logistics networks of several companies in Europe. In each of these 'cases' there is a remarkable focus on consumer products.

The majority of these logistics networks were considered in the contract research and consultancy projects in which we were involved. The case of logistics network for medical supplies in the Netherlands was described by Mourits (1995), the case of the logistics network for beer in the Netherlands was described by Gelders et al. (1987). The European consumer electronics firm with 3,000 customers is the fictitious case that is described in detail in this chapter.

2.2 Case description

The fictitious company in our case description has customers in nearly all European countries. Its clientele includes services centers, wholesalers, dealers, etc. The customers are served by operating companies, some of which serve more than one country; nevertheless we will refer to them as nationally operating companies.

Each nationally operating company is responsible for its own sales, marketing, order handling, invoicing, deliveries to customers and after-sales

Region	type of products	number of customers	number of product types	number of semi-products	number of suppliers	number of plants	number of production lines	number of warehouses
Europe	food	3,000	200	60	120	100	250	25
Europe	food	415	100	15	40	50	750	45
Europe	beverages	2,400	500	90	5	15	300	60
Europe	hospital supplies	1,100	12	4	20	5	40	13
Europe	stationary products	1,000	125	10	33	10	100	14
Europe	consumer electronics	600	180	150	30	3	140	15
Italy	food	1,500	30	5	12	30	90	20
Greece	food	85	24	4	5	35	110	9
The Netherlands	high value products	2.100	10	–	–	5	20	20
The Netherlands	retail products	650	10	–	–	1	1	21
The Netherlands	medical supplies	180	5,000	–	–	1	1	3
Belgium	beer	24,000	1	–	–	2	2	20
Case example Europe	consumer electronics	3,000	200	100	50	5	75	12

Table 2.1: *Dimensions of some logistics networks in practice.*

service. They receive their products from the finished product storage areas of five European production plants. In all, some 200 different types of products can be distinguished. The products are stored at the national warehouses, which are managed by the nationally operating companies. Each of the five plants has its own distribution organization for transporting the finished products to the national warehouses. This results in numerous goods flows across Europe, from all five plants to all twelve national warehouses.

Each plant produces a specific range of products; some products are produced at only one plant, others are produced at three or four plants. In all, 75 production lines are available.

Some semi-products that are used in the production process are purchased from external suppliers, others are produced by suppliers owned by the multinational company itself. In all, about 50 suppliers and 100 types of parts are involved in the multinational's logistics network. Some suppliers supply parts to just one plant, others serve several plants.

The managing board of the multinational company anticipates a range of opportunities and threats in the near future. For instance, some national companies are reporting lost sales, as a result of the long delivery times to the customers (72 hours on average). Some competitors are already advertising a guaranteed 48 hours' delivery time! Of course delivery times may be reduced by maintaining higher stock levels at the national warehouses, but this results in higher inventory costs. As there is also a price battle going on in consumer electronics products, increasing stock levels is not the preferred solution. Moreover, the customers are asking for products made according to customer specifications. Due to technological improvements and changing customer behavior, the life cycles of products grow shorter. This increases the risk of having stocks of products with outdated designs or technology.

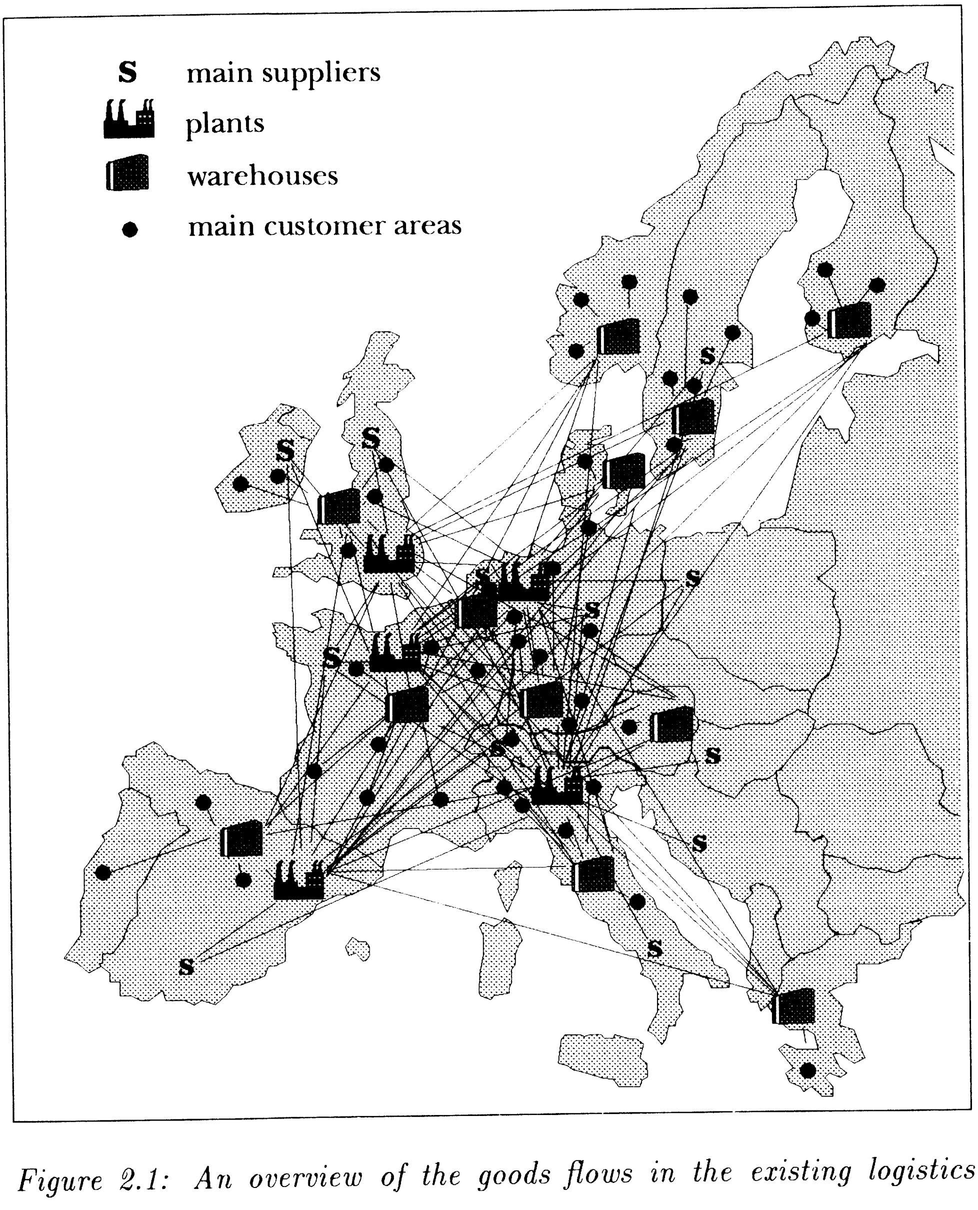


Figure 2.1: An overview of the goods flows in the existing logistics network.

Given these trends, the managing board is seeking to reduce delivery times as well as the total logistics costs in the chain from supplier to customer. Figure 2.1, which provides a schematic representation of the goods flows in the existing logistics network, shows there may be ample opportunities for improvement. During some brainstorming sessions, various ideas for alternative logistics networks are proposed.

For example, there is a proposal for a network with *fewer suppliers* and flexible co-makerships with the suppliers. These co-makerships would focus on just-in-time deliveries to the production lines, with lower stock levels as a result.

Another proposal, inspired by the gradual disappearance of trade and transport barriers in Europe, is to cut down the number of national warehouses, which would reduce inventory levels and at the same time reduce delivery times and handling costs, as a result of economies of scale. This would result in a network with only *a few large European warehouses* which would keep stock for a limited number of transnational regions in Europe, instead of the twelve national warehouses which keep stock for separate countries.

In another proposal the distribution flows from the plants to the warehouses are combined by introducing *inter-plant goods flows.* Each plant would become a distributor to the warehouses in a specific region of Europe. In the logistics process, plants would not send their products intended for a specific region to the warehouses in that region, but to the plant supplying these warehouses.

A fourth proposal is to introduce *customer delivery direct from a finished product storage area of a plant.* Only customers located far away from a plant would be served by one of the European warehouses, as long distances render the delivery time guarantee unrealistic.

Figure 2.2 depicts the goods flows in a situation where all these proposals have been combined: fewer suppliers, fewer warehouses, inter-plant flows and direct delivery from plants to customers. The structure of

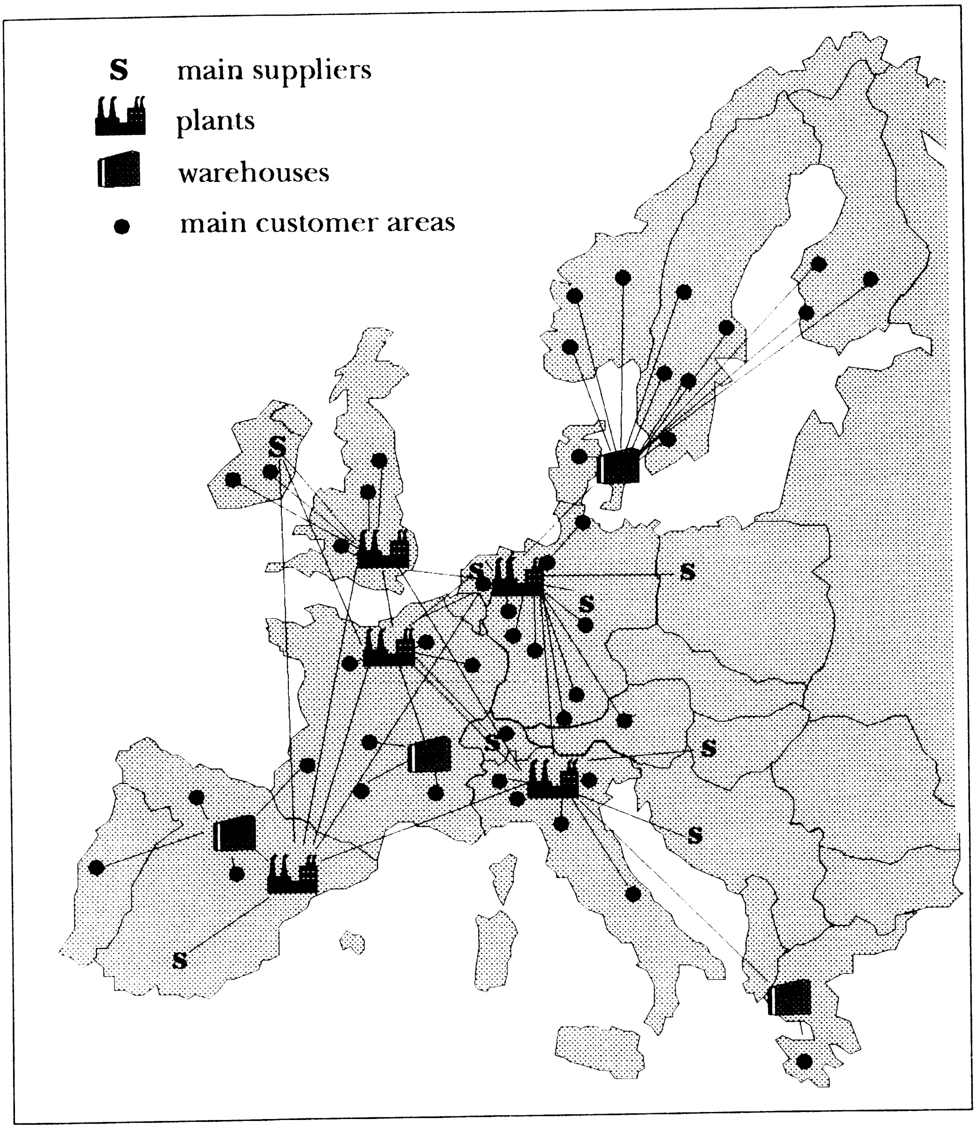


Figure 2.2: Example of an alternative logistics network: fewer suppliers, European warehouses, inter-plant flows and direct delivery to customers from plants (compare figure 2.1).

the logistics network can be further improved by reallocating production between plants, resulting in changed product flows.
A comparison with the goods flows in the existing situation, in figure 2.1, shows that the proposals should be of high interest to the company. Not only would they reduce logistics costs and delivery times; they would also result in a simplified, and therefore more effective and flexible organization.

The managing board commissions an investigation into the possibilities of reducing logistics costs and delivery times by restructuring the European logistics network - while taking advantage of the developing European market -, by realizing economies of scale and by reducing the number of parties involved in the goods flows. On the one hand, the board is interested in a further elaboration and evaluation of the suggested proposals; on the other hand, they want to be informed about alternative logistics networks which may be of interest to the company.

In this chapter we will discuss in detail the complex decision-making problems involved in LND. To understand the questions to be addressed and the degree of freedom in the decision-making, we will develop a quantitative model of the problem. In chapter 3 we will also look at the qualitative aspects of the LND problem and we will show the role of the quantitative model in the strategic decision-making process.

2.3 What decisions need to be made?

The existing situation as well as the alternative proposals presented in the previous paragraph can be described schematically in a representation of a logistics network as given in figure 1.1. It enables the specification of actual and potential suppliers and of optional delivery from suppliers to plants. It takes account of several options for the plants and warehouses: they can be closed down or enlarged and new warehouse locations can be introduced. International deliveries from the warehouses to actual and potential customers are represented by the warehouse-customer connections. The inter-plant flows are represented by the connections between the production lines and the storage areas at different plants. Direct deliveries from plants to customers are shown by the storage area-customer connections. Note that we do not consider return flows.

In our approach, we define a set of potential suppliers, plants, warehouses and customers in advance. This set includes the existing facilities as well as possible locations for new facilities. As it will not be clear in advance which facilities will be selected for the final LND, the number of possible locations for new facilities can be relatively large.

On the basis of this set of potential suppliers, plants, warehouses and customers, we now have to answer the questions raised in chapter 1 about the appropriate locations and sizes of the facilities, the allocation of products to plants, of suppliers to lines, of customers to warehouses, etc.

It will be clear that some of these questions are closely related. In fact, to some extent they overlap: once the questions concerning the optimal goods flows between suppliers, production lines, storage areas, warehouses and customers have been answered, the corresponding optimal locations, product allocations to facilities and facility sizes can be deduced.

In the process of designing a strategic network one has to realize that the designed network should be able to cope with fluctuations in the operations. Moreover, the design should be suitable for both peak periods and low demand periods. Of course bottlenecks in the network will occur during peak periods, so in many cases the design will be based on demand during these periods. In some cases a period of one week was chosen. In other cases the design was based on the yearly demand of the customers, as in the case of our multi-national company. Although in practice several multi-period problems were studied, and although the models used in this thesis can be extended without difficulty[1], for the present moment we will consider a single-period problem. This means that stock levels are considered at a global level.

We can now reduce the problem of LND for the multinational company to determining values for the following decision variables:

$TSL_{sp,s,l}$ = quantity of semi-finished product sp to be delivered from supplier s to production line l.
$TLP_{fp,l,p}$ = quantity of finished product fp to be produced at production line l and shipped to the finished products storage area of plant p.
$TLW_{fp,l,w}$ = quantity of finished product fp to be produced at production line l and shipped to warehouse w.
$TPW_{fp,p,w}$ = quantity of finished product fp to be stored at the plant storage area p for distribution to warehouse w.
$APC_{p,c}$ = 1 if customer c is supplied direct from the storage area of plant p, 0 otherwise.
$AWC_{w,c}$ = 1 if customer c is supplied from warehouse w, 0 otherwise.

In this notation, sp, fp, s, p, l, w and c represent respectively the optional semi-finished products and parts, finished products, suppliers, plant storage areas, production lines, warehouses and customers.

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[1] see for instance Duran (1987) and Haq et al. (1991).

The decision variables of type TSL, TLP, TLW and TPW represent the quantities that are supplied or produced on a yearly basis. The decision variables of type APC and AWC reflect the allocation of customers to storage areas of the plants or to warehouses. For each customer, the allocation holds for the whole product range demanded by this customer. For customer service and administrative reasons, this is often a requirement that has to be fulfilled by the logistics network, as is the case for the multinational company we consider. If this requirement is not needed, APC and AWC can also be transformed to product dependent allocations:

$AFPPC_{fp,p,c}$ = 1 if product fp is delivered to customer c direct from the storage area of plant p,
0 otherwise.

$AFPWC_{fp,w,c}$ = 1 if product fp is delivered to customer c from warehouse w,
0 otherwise.

Note that, by determining values for the above variables, quantities such as the number of products fp produced at line l in the period considered ($\sum_p TLP_{fp,l,p} + \sum_w TLW_{fp,l,w}$) are also known.

We now have defined all the options for production and distribution in the logistics network for all existing and optional parts, semi-finished products, finished products, suppliers, plants, production lines, warehouses and customers. Of course, there are several requirements to be met by the logistics network. For instance, the 'optimal' values for the six types of decision variables have to meet the requirement that all customers receive all the products they have ordered.
Moreover, decisions as to what quantities of goods need to flow between which locations in the optimal logistics network can only be made if

we clarify what evaluation criteria concerning the alternative logistics networks are important in the decision process. The requirements and the criteria for this decision problem will be discussed in the following paragraphs.

2.4 Requirements to be fulfilled

The facilities and goods flows of each alternative logistics network that is proposed should have the capability to guarantee delivery of all the products the customers have ordered. This 'complete delivery' requirement can be denoted using the decision variables of type TSL, TLP, TLW, TPW, APC and AWC as defined. We use several types of constraints to fulfil the 'complete delivery' requirement.

The first set of constraints concerns the requirement that all customers should be supplied either by a warehouse or direct from a plant storage area:

Complete assignment of customers:

$$\sum_{w} AWC_{w,c} + \sum_{p} APC_{p,c} = 1 \qquad \text{for all } c.$$

To supply the customers, the warehouses and the plants should have sufficient finished products to fulfil customer demand. This is represented by the 'input-output balancing constraints' that must be met by the warehouses and the storage areas for each type of finished product:

Input-output balancing at the warehouses:

$$\sum_{l} TLW_{fp,l,w} + \sum_{p} TPW_{fp,p,w} = \sum_{c} d_{fp,c} AWC_{w,c} \qquad \text{for all } fp, w.$$

Input-output balancing at the finished product storage area of the plants:

$$\sum_{l} TLP_{fp,l,p} = \sum_{w} TPW_{fp,p,w} + \sum_{c} d_{fp,c} APC_{p,c} \qquad \text{for all } fp, p.$$

To complete the complete delivery requirement, the production lines should receive sufficient semi-products from the suppliers, to be able to produce the necessary quantity of finished products to supply the plant storage areas and the warehouses:

Input-output balancing at the production lines:

$$\sum_{s} TSL_{sp,s,l} = \sum_{fp} prconv_{sp,fp} \Big(\sum_{w} TLW_{fp,l,w} + \sum_{p} TLP_{fp,l,p}\Big) \text{ for all } sp, l.$$

where

$d_{fp,c}$ = the total demand for products fp ordered by customer c during the time period of one year.

$prconv_{sp,fp}$ = the number of units of semi-product of type sp that are needed for the production of one unit of finished product of type fp.

Each set of values for the decision variables that takes account of these complete delivery requirements generates a logistics network that is able to fulfil customer demand. However, there may be capacity constraints on the size of the plants, warehouses, etc. Moreover, we have not yet formulated criteria for determining the optimal values for the decision variables. This will be done in the following paragraphs.

2.5 Decision criteria

In chapter 4 we will discuss a range of quantitative and qualitative criteria that can be considered decisive in selecting the optimum alternative

logistics network for the multinational company. In this paragraph we will first look at a major criterion in deciding whether or not a logistics network (or, rather, a set of values for the defined decision variables) is 'optimal', viz. *the total variable logistics costs of the operations of the logistics network in the future.* Besides the variable costs, the fixed costs as well as the costs involved in reorganizing of the existing logistics network are also important decision criteria. These costs will differ for each logistics network. It is a highly complicated, time-consuming and, therefore, costly process to determine the fixed costs and reorganization investments for each possible combination of facilities and goods flows we are considering. In fact these costs can only be determined for a limited number of concrete alternative logistics networks. That is why we will first develop these concrete networks and then calculate the fixed costs for operations and the costs of reorganizing. We will take these costs into account in the final evaluation and selection of the alternative logistics networks that will be designed (see chapter 4).
In the sections 2.5.2, 2.5.3 and 2.5.4 we will pay attention to three other important decision criteria: (a) customer order lead time, (b) utilization of facilities and (c) feasibility of the proposed logistics networks and their sensitivity to future change.

2.5.1 Total variable operational logistics costs

The variable logistics costs show the potential savings in operational logistics costs when a new logistics network is implemented. Because of the importance of this criterion, we will incorporate it in the model we are developing as the *objective* of finding a set of values for the decision variables that meet customer demand as defined earlier.

Minimize total variable logistics costs in operations (Z):

$$Z \quad =$$

Purchasing costs:

$$\sum_{sp,s,l} (pcs_{sp,s} + tcsl_{sp,s,l} trconvsp_{sp}) TSL_{sp,s,l} +$$

Production costs:

$$\sum_{fp,l} pcl_{fp,l} (\sum_{p} TLP_{fp,l,p} + \sum_{w} TLW_{fp,l,w}) +$$

Costs for transportation from lines to plants and warehouses :

$$\sum_{fp,l} (\sum_{p} tclp_{fp,l,p} trconvfp_{fp} TLP_{fp,l,p} +$$
$$\sum_{w} tclw_{fp,l,w} trconvfp_{fp} TLW_{fp,l,w}) +$$

Costs for handling and stock keeping at storage areas of plants:

$$\sum_{fp,l,p} hcp_{fp,p} TLP_{fp,l,p} +$$
$$\sum_{fp,p} icp_{fp,p} (\sum_{w} intstockp_{fp,p} TPW_{fp,p,w} +$$
$$\sum_{c} thrputp_{fp,p} d_{fp,c} APC_{p,c}) +$$

Costs for transportation from plants to warehouses and customers:

$$\sum_{fp,p} (\sum_{w} tcpw_{fp,p,w} trconvfp_{fp} TPW_{fp,p,w} +$$
$$\sum_{c} tcpc_{fp,p,c} trconvfp_{fp} d_{fp,c} APC_{p,c}) +$$

Costs for handling and stock keeping at warehouses:

$$\sum_{fp,w,c} (hcw_{fp,w} + icw_{fp,w} thrputw_{fp,w}) d_{fp,c} AWC_{w,c} +$$

Costs for transportation from warehouses to customers:

$$\sum_{fp,w,c} tcwc_{fp,w,c} trconvfp_{fp} d_{fp,c} AWC_{w,c}$$

where

$pcs_{sp,s}$ = purchasing costs of one unit of semi-product sp from supplier s.

$tcsl_{sp,s,l}$ = costs for transportation of one transport unit of semi-product sp from supplier s to production line l.

$trconvsp_{sp}$ = number of transport units needed to transport one unit of semi-product sp.

$pcl_{fp,l}$ = production costs of one unit of finished product fp at production line l.

$tclp_{fp,l,p}$ = costs for transportation of one transport unit of finished product fp from production line l to the storage area of plant p.

$trconvfp_{fp}$ = number of transport units needed to transport one unit of finished product fp.

$tclw_{fp,l,w}$ = costs for transportation of one transport unit of finished product fp from production line l to warehouse w.

$hcp_{fp,p}$ = costs for handling one unit of finished product fp in the storage area of plant p.

$icp_{fp,p}$ = inventory costs for one unit of finished product fp in the storage area of plant p during one time period.

$intstockp_{fp,p}$= intermediate stock time, representing the number of periods needed to combine the goods flows from the various production lines (also from other plants) for distribution to the warehouses.

$thrputp_{fp,p}$ = throughput time, representing the number of periods of stock that are needed to meet the demand for product fp of customers who are served direct from plant p (i.e., without an intermediary warehouse).

$tcpw_{fp,p,w}$ = costs for transportation of one transport unit of finished product fp from plant p to warehouse w.

$tcpc_{fp,p,c}$ = costs for transportation of one transport unit of finished product fp from plant p direct to customer c.

$hcw_{fp,w}$ = costs for handling one unit of finished product fp in warehouse w.

$icw_{fp,w}$ = inventory costs for one unit of finished product fp in warehouse w during one time period.

$thrputw_{fp,w}$ = throughput time, representing the number of periods of stock that are needed to meet the demand for product fp by customers who are served by warehouse w.

$tcwc_{fp,w,c}$ = costs for transportation of one transport unit of finished product fp from warehouse w to customer c.

All cost elements that have been defined are supposed to be linear in the quantities of parts, semi-products or finished products that are considered. Note that the cost components do not necessarily have to be linear in, for instance, distance; only each specific $tcwc_{fp,w,c}$ should be linear with the quantity of finished product fp transported from that specific warehouse w to that specific customer c! So the cost components may depend on finished product, customer and/or warehouse. This line of reasoning holds for all cost elements defined above. This requirement is valid or can be approximated very closely in most real-life situations.

All the logistics networks that can so far be generated by the model meet customer demand against minimum total variable operational logistics costs. A second important evaluation criterion - customer order lead time - is described in the next section.

2.5.2 Customer order lead time

Market requirements and the marketing campaigns of the competitors may force the board to decide on a logistics network that can guarantee delivery of orders within 48 hours or even within 24 hours.
This decision criterion can be considered from two angles: as an evaluation criterion for each alternative logistics network, or as a constraint ensuring that all alternative logistics networks proposed by the model meet a predefined level of maximum customer order lead time.

For the company in the case example, customer order lead time is an issue of such strategic importance that it is not enough just to evaluate alternative networks by lead time performance; the factor needs to be included in the model as a constraint. To ensure that all alternative logistics networks developed with the help of the model meet the requirement of, say, 24 hours delivery time, we will exclude some of the decision variables of type APC and AWC as follows.
Deliveries to customers will take place from a warehouse or direct from a plant. This means that the order cycle time, which includes order registration, handling etc. plus the maximum time for transport to the customer, must not exceed 24 hours. This can be modelled by excluding a decision variable $APC_{p,c}$ or $AWC_{w,c}$ if the transport time from plant p or warehouse w to customer c exceeds 24 hours minus the time needed for order registration, handling etc. In other words, the value of these decision variables $APC_{p,c}$ or $AWC_{w,c}$ is set at zero.

The requirement of 24 hours lead time may entail high total operational logistics costs. It is also possible to design logistics networks with other customers service levels (for instance, 36 or 48 hours). This is done as follows. Different sets of $APC_{p,c}$ and $AWC_{w,c}$ are defined in which specific variables $APC_{p,c}$ and $AWC_{w,c}$ are set at zero in case of potential lack of customer service (more than 36 or 48 hours, respectively). This exclusion can be based on market-specific requirements and is often determined by geographically factors. The total operational logistics cost differences related to the different values of these variables can be used in the decision-making process.

All alternative logistics networks that can be generated by the model at this stage meet customer demand within the guaranteed lead time against minimum total variable operational logistics costs. We will now turn to a third important decision criterion for the multinational: the use of the facilities.

2.5.3 Use of facilities

Evaluation of the use of facilities in a proposed alternative logistics network may give rise to discussions about the size of plants, the need for economies of scale, the need for a warehouse in a specific country, etc. As a result of these discussions, it may be desirable to set requirements for the logistics network with respect to the capacity of a plant or a warehouse.

Delivery from facilities

If one of the connections represented by a decision variable of the type TSL, TLP, TLW, TPW, APC or AWC is of low interest or even unacceptable, the value of the corresponding decision variable can be set at zero a priori. This is not only true for the earlier mentioned deliveries from warehouses to customers which exceed the guaranteed delivery time of 24 hours. It also holds for suppliers' deliveries to the production lines: depending on the existing contracts or options for new contracts with the suppliers, some of the decision variables of type TSL have to be set at zero.

Capacities of facilities

Besides the issues related to managing the goods flows to the customers (i.e., the complete delivery requirements, the 24 hours customer service level and the options for deliveries between the facilities), major issues that need to be considered are the number, location and size of facilities necessary for manufacturing, shipping, storing and delivering the products.

The main decisions to be taken by the managing board with respect to the facilities concern closing down, opening or modifying (reducing or enlarging) the size of plants and warehouses. These decisions are influenced by a range of factors. For example, investments recently made in a particular facility will deter the board to close down this facility. Moreover, environmental legislation or local circumstances may encourage or discourage the establishment of new plants or warehouses. In some cases it may be impossible to enlarge a warehouse simply because there is no space available. This could be a reason to build another warehouse elsewhere or to close the warehouse and to enlarge another one, or to rebuild it somewhere else. As a consequence of decisions of this type, it may be necessary to lay off personnel. This is an unattractive option in most cases, because of the social consequences, the risk of strikes, etc. So, qualitative arguments play a role in evaluating network designs which involve closing or slimming down facilities. Such aspects also play a role when facilities are expanded or new facilities opened, since it may be difficult in some areas to find new employees with the required skills.

In short, there are many factors that affect the possibilities for changing the size of facilities or setting up new facilities. These factors constitute a set of capacity constraints that have to be taken into account when determining the 'optimal' values for the goods flows:

Capacities of warehouses and storage areas at the plants:
For the warehouses and the storage areas at the plants there may be lower bounds on the utilization and capacity limits. For consumer electronics the technical conditions for storage are similar for all types of finished products.

The capacity limits of the warehouses can be denoted as follows:

$$locapw_w \leq \sum_{fp} (stconvw_{fp,w} thrputw_{fp,w} (\sum_{l} TLW_{fp,l,w} + \sum_{p} TPW_{fp,p,w})) \leq upcapw_w \qquad \text{for all } w.$$

where

$locapw_w$ = minimum number of storage units (e.g. square metres, pallets) to be used in warehouse w.

$stconvw_{fp,w}$ = number of storage units needed by one unit of product fp in warehouse w.

$upcapw_w$ = maximum number of storage units available in warehouse w.

The capacity limits of the storage areas of the plants can be denoted similarly:

$$locapp_p \leq \sum_{fp} stconvp_{fp,p}(\sum_{w} TPW_{fp,p,w} intstockp_{fp,p} + \sum_{c} APC_{p,c} d_{fp,c} thrputp_{fp,p}) \leq upcapp_p \qquad \text{for all } p.$$

where

$locapp_p$ = minimum number of storage units (e.g. square metres, pallets) to be used at the finished product storage area of plant p.

$stconvp_{fp,p}$ = number of storage units needed for one unit of product fp in the storage area of plant p.

$upcapp_p$ = maximum number of storage units available at plant p.

Capacity of the production lines at the plants:
The capacity of a production line is defined as the maximum number of products it is able to produce in the time period considered. The production lines in our case description can be used for different types of products, so the total capacity of each line has to be shared by different products. The number of products that can be produced by a line within a particular time period differs per product, because of the varying complexity of the products.
Not only does each production line have a maximum capacity, it may also be necessary, on account of economic considerations, to set a requirement for a minimum utilization rate of each production line.
The bounds on the utilization of the production lines can be denoted as follows:

$$locapl_l \leq \sum_{fp}\left(\frac{\sum_w TLW_{fp,l,w} + \sum_p TLP_{fp,l,p}}{capl_{fp,l}}\right) \leq upcapl_l \qquad \text{for all } l.$$

where

$locapl_l$ = minimum fraction of the total capacity of the production line l that must be used; $locapl_l \in [0, upcapl_l]$.

$capl_{fp,l}$ = maximum quantity of finished products fp that can be produced by production line l in the considered time period, when it is used completely for producing finished products of type fp.

$upcapl_l$ = maximum fraction of the total capacity of the production line l that can be used; $upcapl_l \in [locapl_l, 1]$.

Capacities of the suppliers:
There are also constraints on the maximum or minimum number of products that may be or must be ordered from one supplier. For example, on the one hand, a supplier's production capacity may be limited to a maximum number of semi-products; on the other hand, the multinational company may be obliged to order a minimum number of semi-products under an existing contract. This capacity constraint can be denoted with the help of the decision variables $TSL_{sp,s,l}$:

$$locaps_{sp,s} \leq \sum_{l} TSL_{sp,s,l} \leq upcaps_{sp,s} \qquad \text{for all } sp, s.$$

where

$locaps_{sp,s}$ = smallest total quantity of semi-products sp that must be ordered within the considered time period by all plants from supplier s.

$upcaps_{sp,s}$ = maximum total quantity of semi-products sp that can be delivered within the considered time period to the plants by supplier s.

The above-mentioned constraints are semi-product dependent. Sometimes a producer and a supplier have a product independent contract that guarantees, for instance, a minimum or maximum value for the total contract. In these cases the capacity constraints can be formulated as follows:

$$locaps_s \leq \sum_{sp,l} vconv_{sp,s,l} TSL_{sp,s,l} \leq upcaps_s \qquad \text{for all } s.$$

where

$locaps_s$ = smallest total value of semi-products that must be ordered from supplier s by all plants within the considered time period.

$vconv_{sp,s,l}$ = the value of semi-product sp when it is purchased from supplier s to production line l.

$upcaps_s$ = maximum total value of semi-products that can be delivered within the considered time period to the plants by supplier s.

The constraints on the use of facilities complete the mixed integer linear programing (MILP) model for LND we have developed in this chapter. In chapters 3 and 4 we will discuss how other quantitative and qualitative decision criteria are related to the quantitative aspects in this MILP model.

2.5.4 Feasibility and sensitivity

The total variable operational logistics costs, customer order lead times and use of facilities are major indicators for the board's evaluation of possible LNDs. However, the board will not opt for a specific logistics network before a thorough investigation has been made of its feasibility

at the tactical and operational level. Also the risk and uncertainty that follow from its sensitivity to uncertain future developments in markets, demand levels, cost levels, competition, economies of scale levels, flexibility in production etc., is an important evaluation criterion. The MILP model we have developed in this chapter helps to provide an insight into the risks and rewards related to these uncertainties.
Moreover, the model facilitates the evaluation of proposals for modifications to a logistics network - modifications that may be put forward by departments, business units, operating companies or other parties within or outside the company. It enhances insight into the costs and benefits of modifications to the network and the quality of proposed new alternatives.

In chapters 3 and 4 we will demonstrate how the issues of feasibility and sensitivity can be incorporated into the decision process.

2.6 Evaluation

In the preceding sections, we described the problem of LND for a multinational company. For this company, existing logistics network is redesigned. The quantitative model we have described and the approach for LND we will describe in the following chapters, can also be applied to the design of new or partly new logistics networks, for instance when an American company is considering entering the European market.
In the case description we focused on several quantitative aspects of the problem. We developed an MILP model that supports the design of logistics networks with minimal total variable logistics costs and that takes account of customer order lead time requirements and options for the utilization of facilities. Note that, although we focused on an MILP model, many other types of quantitative models for LND can be

developed (for overviews, see Aikens, 1985, Brandeau and Chiu, 1989, Current et al., 1990 and Sridharan, 1995).
In appendix B, the MILP model we described is summarized. To make the MILP model operational for decision support, we incorporated it in a DSS called SLAM (see also appendix A).

We have made a number of implicit assumptions and simplifications in our MILP model. As mentioned in section 2.5, we did not take account of the fixed costs in operations and the costs for the reorganization process. Moreover, we constructed a single-period model (see section 2.3), whereas in real situations a multi-period model will often be more appropriate, for instance in case of a seasonal demand pattern. Also, we have not considered the return flows used, for instance, for recycling, repair or remanufacturing[2]. Furthermore, the routing aspects of the deliveries to the customers have not been worked out in detail[3]. The model allows for the inclusion of multiple transport modes, although per delivery only one transport mode has been modeled. Finally, we assumed that all the data are available or can be gathered and that the model can be solved.

The problem of the availability of the data for the MILP model and, more specifically, the required level of detail of the data, will be discussed in chapter 5.
The assumption of the solvability of the MILP model is related to the computational complexity of the MILP model. The size of a specific model instance and the number of integer variables are two major determinants of this computational complexity.

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[2] see Bloemhof et al. (1994), Thierry et al. (1995) and Salomon et al. (1996) for examples of models that do consider these return flows.

[3] see Beulens et al. (1988) and Drezner (1995) for examples of models that do consider routing aspects.

Region	Type of products	Number of decision variables: non-integer variables	Number of decision variables: 0-1 variables	Number of decision variables: total	Number of constraints: capacities	Number of constraints: balancing	Number of constraints: assignment	Number of constraints: total
Europe	food	8,550,000	375,000	8,925,000	15,150	40,000	3,000	58,150
Europe	food	7,800,000	39,425	7,839,425	2,890	20,750	415	24,055
Europe	beverages	11,835,000	180,000	12,015,000	1,650	64,500	2,400	68,550
Europe	hospital supplies	12,620	19,800	32,420	276	376	1,100	1,752
Europe	stationary products	350,500	24,000	374,500	908	4,000	1,000	5,908
Europe	consumer electronics	1,091,700	10,800	1,102,500	9,316	24,240	600	34,156
Italy	food	158,400	75,000	233,400	400	1,950	1,500	3,850
Greece	food	125,920	3,740	129,660	348	1,496	85	1,929
The Netherlands	high value products	6,000	52,500	58,500	90	250	2,100	2,440
The Netherlands	retail products	430	14,300	14,730	46	220	650	916
The Netherlands	medical supplies	21,000	720	21,720	10	12,000	180	12,190
Belgium	beer	84	528,000	528,084	48	22	24,000	24,070
Case example Europe	consumer electronics	642,000	51,000	693,000	10,184	10,900	3,000	29,084

Table 2.2: Maximum dimensions of the MILP model instances for logistics networks in practice as presented in table 2.1.

Table 2.2 shows the maximum dimensions of the MILP model for the real-life logistics networks presented in table 2.1. Clearly, some of these model instances are of enormous size, which inevitably leads to a huge increase in the time needed for data gathering and for finding an optimal solution. The maximum numbers increase when optional new products, customers, suppliers or facilities are incorporated in the MILP model. However, the number of decision variables (especially the integer variables of type AWC and APC) and constraints can be reduced by critically considering the model instance, for instance by fixing in advance the values of decision variables that have already been decided on or by eliminating (or setting at zero) decision variables that are not expected to be included in the optimal solution. The number of decision variables of type APC and AWC can also be reduced by aggregating individual customers into customer groups. This topic will be discussed in chapter 5. Aggregation of products into product groups will reduce both the number of decision variables and the number of constraints.

To further reduce the time needed for finding an optimal solution, we can use the relaxation of the integer 0-1 variables of type AWC and APC. This means that these decision variables may be given values in the interval [0,1]. The model then becomes a linear programing model, which can be solved much faster. Benders and Van Nunen (1983) and Van Nunen et al. (1984) showed that the solutions of the relaxation of an assignment type MILP model give very useful solutions for the MILP model itself[4]. In Appendix B, we prove that this also holds for the MILP model defined in this chapter.

We conclude this chapter with the observation that the case situation

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[4] In the sequel of this thesis we consider the relaxation of the MILP model. We will also name it an MILP model.

illustrates the challenges and the complexity of the LND problem. The MILP model we have developed makes it possible to consider many different requirements and objectives for a competitive logistics network. The model facilitates the construction of alternative logistics networks and allows consideration of the company's expectations with respect to future demand, new products, new markets, development of cost levels, etc. Moreover, with the help of the model it is relatively easy to investigate the sensitivity of a logistics network to unexpected future developments.

Chapter 3

Steps towards an LND

3.1 Introduction

In this chapter we will discuss the strategic decision making process involved in the design of a logistics network for a company such as the multinational company introduced in chapter 2.
The time period for a strategic planning process should correspond to the time horizon of the most important investment decisions (Porter, 1985). For strategic logistics plans in general, the planning horizon ranges from three to twenty years (Cooper et al., 1992). Referring to the design processes of logistics networks in which we were involved, we will consider a time horizon of about ten years.

In chapter 1 we already indicated that the complex process of designing a logistics network for a company centers around eight types of questions, concerning the type of echelons, the type, locations and sizes of facilities, the allocation of products and the way in which the products are supplied to the customers. Moreover, in chapter 2 we formulated an MILP model that can be used to determine the values of the defined variables. We also showed that some of the required input data depend on decisions that are based on the company's view of future developments and its planned response to these developments. This means that a structured process has to be organized to answer the eight fairly general questions and to determine certain options for the required input data.

In fact, two types of decision have to be made: decisions related to various aspects of the facilities, such as type, number, location and size and decisions related to the flows of parts and products within and between the facilities. In other words, the decisions concern both the activities within the facilities and the transportation flows between them. Using this distinction between types of decisions, we denote a specific LND as follows:

$$LND \quad = \quad \{D_{Facilities}, D_{Flows}\}$$

where

$D_{Facilities}$ represents the decisions on various aspects of the facilities:

d_{types} = decisions w.r.t. the types of facilities that are needed (e.g., plants, warehouses).

d_{number} = decisions w.r.t. the number of each type of facility that is needed.

$d_{locations}$ = decisions w.r.t. the locations to be used for the facilities.

d_{sizes} = decisions w.r.t. the sizes of the facilities that are needed.

D_{Flows} represents the decisions on the flows of the parts and products within and between the facilities:

$d_{activities}$ = decisions w.r.t.
which actions should be performed on which parts or products and at which facilities (e.g., supply, production, packaging, inventory).

$d_{transport}$ = decisions w.r.t.
which parts or products should flow between which facilities and by which mode of transport.

Some of the decisions to be taken will be based on qualitative arguments. For example, the decision as to whether or not to build a plant in eastern Europe will depend on expectations regarding market developments in that area. Other decisions may be computed from a solution of an MILP model as described in chapter 2. In fact, the first type of decision determines the input data (parameters) for the MILP model, such as the presence of a particular variable, the potential set of customers or the upper capacity of a warehouse.

As illustrated in chapter 2, there are many uncertainties related to the future that need to be considered when taking the above mentioned decisions. Figure 3.1 shows the various steps in a structured approach to dealing with such uncertainties. The first step is to construct several different views of the external environment. In the second step, each of these views is explicated into business choices, which describe how the company will interpret and respond to the uncertainties in the external environment in terms of its own business situation. As a third step, concrete alternative logistics networks are designed. This translation of what are usually globally formulated business strategies into specific, alternative plans for a company has received little attention in the literature (Schoemaker, 1993).

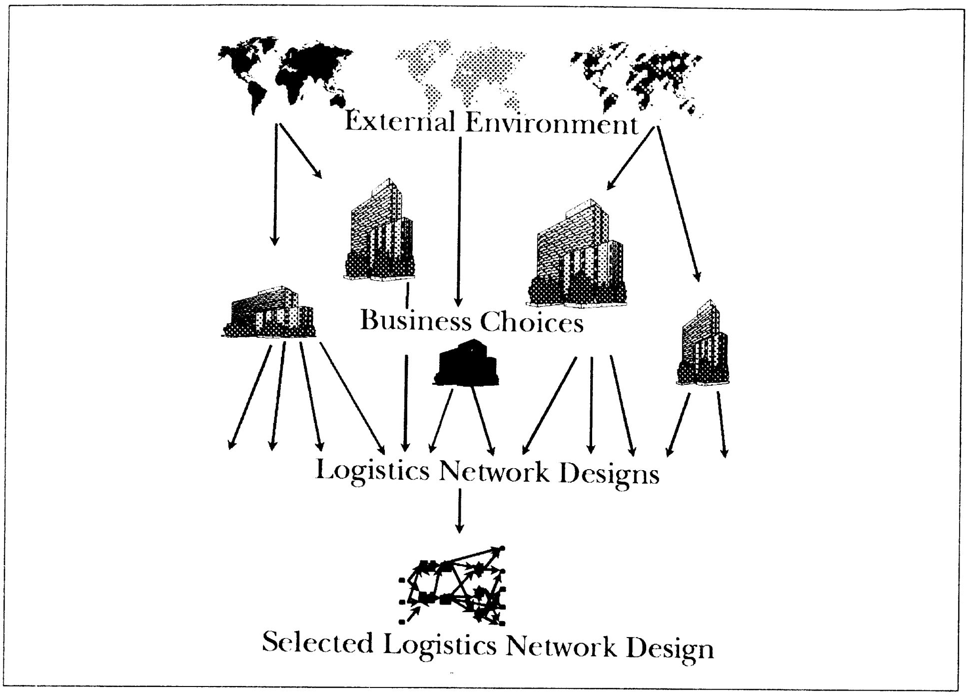

Figure 3.1: Process of the design of a logistics network.

In real life, it is fairly uncommon for business strategies to be elaborated into concrete plans (Wilson, 1982). As a fourth and final step in the process depicted in figure 3.1, the most competitive LND is selected.

In chapter 4 we will expand this process into a framework for LND. In addition to the four steps described of the present chapter, the framework presented in chapter 4 includes the loops in the design process, the selection of the most competitive LND and the roles of the various players in the different steps of the design process.

3.2 Developments, uncertainties and scenarios

3.2.1 Classification of developments

In this section we will classify the developments and uncertainties that represent the external environment and influence the business choices referred to above. To this end, we will use Broekstra's Consistency Model for Organizational Assessment and Change (1984, 1989) depicted in figure 3.2. This model divides the developments and uncertainties into an external category, related to the environment, and an internal category, related to the company. It also shows the links between these two categories. Several other models exist for analyzing developments and uncertainties (see Aaker, 1984, Wheelen and Hunger, 1995), but these do not show the relationships between external and internal developments and uncertainties as clearly as Broekstra's model.

Broekstra's Consistency model allows us to classify the developments and uncertainties into four subcategories with each an external component and a company component. Within each of these four categories we will define factors. For each factor a range of potential values can be defined, representing different views of the development represented by that factor. At a later stage, we will use these factors and some specific potential values to define scenarios.
The four categories distinguished by Broekstra, as well as the corresponding factors, are discussed below:

1. The *'Market Developments'* factors represent the external developments with respect to markets, customers, suppliers, competition, governmental policies, regulations and economics.

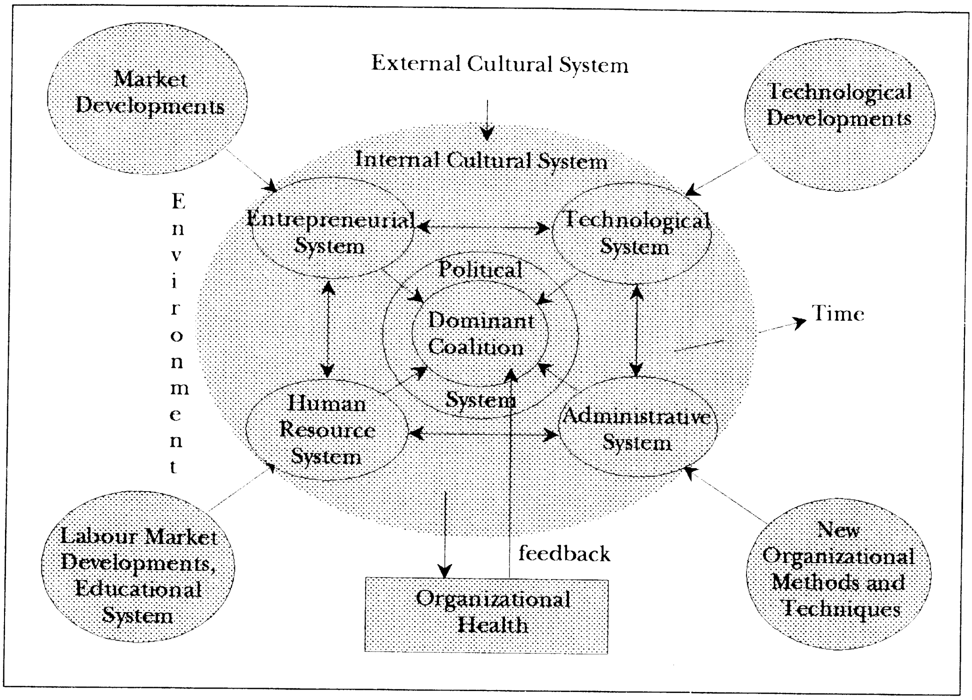

Figure 3.2: A Consistency Model for Organizational Assessment and Change (Broekstra, 1984, 1989).

These external developments determine to a large extent the potential internal options of a company regarding *'Entrepreneurial Elements'*. Broekstra's entrepreneurial aspect system basically refers to product-market combinations. It also covers the options of a particular competitive strategy, for example, differentiation in cost leadership or in customer valued items (see Porter, 1985). The entrepreneurial choices reflect important requirements that must be fulfilled by the logistics network that is being designed.

2. *'Technological Developments'* factors concern innovation in products, production methods, distribution methods, computer facilities,

electronic data interchange, multi media applications, etc. How a company can take advantage of these innovations is expressed by Broekstra in the business options regarding *'Technological Elements'*. Broekstra's technological aspect system refers to the company's production and distribution 'hardware', i.e. its primary conversion process. It also includes the tools for daily operations, such as automation of manufacturing or warehousing processes, flexible manufacturing processes, techniques for remanufacturing or recycling used products, appropriate transportation facilities, tools for information processing within the logistics network like EDI, etc.

3.'New Organizational Methods and Techniques' factors refer to developments and new insights in organizational structures, for instance centralization versus decentralization, product-oriented approaches versus market-oriented approaches, mergers, take-overs, co-makerships, etc. New management control techniques, changing accounting methods, etc., also belong to this category of external changes. In the company's administrative aspect system, these external developments are evaluated and options for their implementation in the organizational structure developed in terms of distinct *'Administrative Elements'*. With respect to this aspect system, the logistics network needs to consider such options as national or international structure, local plants for local production or special purpose plants for international production, comakerships with suppliers and transport companies, centralized versus decentralized activities, etc.

This aspect system also includes the systems that administer and control the activities of the technological and human resources (sociotechnical) system. This means that it also includes the options for logistics planning concepts, such as MRP II, JIT, OPT, DRP II, ERP, the cost accounting method, management information at the various control levels, decision-making processes, etc.

4. 'Labour Market and Educational System Developments' factors illustrate the changes and developments in the labor market with respect to the available labor force, its educational level, wage rates, developments in the flexibility of the labor force, etc. These external developments are reflected in the company by Broekstra's internal aspect system of *'Human Resource Elements'*. This aspect system refers to the organizational 'software', the characteristics of employees (age, skills, knowledge, turnover, motivation, satisfaction, leadership styles, flexibility, etc.) and the nature and quality of the social relations (the socio-psychological system). Human resource elements are, for example, training of employees in order to benefit from changed technology, and control concepts. It also includes the dismissal, recruitment and transfer of employees in case of closure, reduction or expansion of plants or warehouses.

Note that the elements of Broekstra's Consistency Model are closely related to the elements of systems, style, skills, staff, strategy, structure and superordinate goals in the famous 7-S framework for effective organizational change of Waterman et al. (1980).

Figure 3.3 gives an impression of relevant external developments that could be taken into account in the process of designing a logistics network for a multinational company such as the one described in chapter 2. The factors are grouped in accordance with Broekstra's Consistency model. Figure 3.3 also shows the enormous variety of aspects that can influence the LND.
Overviews of external developments are provided, for example, by the Central Planning Bureau (1992), which considers the world economy and industry-specific scenarios in Europe, by Cooper et al. (1991), by O'Laughlin et al. (1993), who focus on industry branches, by Van der Hoop (1992) and by the 'European Trends' journal.

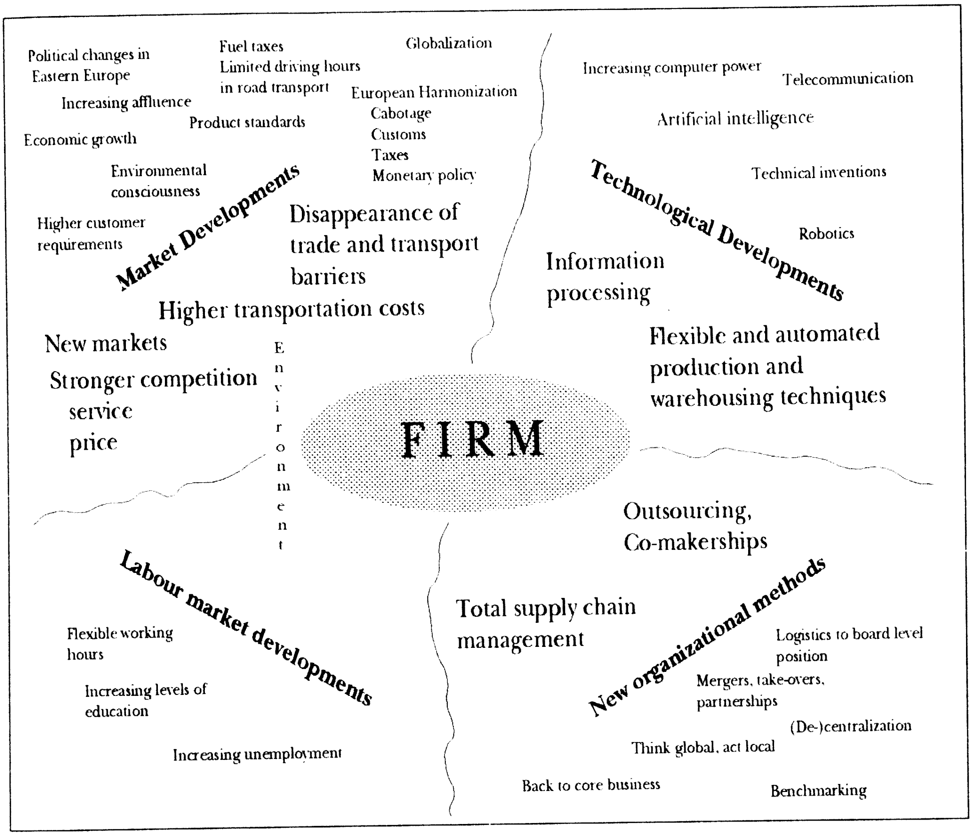

Figure 3.3: Some relevant external developments for the consumer electronics industry, in line with Broekstra's Consistency Model for Organizational Assessment and Change (Broekstra, 1984, 1989).

According to Broekstra, awareness of external developments can help a company identify many of the threats and opportunities for its business. In the following paragraphs we will show how the concept of scenarios can be used to deal systematically with the many different views of external developments and to translate these views into alternative business strategies and especially LNDs.

3.2.2 Definition of scenarios

Scenarios in general

Different views on uncertainties in developments determine different possible futures which may require different logistics networks. We define each future that is represented by an internally consistent view of the factors described in the previous paragraph as a scenario. This definition is in accordance with the definitions found in the literature. Porter (1985) defines a scenario as "an internally consistent view of what the future might turn out to be." Leemhuis (1985) is more specific: "a scenario is a description of a possible future in which social, political, economic and technological developments evolve in an internally consistent order."

Scenario planning is a well-known phenomenon and a powerful aid in strategic decision-making, as the successful pioneers in scenario planning - Royal Dutch/Shell - have emphasized. Wack (1985) states: "By listening to planners' analysis of the global business environment, Shell's management was prepared for the eventuality - if not the timing - of the 1973 oil crisis". In the case of Shell, scenarios help to develop strategies to deal as effectively as possible with uncertainties in the future. Another reason for using scenarios is the pace of technological and competitive change, which makes it inevitable to speed up strategic decision-making processes. The simultaneous development of multiple scenarios and alternative strategies enables fast decision-making (see also Eisenhardt, 1990) and facilitates consensus in decision-making (Linneman and Klein, 1985). Porter (1985) and Schoemaker (1993) stress that the development of scenarios strongly contributes to creativity in strategic planning and to widening the range of alternatives considered. Mason (1994) illustrates that scenario-based planning is a useful decision model for the learning organization, provided that

scenarios are developed in an interactive process involving the management teams in the company. We will incorporate this interactivity in our framework for LND in chapter 4.
In their survey of the Fortune 1000 companies, Linneman and Klein (1985) found that approximately half of these companies said to use scenario analysis, and in a similar survey of large European companies by Malaska et al. (1984), the percentage of scenario users was 36%, a figure which by 1985 had risen to 40% (Malaska, 1985, Meristö, 1989).

We will now make our definition of 'scenario' more concrete by introducing the following notation:

$$S = \{\lambda_{f_1}, \lambda_{f_2}, \lambda_{f_3}, ..., \lambda_{f_F}\}$$

where

λ_{f_i} = a value of factor f_i (for $i = 1, 2, ..., F$)

and

$\lambda_{f_1}, \lambda_{f_2}, \lambda_{f_3}, ..., \lambda_{f_F}$ are mutually consistent

At a later stage the factors f_i will be connected to the factors e and c as defined in section 3.2.1.
Note that this notation shows that a scenario is *not* a series of single independent forecasts for the factors $f_1, f_2, f_3, ..., f_F$, which however results in one possible, credible future, as guaranteed by the mutual consistency of the factors (see also Bunn and Salo, 1993, Porter, 1985). Schnaars (1987) also emphasizes the mutual consistency of these factors by stating that: "A scenario provides a more qualitative and contextual description of how the present will evolve into the future, rather than one that seeks numerical precision. It is based on the assumption that the future is not merely some numerical manipulation of the past, but the confluence of many forces, past, present and future." Factors that are included in a scenario are, for example: demand for consumer electronics and availability of technically skilled labor. If a high demand

for consumer electronics coincides with a poor supply of skilled labor, an inconsistency may arise if the production technology cannot be improved. This example shows that in the development of a scenario, it is not only the values of the individual factors that are important, but also, if not more so, the interactions between the factors.
During the development of a scenario, the mutual consistency of the λ_{f_i}'s is reached step by step. However, we will consider a set $\{\lambda_{f_1}, \lambda_{f_2}, \lambda_{f_3}, ..., \lambda_{f_F}\}$ a scenario even if the scenario is not finished, i.e. the λ_{f_i}'s are not yet mutually consistent.

External and company scenarios

As we have defined two types of factors (external and company factors), we will now also define two types of scenarios: the external scenario and the company scenario.

In the literature, *external scenarios* are often subdivided into macro scenarios and industry scenarios (see Linneman and Klein, 1985, Porter, 1985 and Schoemaker, 1991). Macro scenarios represent developments in the world, the continent and the country. Industry scenarios focus on one specific industry, analysing the developments and uncertainties in macroeconomic, political, technological and other relevant areas and probing their implications for competition in the industrial sector concerned. In this thesis we will mainly be concerned with external scenarios of the industry type.
To define an external scenario, we introduce a notation for the external factors e:

The external market factors of class e^M are represented by e_1^M, e_2^M, e_3^M, ..., e_{EM}^M, where EM is the number of external market factors that are considered.

The external technological factors of class e^T are represented by e_1^T, e_2^T, $e_3^T, \ldots, e_{ET}^T$, where ET is the number of external technological factors that are considered.
The external organizational factors of class e^O are represented by e_1^O, e_2^O, $e_3^O, \ldots, e_{EO}^O$, where EO is the number of external organizational factors that are considered.
The external labour market factors of class e^L are represented by e_1^L, e_2^L, $e_3^L, \ldots, e_{EL}^L$, where EL represents the number of external labour market factors that are considered.

According to this notation of the external factors and the notation of a general scenario, we denote an external scenario S_{ext} as :

$$
\begin{aligned}
S_{ext} &= \Lambda_{e^M} \bigcup \Lambda_{e^T} \bigcup \Lambda_{e^O} \bigcup \Lambda_{e^L}\\
&\text{where}\\
\Lambda_{e^M} &= \{\lambda_{e_1^M}, \lambda_{e_2^M}, \ldots, \lambda_{e_{EM}^M}\},\\
\Lambda_{e^T} &= \{\lambda_{e_1^T}, \lambda_{e_2^T}, \ldots, \lambda_{e_{ET}^T}\},\\
\Lambda_{e^O} &= \{\lambda_{e_1^O}, \lambda_{e_2^O}, \ldots, \lambda_{e_{EO}^O}\},\\
\Lambda_{e^L} &= \{\lambda_{e_1^L}, \lambda_{e_2^L}, \ldots, \lambda_{e_{EL}^L}\}\\
&\Lambda_{e^M}, \Lambda_{e^T}, \Lambda_{e^O}, \Lambda_{e^L} \text{ internally and mutually consistent}\\
\lambda_{e_i^j} &= \text{a value of the external factor } e_i^j
\end{aligned}
$$

An example of an external factor for the consumer electronics industry is the development of new markets in Europe, denoted as $e^M_{new-markets}$. Interesting aspects of these potential new markets are the geographical areas and the potential turnover in each area. They are represented by the value of this factor $\lambda_{e^M_{new-markets}}$, where:

$$
\begin{aligned}
\lambda_{e^M_{new-markets}} \in \{(a_e, t_e) \mid\ & a_e \in \{\text{European areas}\},\\
& t_e \in [0, 150] \text{ billion EURO}\},\\
\text{where}\quad & a_e \text{ represents a geographical area and}\\
& t_e \text{ represents the potential turnover in this area.}
\end{aligned}
$$

If for a specific external scenario a new market is expected to develop only in Eastern Europe, with a potential turnover of 10 billion EURO, then $\lambda_{e^M_{new-markets}}$ = (Eastern Europe, 10 billion EURO).

A *company* scenario as defined by Schoemaker (1991) is a scenario for a company in which an external scenario has been translated into a view of the company's future development. This view is an internal view of persons in the company. We denote a company scenario S_{comp} along the same lines as the external scenario:

$S_{comp} = \Lambda_{c^E} \bigcup \Lambda_{c^T} \bigcup \Lambda_{c^A} \bigcup \Lambda_{c^H}$
where
$\Lambda_{c^E} \; = \{\lambda_{c_1^E}, \lambda_{c_2^E}, ..., \lambda_{c_{CE}^E}\},$
$\Lambda_{c^T} \; = \{\lambda_{c_1^T}, \lambda_{c_2^T}, ..., \lambda_{c_{CT}^T}\},$
$\Lambda_{c^A} \; = \{\lambda_{c_1^A}, \lambda_{c_2^A}, ..., \lambda_{c_{CA}^A}\},$
$\Lambda_{c^H} \; = \{\lambda_{c_1^H}, \lambda_{c_2^H}, ..., \lambda_{c_{CH}^H}\}$
$\Lambda_{c^E}, \Lambda_{c^T}, \Lambda_{c^A}, \Lambda_{c^H}$ internally and mutually consistent
$\lambda_{c_k^n} \; =$ a value of the company factor c_k^n

where

c^E represents the class of the CE entrepreneurial company factors $c_1^E, c_2^E, c_3^E, ..., c_{CE}^E$.
c^T represents the class of the CT technological company factors c_1^T, c_2^T, $c_3^T, ..., c_{CT}^T$.
c^A represents the class of CA administrative company factors c_1^A, c_2^A, $c_3^A, ..., c_{CA}^A$.
c^H represents the class of CH human resource company factors c_1^H, c_2^H, $c_3^H, ..., c_{CH}^H$.

It will be clear that there is a close connection between external scenarios and company scenarios. In line with Broekstra's Consistency model (see figure 3.2), the external market developments will be translated into choices for the entrepreneurial system, the external technological developments will be translated into options for the company's technological system, new organizational methods and techniques will be translated into alternative administrative systems and the developments on the labor market and in the educational systems will be translated into options for the future human resource system. In our notation, this means that the values of the factors in Λ_{c^E} are a translation of the values of the factors in Λ_{e^M} and the same type of reasoning holds for the other three types of factors. For instance, the external factor $e^M_{new-markets}$ we discussed earlier, with its value $\lambda_{e^M_{new-markets}} =$ (Eastern Europe, 10 billion EURO) can be translated into company factors as follows:

Eager to take advantage of the developing market in Eastern Europe, a specific company has to decide whether or not to enter this new market and in case it decides to do so, it will also have to define a desirable turnover. In our notation, this could result in a company factor $c^E_{new-market-in-Eastern-Europe}$, with value

$\lambda_{c^E_{new-market-in-Eastern-Europe}} \in [0, 10]$ billion EURO.

For different company scenarios, the value of $\lambda_{c^E_{new-market-in-Eastern-Europe}}$ can be for instance 0, 4, 8 or 10 billion EURO.

Note that the translation of the various external factors into company factors is not a series of independent processes; ultimately, Λ_{c^E}, Λ_{c^T}, Λ_{c^A}, Λ_{c^H} must be internally and mutually consistent!

In the translation process, some factors e and their values λ_e of the external scenario will be converted into factors c and their values λ_c of a corresponding company scenario without change (e.g. 'interest

rates will increase by 25%'). External factors can also be converted into company factors with values representing business choices. This is the case of the external factor $e^M_{new-markets}$, which is translated into the company factor $c^E_{new-market-in-Eastern-Europe}$. Besides the company factors that are derived direct from the external factors, there will also be many new factors in the company scenario, for example the factors
$c^E_{product-range-in-Eastern-europe}$,
$c^E_{service-level-in-Eastern-europe}$ and
$c^E_{sales-prices-in-Eastern-europe}$.
Note that a logistics network is part of a company scenario. This means that the set of decisions $\{D_{Facilities}, D_{Flows}\}$ has to be represented by values of company factors in a company scenario.

3.3 Towards an LND, using scenarios

In this paragraph, the LND process shown in figure 3.1 will be extended by incorporating external and company scenarios. Moreover, as the process of designing a logistics network is a strategic decision-making process, the phases in this process will be distinguished with the help of frameworks for strategic decision-making defined by Mintzberg et al. (1976) and Simon (1977). This chapter will only consider the separate phases in the process. The loops and interruptions, as well as the various participants involved in the process, will be discussed in chapter 4. Figure 3.4 depicts the different phases we will discuss in this section.

According to Simon and Mintzberg, every strategic decision-making process begins with an *identification phase*, in which the problem area is identified, and the first diagnoses are made. "Opportunities, problems or crises are recognized and the evoking stimuli are comprehended"

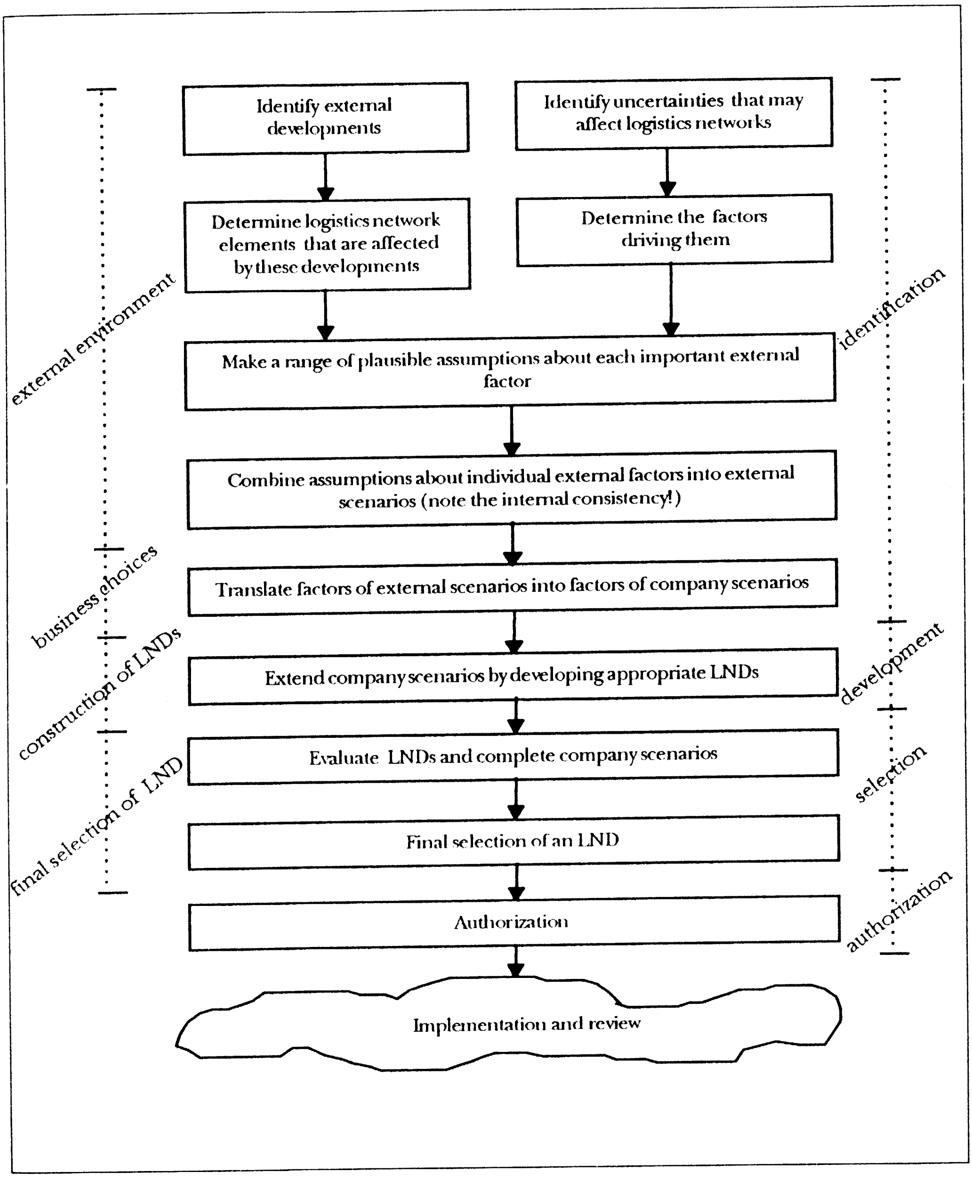

Figure 3.4: Process of the design of a logistics network, using scenarios and characterized as a strategic decision-making process.

(Mintzberg et al., 1976). Often the existing situation with regard to the topic on which decisions have to be taken needs to be investigated in more detail. Starting points and targets for the desired situation are set.

For the LND decision process, we divide the identification phase into two major components: the analysis of the *external environment* and the analysis of the *business choices*.

In the first four steps of the analysis of the external environment (see figure 3.4), the factors e as defined in the previous section, are investigated. Two valuable ways of investigation are distinguished. One is to search for uncertainties that may affect the logistics network from the point of view of the existing logistics network. This method is suggested by Porter (1985) in his description of the process of constructing external scenarios. The other method starts from a general view of the external environment and addresses at a later stage developments and uncertainties that may affect the logistics network. Bunn and Salo (1993) refer to the two different types of scenario resulting from these methods as exploratory scenarios and anticipatory scenarios. They suggest to combine both methods.

The next step is to address a range of possible values λ_e for the external factors e. A discussion of each factor and its range should result in one or more specific values for each factor. The final step is to synthesize the specific values of the different external factors into consistent combinations, which yields external scenarios S_{ext}. In section 3.4 this process is worked out for the case example presented in chapter 2.

By making business choices, a start is made with the translation of each of the external scenarios into one or more company scenarios S_{comp}. This is the second part of the identification phase. First the factors of the external scenario that is being considered are translated into company factors. When these company factors and their related external factors are discussed, business choices are made by assigning ranges of

values or even specific values to these company factors. Often the focus is first on the factors c^E, which represent the entrepreneurial choices for product-market combinations, customer service levels, etc..
It is also possible to define other important factors c that are not necessarily a direct translation from an external factor e.

Following the identification phase of the strategic decision-making process, a range of alternative 'solutions' to the identified problem are developed. As a first step, suggestions for improving the existing situation are made and constraints for the new situation are set.
Mintzberg refers to this phase as the development phase, with the design phase being a part of it. Simon calls it the design phase, with development being a part of it! Besides the difference in names, there is also a significant difference between the two frameworks: in Simon's framework, the analysis of the alternatives is a part of the design phase, whereas in Mintzberg's framework this is part of his next phase: the selection phase. On the basis of our own experiences, we have decided to opt for Mintzberg's approach.
In the *development phase*, then, the company scenarios are extended by the *construction of LNDs*. Each LND that is developed should be consistent with the business choices made in the identification phase.
In section 3.4 the process of constructing LNDs will be worked out in detail. Special attention will be paid to the support of the quantitative model developed in chapter 2.

As the development phase of a strategic decision-making process often results in a large number of options, these options need to be screened and evaluated by a range of qualitative and quantitative aspects and a choice has to be made on the basis of a combination of analysis, bargaining and assessment.
As stated above, we prefer Mintzberg's approach, which combines the

analysis of the alternatives and the selection of the best solution in one phase: the *selection phase.*
As far as the LND decision process in concerned, in this phase the alternative company scenarios that have been developed so far are evaluated, with special attention being given to the LND part. In chapter 4 the evaluation criteria are discussed. These evaluation criteria may introduce new company factors in the scenario or may lead to ranges of values or specific values for factors that did not yet have a value (often factors of type c^T, c^A or c^H). So, the evaluation of the LND leads to factors c and values λ_c, which completes the company scenario. Note that the values of all factors in the company scenario should be mutually consistent!
Finally, the *selection of the most appropriate LND* has to be made. In chapter 4 several selection approaches for the choice of the optimum LND are considered.

In the authorization phase, the final approval for the implementation of the selected LND should be reached. Simon does not mention an *authorization* phase. In Mintzberg's framework, it is the final part of the selection phase (and also the final part of his entire framework). Because of the importance of this phase and because of the involvement in the decision process of several participants inside and outside the company (see chapter 4), we consider this phase as a separate one.

Following the authorization phase, a start can be made with the detailed preparations for the implementation of the selected LND. Ackoff et al. (1984) present useful guidelines for this preparation process. The preparation ends with the start of the implementation process of the selected LND.
By reviewing the implemented LND, the choices made previously are assessed (Simon, 1977). This may lead to adaptations in the LND.

3.4 Creation of scenarios for the case example

3.4.1 External scenarios

In this paragraph we will illustrate the creation of external scenarios for the company introduced in chapter 2.
Following the procedure suggested in figure 3.4, we will present some examples of external factors, their potential values and the construction of external scenarios.

Factors and ranges of values

We will first discuss some important external factors for the consumer electronics industry, the multinational company's area of activity (see also figure 3.3):

Factors *'new market in Eastern Europe'* and *'new market in Southern Europe'*, $e^M_{Eastern-Europe}$ and $e^M_{Southern-Europe}$:
Given the changed political situation in Eastern Europe, the disappearance of trade barriers in the European Union and the economic growth in both Eastern and Southern Europe, it is anticipated that a new market may develop in Eastern Europe with a turnover of up to 10 billion EURO and that a substantial growth of up to 100% may take place in the Southern European market. Like the example on page 53, this can be represented by the values of the factors $\lambda_{e^M_{Eastern-Europe}}$ and $\lambda_{e^M_{Southern-Europe}}$, where:

$\lambda_{e^M_{Eastern-Europe}} \in [0, \text{10 billion EURO}]$,
$\lambda_{e^M_{Southern-Europe}} \in [0, 100\%]$

For the construction of external scenarios, interesting values are for instance:
$\lambda^M_{Eastern-Europe} = 10$ billion EURO and $\lambda^M_{Southern-Europe} = 100\%$, representing the extreme situation where in Eastern Europe a new market with a 10 billion EURO turnover will emerge and in Southern Europe a growth of 100% will take place, $\lambda^M_{Eastern-Europe} = 0$ and $\lambda^M_{Southern-Europe} = 0$, representing another extreme situation where no new market in Eastern Europe develops and no growth takes place in the Southern European market, $\lambda^M_{Eastern-Europe} = 2$ billion EURO and $\lambda^M_{Southern-Europe} = 50\%$, representing 'in between' alternatives in which in Eastern Europe a market of 2 billion EURO develops and in Southern Europe the market grows by 50%.

Factor *'transport time'*, $e^M_{transport-time}$:
Due to the rapid disappearance of trade and transport barriers between European countries, international transport and distribution at all levels of the logistics network are becoming less time-consuming. Theoretically, a time reduction ranging from 0% to 100% may occur. A more realistic value, which is expected by Cooper et al. (1991), is an average reduction in time of 50%. This results in $\lambda_{e^M_{transport-time}} = 50\%$, where $\lambda_{e^M_{transport-time}}$ represents the time reduction in international transport and distribution.

Factor *'lead times'*, $e^M_{lead-times}$:
As described in chapter 2, several companies in the same line of industry are already advertising a guaranteed 48 hours delivery time. It depends on the success of the competitors and the demands of the market whether or not lead time really becomes an issue in competition. Therefore we take as a range for the lead time 24 to 72 hours. Using our notation, $\lambda_{e^M_{lead-times}} \in [24, 72$ hours], where $\lambda_{e^M_{lead-times}}$ represents the lead time to be guaranteed to the customers.

For the construction of external scenarios, $\lambda_{e^M_{lead-times}}$ $\in$\{24, 48, 72 hours\} are examples of interesting values for the factor $e^M_{lead-times}$.

Factor *'price'*, e^M_{price}:
Besides the competition in customer order lead time, there is also competition in the sales price of the products. The expected reduction in sales prices in the industry ranges between 0% and 20%. So, $\lambda_{e^M_{prices}} \in$ [-20, 0%], where $\lambda_{e^M_{prices}}$ represents the change in the level of sales prices in the consumer electronics industry.
For the construction of external scenarios, interesting values for the factor e^M_{prices} are for example 0%, -10% or - 20%.

Factor *'fuel rates'*, $e^M_{fuel-rates}$:
Due to policy developments prompted by overcrowded roads and increasing environmental awareness, especially in Western Europe, it is very likely that fuel rates will increase, maybe even up to 100%. This means that $\lambda_{e^M_{fuel-rates}} \in$ [0, +100%], where $\lambda_{e^M_{fuel-rates}}$ represents the change in the fuel rates.
The two extreme values 0% and 100% are options that may be interesting as values for the factor $e^M_{fuel-rates}$ in an external scenario. As a third value, an increase of 25% is suggested by O'Laughlin et al. (1993).

Factor *'telecommunication and information management'*, $e^T_{telecommunication}$:
Developments in telecommunication and information management will affect the future role of plants, warehouses, ordering processes, customer service levels etc. The range of values $\lambda_{e^T_{telecommunication}}$ of this factor can be defined for example as \{slow (Sl), moderate (M), fast (F)\}. It is expected that these developments will move forward fast.

Factor *'flexible production and warehousing techniques'*, $e^T_{flexible-production-and-warehousing-techniques}$:
This development also affects the future role of warehouses and plants. Its value $\lambda_{e^T_{flexible-production-and-warehousing-techniques}}$ can be qualified for instance as 'stabilizing' (St), 'improving' (Im) or 'breaking through' (B). It is expected that Im is a realistic value.

Factor *'outsourcing, co-makership'*, $e^O_{outsourcing-and-co-makership}$:
As a consequence of increasing competition, many production companies are focusing (or refocusing) on their core business. This creates an opportunity for transport agencies to extend their services by transforming themselves into "logistics service providers" that also offer such services as warehousing, order processing, packaging and even assembly activities. These services may remain on the same level (Rs) or increase considerably (Ic). It is expected that Ic is a realistic value for the factor $e^O_{outsourcing-and-co-makership}$.

Factor *'total quality management'*, $e^O_{total-quality-management}$:
To enable the reduction of logistics costs and the improvement of the customer service level, concepts of total quality management have been developed. The attention for this concept may increase (I), remain constant (C) or reduce (R). The expected value $\lambda_{e^O_{total-quality-management}}$ is C.

Table 3.1 gives an overview of these examples of factors that are important for the industry. For each factor, a range of values is shown, as well as some interesting values for the development of external scenarios. For some factors, only one single value for the development of external scenarios is selected. Following Porter (1985), we classify these factors as 'predetermined', arguing that these factors represent developments which are apparent and to a large extent predictable. From table 3.1

Factor	*Class*	*Range of values*	*Values for external scenarios*
New market East. Europe	e^M	[0,10 billion EURO]	0, 2, 10 billion EURO
New market South. Europe	e^M	[0,100%]	0, 50, 100%
Lead time	e^M	[24, 72 hours]	24, 48, 72 hours
Price	e^M	[-20, 0%]	-20, -10, 0%
Fuel rates	e^M	[0, 100%]	0, 25, 100%
Transport time	e^M	[0, 100%]	50%
Telecommunication and information management	e^T	Sl, M, F	F
Flexible production and and warehousing techniques	e^T	St, Im, B	Im
Outsourcing and co-makership	e^O	Rs, Ic	Ic
Total quality management etc.	e^O	I, C, R	C

Table 3.1: External factors and their values for the case example.

it will be clear that the factors transport time, telecommunication and information management, flexible production and warehousing techniques, outsourcing and total quality management are predetermined, but in a very qualitative way. The other factors - new markets, lead time, price and fuel rates - are classified as 'uncertain', which means that their value can differ per scenario.
To some factors, quantitative values can be assigned (e.g., lead time, fuel rate, price); other factors are only represented by mainly qualitative descriptions (e.g., outsourcing, total quality management).

In the next paragraph we will show how external scenarios can be constructed by eliminating the inconsistent combinations of the values of the external factors that are shown in table 3.1.

Construction

In accordance with the definition on page 53, an external scenario for the multinational company can be denoted as:

$$\begin{aligned}
S_{ext} &= \Lambda_{eM} \bigcup \Lambda_{eT} \bigcup \Lambda_{eO} \bigcup \Lambda_{eL} \\
&\text{where} \\
\Lambda_{eM} &= \{\lambda_{eM_{Eastern-Europe}}, \lambda_{eM_{Southern-Europe}}, \lambda_{eM_{lead-time}}, \lambda_{eM_{price}}, \\
&\quad \lambda_{eM_{fuel-rates}}, \lambda_{eM_{transport-time}}\}, \\
\Lambda_{eT} &= \{\lambda_{eM_{telecommunication}}, \lambda_{eM_{flexible-prod.-and-wareh.-techniques}}\}, \\
\Lambda_{eO} &= \{\lambda_{eM\,outsourcing}, \lambda_{eM_{total-quality-management}}\}, \\
\Lambda_{eL} &= \emptyset \\
&\Lambda_{eM}, \Lambda_{eT}, \Lambda_{eO}, \Lambda_{eL} \text{ internally and mutually consistent}
\end{aligned}$$

It will be clear that the differences in the external scenarios described above are mainly determined by the values of the 'uncertain' factors new markets, lead time, price and fuel rates and that the 'predetermined' factors are part of every scenario.

Although our simplified case example has only five factors representing 'uncertain' elements, with three or five different options for each of them, a total of at least 3^5 =243 different combinations of values of external factors can be made. We are only interested in the consistent combinations, which form an external scenario.

To identify consistent sets of values of factors, several methods and techniques are available (see for instance, Schwartz 1991, Reibnitz 1988, Godet 1987, Huss and Honton 1987, Schnaars 1987, Porter 1985). We will follow almost the same route as the one proposed by Porter (1985), combining potential values of different factors and considering their consistency.

Let us start by looking at how consistencies and inconsistencies can be detected in the elements of competition we are considering: the customer order lead time and the sales price of the products.

It is not sure whether the competition will focus on sales price or on lead time. Extreme reductions in both seem unrealistic. However, it is certain that the market, encouraged by the competitors, will demand lower prices or shorter lead times. Table 3.2 shows five combinations which represent realistic developments in the industry.

	Lead time		
Sales price	*72 hours*	*48 hours*	*24 hours*
0 %	i	i	c
- 10 %	i	c	c
- 20 %	c	c	i

Table 3.2: Consistencies (c) and inconsistencies (i) in competitive elements 'lead time' and 'sales price' in external scenarios.

As a next step, we combine these five consistent combinations with the factor 'fuel rates'.

The development of the fuel rates affects the potential reduction of the sales price. An increase of fuel rates makes substantial sales price reductions unrealistic. This means that we can consider the combination of a fuel rate increase by 100% with any sales price reduction inconsistent. The same holds for the combination of a fuel rate increase by 25% and a sales price reduction of 20%.

In the case of a 24 hours delivery time, the frequency of transport is high and, consequently, the transportation costs will constitute a larger part of the sales price. So a sales price reduction and an increase of the fuel rates is again an unrealistic option.

The results are represented in table 3.3.

The fourth and fifth uncertain factors in our case example are the development of a new market in Eastern Europe and the growth of the existing market in Southern Europe. The determining trends related

Elements of competition		*Fuel rates*		
Lead time	*Sales price*	*same*	*+ 25 %*	*+ 100 %*
24 hours	*0 %*	c	c	c
	- 10 %	c	i	i
48 hours	*- 10 %*	c	c	i
	- 20 %	c	i	i
72 hours	*- 20 %*	c	i	i

Table 3.3: Consistencies (c) and inconsistencies (i) in factors 'lead time', 'sales price' and 'fuel rates' in external scenarios.

to these factors (i.e. harmonization in the European Union, economic growth in the South of Europe and political changes in the Eastern part of Europe) may lead to all nine possible combinations of these two factors. Moreover, these trends are virtually independent of the factors 'sales price', 'lead times' and 'fuel rates'. This means that we can combine each of the nine options of the market developments in Southern and Eastern Europe with the eight internally consistent combinations of 'fuel rates', 'lead time' and 'sales price'.

We have now combined the possible values of all uncertain factors and have selected 9x8=72 consistent combinations out of 243 possible combinations. This means that we still have 72 external scenarios[1]!

3.4.2 Company scenarios

The company has to select external scenarios as a basis for its company scenarios[2]. To illustrate the construction of company scenarios, we select one single external scenario *'High service against high cost rates,*

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[1] Note that in all 72 scenarios, the 'predetermined' factors (see table 3.1) are of major importance.

[2] How to deal with the high number of 72 external scenarios in the LND process will be discussed in chapter 4.

Factor	*Class*	*Value*
New market in Eastern Europe	e^M	10 billion EURO
New market in Southern Europe	e^M	100%
Lead time	e^M	24 hours
Price	e^M	0%
Fuel rates	e^M	+100%
Transport time	e^M	50%
Telecommunication and information management	e^T	F
Flexible production and warehousing techniques	e^T	Im
Outsourcing	e^O	Ic
Total quality management	e^O	C

Table 3.4: External factors and their values for the external scenario 'High service for expanding markets against high cost rates'.

while markets expand' (see table 3.4). This specific external scenario describes the future as follows:

> In the existing markets for consumer electronics, the customer order lead time will be reduced to 24 hours, while the sales price level will remain constant. A new market in Eastern Europe will develop with a turnover of 10 billion EURO and a growth of 100% will occur in the Southern European market. The fuel rates are expected to double and, in consequence, transport costs will increase substantially. International transport and distribution will become 50% less time-consuming. The developments in telecommunication and information management will move forward fast, flexible production and warehousing techniques will improve gradually, outsourcing and co-makerships will increase considerably and the attention for total quality management will remain constant.

The construction of company scenarios is to some extent comparable to the construction of external scenarios. The MILP model developed in chapter 2 plays an important role, as will be explained. In the translation of an external scenario into a company scenario, we distinguish three types of factors and values:

- *The factors and values that are input for the MILP model.*
  These factors are related to products, markets, demand forecasts, cost rates, optional types, locations and sizes of facilities, lead times, etc. Many of these factors belong to the class c^E. We denote this set of values as $\Lambda_{input-LND}$.

- *The factors and values that are the outcome of the MILP model.*
  In fact, these values are the choices for the D_{flows} and $D_{facilities}$ defined in section 3.1. They concern the type, number, locations and activities of facilities and the transport flows between the facilities. We denote this set of values as $\Lambda_{specify-LND}$.
  Note that the value of an input factor for the MILP model, for instance a fixed customer warehouse allocation, may also be element of $\Lambda_{specify-LND}$.

- *The factors and values that are determined otherwise.*
  These are factors and values that are not related direct to the calculations of the MILP model, but that are nonetheless very important in the development of and LND. These are mainly the factors that represent technological, administrative and human resource aspects (factors of the classes c^T, c^A, c^H). The values of these factors are often globally set when an external scenario is translated into company scenarios. Sometimes the values of these factors generate values of the factors in $\Lambda_{input-LND}$, e.g. technological developments that lead to maximum or minimum sizes of plants. When calculations are made with the MILP model, the values of these factors are often specified in greater detail and used as evaluation criteria for the LND proposed by the MILP

model, e.g. the type of personnel that is needed. We denote this set of factors and values as $\Lambda_{evaluate-LND}$.

In addition to the definition of a company scenario on page 54, the following definition may also be used:

$S_{comp} = \Lambda_{input-LND} \bigcup \Lambda_{specify-LND} \bigcup \Lambda_{evaluate-LND}$
where
$\Lambda_{input-LND}, \Lambda_{specify-LND}, \Lambda_{evaluate-LND}$ internally and
mutually consistent.

Figure 3.5 illustrates the construction of a company scenario as a step by step procedure, using this distinction between two sets of values of factors. We will explain each of the steps in this process for the case example:

Step 1. Determine factors and values that are input for the MILP model:
The values of the external factors $e^M_{Eastern-Europe}$, $e^M_{Southern-Europe}$, $e^M_{lead-time}$, e^M_{price}, $e^M_{fuel-rates}$ and $e^M_{transport-time}$ of the external scenario 'high service against high cost rates' provide information for the company factors of class c^E. The factors $e^M_{fuel-rates}$ and $e^M_{transport-time}$ are predetermined. So, the values of the related company factors $c^E_{fuel-rates}$ and $c^E_{transport-time}$ are respectively +100% and 50%.
On the basis of the values of the external factors $e^M_{Eastern-Europe}$ and $e^M_{Southern-Europe}$, the company has to decide whether or not to enter the Eastern European market and to expand its business in the Southern European market. For example, the company may decide to enter the Eastern European market and aim at a market share of 50%; at the same time, it decides to increase its market share in the Southern European market, aiming for an increase in turnover of as much as 200%.

Step 1. Determine factors and values that are input for the MILP model.

- Determine interesting factors. Start with the company factors that can be translated direct from the external scenario. Focus especially on the entrepreneurial factors.
- Determine ranges of values for each of the individual factors.
- Select specific mutually consistent values for each of these individual factors.

Result: A set $\Lambda_{input-LND}$.

Step 2. Determine factors and values that specify an LND.

- Determine factors that represent $\{D_{flows}, D_{facilities}\}$.
- Determine ranges of values for each of the individual factors.
- Select specific mutually consistent values for the individual factors, based on $\Lambda_{input-LND}$. The MILP model of chapter 2 will be very helpful.

Result: A set $\Lambda_{specify-LND}$.

Step 3. Evaluate the LND.

- Determine interesting factors. Start with the company factors that can be translated direct from the external scenario. Focus especially on the technological, administrative and human resource factors.
- Determine ranges of values for each of the individual factors.
- Select specific mutually consistent values for each of these individual factors, based on $\Lambda_{specify-LND}$.

Result: A set $\Lambda_{evaluate-LND}$.

Step 4. Evaluate the mutual consistency of values.

- Combine the values assigned in the steps 1, 2 and 3 into consistent combinations. This completes the company scenario.

Figure 3.5: Procedure for the development of a company scenario.

For the existing market, too, the company has to decide on the turnover target figures. These entrepreneurial decisions are represented by the following company factors and ranges of values[3]:

$c^E_{existing-European-market}$ with value
$\lambda_{c^E_{existing-European-market}} \in [0, 15\%]$, representing the expected increase in the company's turnover in the existing European market,

$c^E_{Eastern-European-market}$ with value
$\lambda_{c^E_{Eastern-European-market}} \in$ [0, 5 billion EURO], representing the company's expected turnover in the Eastern European market,

$c^E_{Southern-European-market}$ with value
$\lambda_{c^E_{Southern-European-market}} \in [0, +200\%]$, representing the expected increase in the company's turnover in the Southern European market.

Table 3.5 shows these factors and some examples of specific values that are interesting for the construction of company scenarios.

Besides the decisions concerning entering the market and targeted turnover, for each market decisions need to be taken concerning product ranges, sales prices and lead times to be offered.

In order to determine the appropriate product range for each market area, it will be necessary to conduct research on the consumers, competitor behavior, etc.

At this stage we specify that the values for each of the factors $c^E_{products-existing-markets}$, $c^E_{products-Eastern-Europe}$, $c^E_{products-Southern-Europe}$ must be a subset of the set {existing, new}, where 'existing' represents the set of the existing products and 'new' the set of new products (see table 3.5).

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[3] Note that a value 0 represents the company's decision not to enter this specific market.

External scenario High service against high cost rates, while markets expand			*Company scenario*			
Factor	Class	Value	Factor	Class	Range of values	Specific values
Fuel rates	e^M	+100%	Fuel rates	c^E	+100%	+100%
Transport times	e^M	50%	Transport times	c^E	50%	50%
Markets			Markets			
			- existing markets	c^E	[0, +15] %	0, +5, +15%
- Eastern Europe	e^M	10 billion EURO	- Eastern Europe	c^E	[0, 5] billion EURO	0, 2, 5 billion EURO
- Southern Europe	e^M	100%	- Southern Europe	c^E	[0, +200] %	0, +50, +200%
			Products			
			- existing markets	c^E	{existing, new}	{existing, new}, {existing}, {new}
			- Eastern Europe	c^E	{existing, new}	{existing, new}, {existing}, {new}
			- Southern Europe	c^E	{existing, new}	{existing, new}, {existing}, {new}
Lead time			Lead time			
- existing markets	e^M	24 hours	- existing markets	c^E	[12, 36] hours	12, 24, 36 hours
			- Eastern Europe	c^E	[2, 7] days	2, 4, 7 days
			- Southern Europe	c^E	[24, 72] hours	24, 36, 72 hours
Price			Price			
- existing markets	e^M	-10%	- existing markets	c^E	[-30, 0]%	-30, -10, 0%
			- Eastern Europe	c^E	[-50, +30]%	-50, 0, +30%
			- Southern Europe	c^E	[-20, 0]%	-20, -10, 0%

Table 3.5: Factors of class c^E of the company scenario and their relationship with the selected external scenario.

In order to set suitable sales prices and lead times for each potential market area and product range, more detailed investigations are needed. For the sake of simplicity, we will only discuss sales prices and lead times for the three market areas distinguished so far. For each of these, the values of the factors related to sales prices and lead times depend strongly on the competitive strategy adopted for the area concerned. In general, there are two options for a competitive strategy (Porter, 1985): competition by differentiation in customer-valued items or competition in cost leadership. For example, if a company opts for competition in customer-valued items for the existing market, a lead time reduction to 24 hours or even to 12 hours may be required. Moreover, this reduction would ideally have to be realized before the competition becomes aware of it. On the other hand, if a company decides to compete for cost leadership, customer order lead time may have to be reduced to, say, 36 hours only. The same line of reasoning holds for the markets in Eastern and Southern Europe. This results in the following factors:

$c^E_{sales-price-existing-markets}$ $\lambda_{c^E_{sales-price-existing-markets}}$	with value ∈ [-30, 0%], representing the expected change in sales price the company will offer in the existing markets,
$c^E_{lead-time-existing-markets}$ $\lambda_{c^E_{lead-time-existing-markets}}$	with value ∈ [12, 36 hours], representing the expected lead time the company will offer in the existing markets,
$c^E_{sales-price-Eastern-European-market}$ $\lambda_{c^E_{sales-price-Eastern-European-market}}$	with value ∈ [-50, +30%], representing the sales price level the company will offer in the Eastern European market. The level is specified in comparison with the sales price offered in the existing markets,

$c^E_{lead-time-Eastern-European-market}$ with value
$\lambda_{c^E_{lead-time-Eastern-European-market}}$ $\in$ [2, 7 days], representing
the expected lead time the company will offer in the Eastern European market,

$c^E_{sales-price-Southern-European-market}$ with value
$\lambda_{c^E_{sales-price-Southern-European-market}}$ $\in$ [-20, 0%], representing
the expected change in sales price the company will offer in the Southern European market,

$c^E_{lead-time-Southern-European-market}$ with value
$\lambda_{c^E_{lead-time-Southern-European-market}}$ $\in$ [24, 72 hours], representing
the expected lead time the company will offer in the Southern European market.

The factors and values that represent the decisions discussed above, are summarized in table 3.5.
Note that, if we combine each of the specific values of the fourteen company factors in table 3.5, this already results in 3^{12}= 0.5 billion potential company scenarios![4]

Step 2. Determine the factors and values that specify an LND:
In section 3.1, we stated that a specific LND has been created when the decisions D_{flows} and $D_{facilities}$ have been made. So, the company factors and their values should represent these decisions, focusing on type, number, locations and activities of facilities and the transport flows between the facilities. A detailed specification of these company factors is provided by the set of decision variables of the MILP model developed in chapter 2. The DSS SLAM (see also appendix A) and the MILP model can be used to determine specific values for these factors. Figure 3.6 provides a detailed picture of the contribution of the MILP model and the DSS to the design of alternative logistics networks.

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[4] In chapter 4 we will discuss how to deal with large numbers of scenarios.

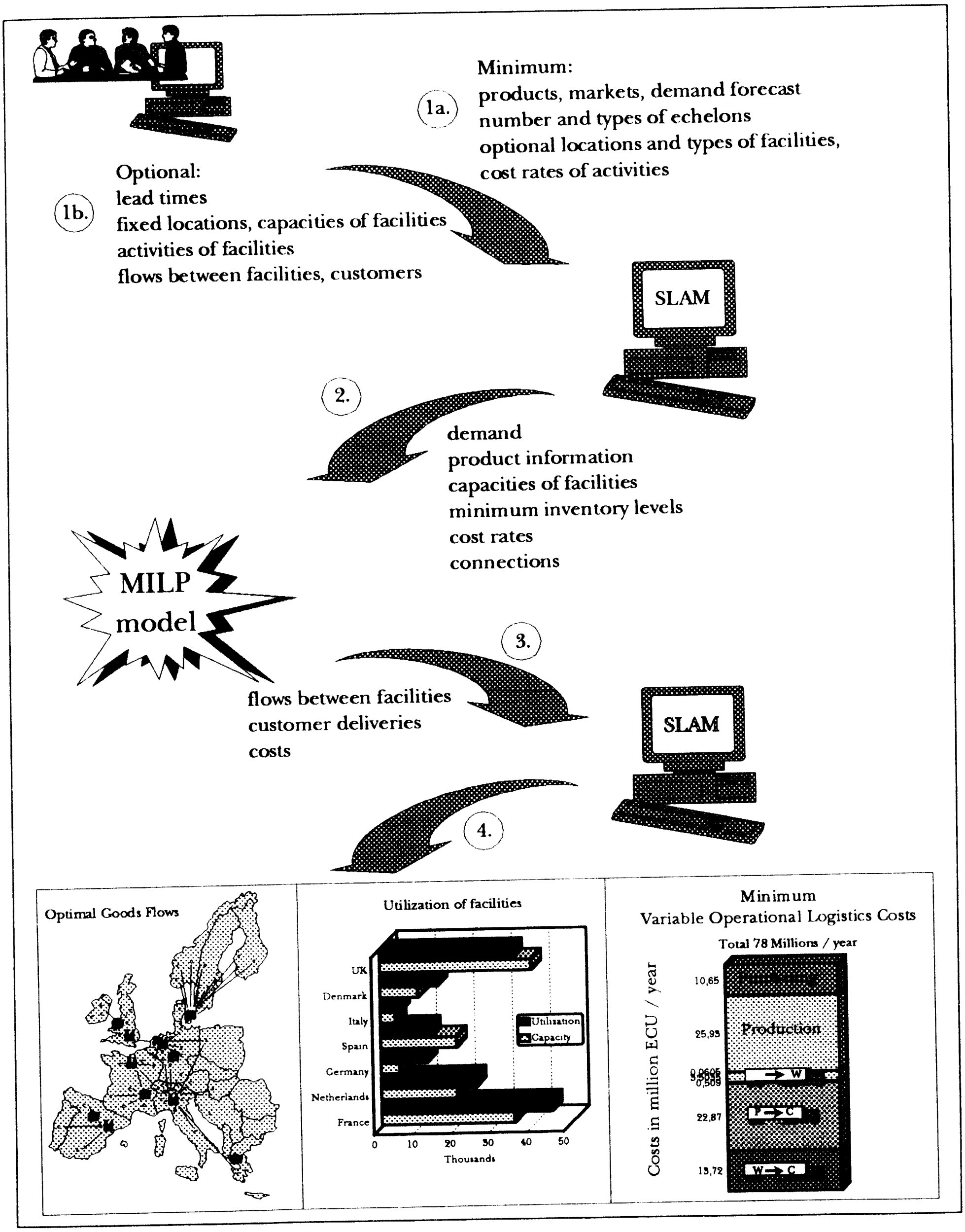

Figure 3.6: Contribution of DSS SLAM and MILP model.

The minimum information needed for the DSS and the MILP model is information on products, markets, demand forecasts, optional number and types of echelons in the logistics chain, optional types and locations of facilities and cost levels of the activities (figure 3.6, 1a). If more details on the business choices are available, information on customer service levels (represented by lead time and inventory levels), fixed locations and activities of facilities, minimum and maximum sizes of facilities and transportation flows between facilities can be added as input for the DSS and the MILP model (figure 3.6, 1b).
On the basis of this information, the DSS and the MILP model determine the values of the factors concerning the facilities and the flows in an LND with the lowest possible level of total variable logistics costs (figure 3.6, 2 and 3).
The values concerning the facilities and flows constitute a logistics network structure, which is reported by the DSS on a range of quantitative aspects (figure 3.6, 4), such as number and sizes of facilities, customer deliveries, lead times and logistics costs.

Step 3. Evaluate the LND:
In this step the LND suggested by the MILP model in the previous step is evaluated and its consequences are worked out. The factors and values in the external scenario that have not yet been translated into company factors (or only to generate input for the LND in step 1.) are: 'Telecommunication and information management', 'Flexible production and warehousing techniques', 'Outsourcing' and 'Total quality management'. These are external factors of the classes e^T and e^O, which can be translated into company factors of classes c^T, c^A and possibly c^H. We will briefly illustrate the translation of the external factor 'Telecommunication and information management' into company factors. The value of this factor in the external scenario is F ('developments move forward fast'). Examples of these developments are: multi-

media communication, EDI, interorganizational information systems, Internet, etc. All these developments contribute to 'moving the right information to the right place at the right moment'. As this is done electronically, a tremendous speed of information processing may be the result. This means that for instance the information of an order can be available at a plant at any location in the world within seconds after the order is placed. This opportunity will enable to reduce customer order lead times and inventories tremendously and enables worldwide cooperation. Moreover, the customer may have product specifications at his disposal within seconds, too, which increases the sales potential. If the company in our case example considers reducing lead times and at the same time reducing costs and maybe also entering the new Eastern European market and increasing turnover in the existing market and in Southern Europe, these developments in telecommunication and information management are both a challenge and a necessity. Of course, in order to benefit from these developments, investments in technology, people, organization, procedures, standardization, etc. are required. These investments are represented for example by the following company factors:

- $c^{A}_{business-procedures}$
  which represents the degree to which business procedures in general and administrative procedures in particular are redesigned. Potential values of this factor are alternative levels of redesign.

- $c^{A}_{European-cooperation}$
  representing logistics cooperation in Europe. Potential values of this factor are for instance alternative types of cooperation between plants by supporting each other in dealing with fluctuations in demand.

- $c^{T}_{computer-infrastructure}$
  which represents the hardware and software needed to fulfil information processing needs. Potential values of this factor are alternative plans for the hardware and software infrastructure.

- $c^{H}_{personnel}$
  representing the skills, knowledge and attitudes that are needed to reap the benefits of the developments. Potential values of this factor are an alternative composition of the workforce, management and staff needed.

Of course, only a few examples of potential factors are given. Moreover, during the process of developing a company scenario, they need to be narrowed down into more detailed factors.

Step 4. Evaluate the mutual consistency of values:
As a final step, the mutual consistency of all the values of factors in the company scenario must be checked. This means that the internal and mutual consistency of each of the three sets of values $\Lambda_{input-LND}$, $\Lambda_{specify-LND}$ and $\Lambda_{evaluate-LND}$ has to be examined. These consistent combinations can be found with the help of the same method as the one used for the construction of external scenarios (see paragraph 3.4.1). Moreover, when fixing the values in the set $\Lambda_{input-LND}$, the company is in fact making strategic entrepreneurial choices, which usually lead to consistent combinations. For example, if the company decides to compete in customer-valued items in Europe, the lead times need to be set at a minimum level: 12 hours in the existing markets, 2 days in the Eastern European market and 24 hours in the Southern European market. In this strategy, the sales prices in the existing markets might follow the general trend in industry, meaning that they would remain the same. For the Eastern European market the company might decide to introduce the same sales prices as in the existing markets, while the

Southern European market would be offered a reduction in sales prices of about 10%.

Although this is a rather rough description of how business choices are made, it illustrates the line of reasoning which ultimately leads to an internally consistent set of values of factors based on entrepreneurial choices.

The values in $\Lambda_{specify-LND}$ are usually mutually consistent, because they are based on an optimal solution of a MILP model. The values are also consistent with the information used as input for the MILP model, i.e. the values in $\Lambda_{input-LND}$. In fact, the inconsistencies can be created by $\Lambda_{evaluate-LND}$. This may lead to changes in the LND or changes of the values in $\Lambda_{input-LND}$ or $\Lambda_{evaluate-LND}$. This often causes a return loop in the scenario development process. This issue is dealt with in chapter 4.

3.5 Evaluation

In this chapter, we discussed some elements of the process and the tools for the development of an LND for a company:

We discussed the external environment, developed an external scenario, and showed how a company scenario and its LND can be developed. In fact, each external scenario can be translated into several company scenarios. As part of each company scenario, a logistics network is designed. The LNDs are developed with the help of a DSS and an MILP model.

Scenario development, especially the construction of company scenarios, is a process in which different insights of management teams and experts in functional areas are combined. It will be clear that the factors, the factor values and, in consequence, the company scenarios and its LNDs, will differ for each group of scenario developers. Nevertheless, the procedure discussed may well improve the quality and the speed of scenario development.

We described the process of developing a company scenario and, more particularly, its LND as a straightforward, technical process. Of course, a large number of people, from various departments and business units at various organizational levels, will be involved in the design process: to initiate the process, to gather the necessary information, to develop scenarios, to gain insight into the merits and disadvantages of the proposed alternatives, to make proposals for improvements, to select the best alternative, to authorize the decisions, etc. Due to the complexity of the problem and the involvement of many actors at many organizational levels, many loops and cycles will occur in the development process.

The overall process for defining the most competitive LND for a company will be discussed in the next chapter in a framework for the design of logistics networks.

Chapter 4

A framework for LND

4.1 Introduction

In chapter 1 we compared eight existing frameworks for designing a logistics network, concluding that the following elements could be improved or added:

- Focusing simultaneously on production and distribution.
- Analyzing the design process as a strategic decision-making process.
- Taking account of the involvement of different parties and disciplines.
- Structuring the process of scenario development, in which both qualitative and quantitative evaluation criteria are used.
- Specifying the valuable role of a DSS in the design process.

In this chapter we will develop a framework that meets these criteria. The basis for the framework has been explained in section 3.3, which described designing a logistics network as a strategic decision process, using scenarios.

The simultaneous focus on production and distribution in the framework is achieved by using external and company scenarios, which consider the company and its environment as an integrated whole, including production factors as well as factors related to distribution. In addition, the MILP model developed in chapter 2 and discussed in some detail in section 3.4.2, covers both production and distribution decisions.

In this chapter we will explain how the various participants that play an important role are integrated in this framework. We will specifically look at their interaction during the decision-making process, the so-called return loops. In addition, we will further discuss the use of scenarios and the support of DSSs.

For the development of the framework we used several real-life case studies in which we were involved. We combined this experience with existing frameworks and with theoretical concepts related to decision-making and strategy formulation.

4.2 Participants in the framework

In our framework we distinguish three types of participants: top management, the task force and the field (see figure 4.1). In specific situations more categories of participants may be involved. In those cases, the framework may be adapted. However, in the majority of the cases in which we were involved, three parties played a role. In one national case only two parties were involved.

We will discuss the roles of the participants below.

Chakravarthy and Lorange (1991, see figure 4.2) also distinguish several

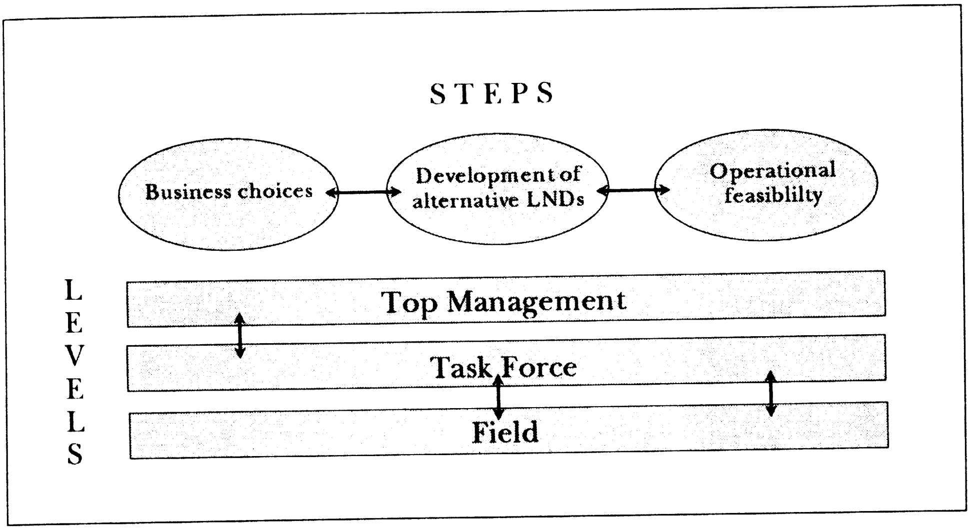

Figure 4.1: A global view of a new framework for LND.

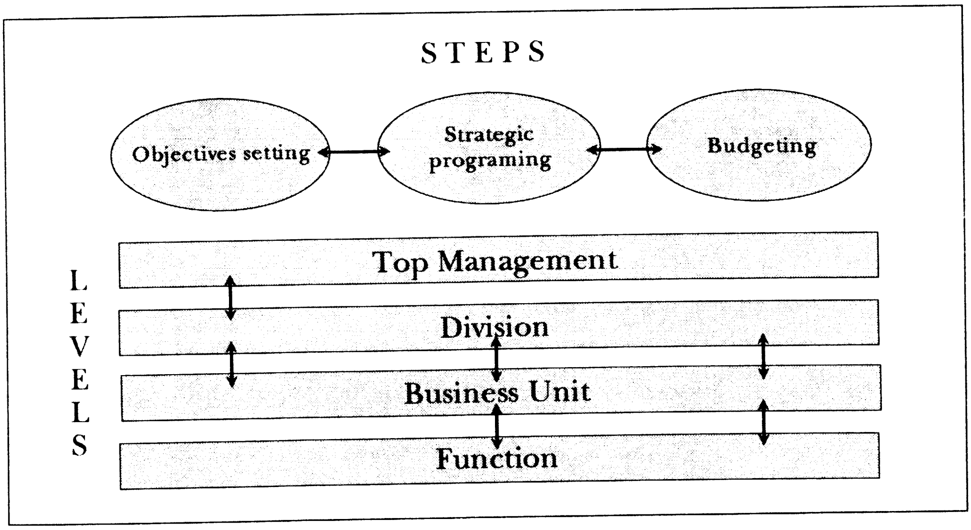

Figure 4.2: A framework for strategic planning (Chakravarthy and Lorange, 1991).

parties in the strategic decision-making process. The conceptual framework they have developed describes the management of developing a business strategy for a multi-business firm. Although our framework does not specifically focus on multi-business firms, there are several similarities between the frameworks.

We will now describe the roles of the participants in our framework and relate them to the framework of Chakravarthy and Lorange.

The top management

The top management plays a major role in the process of designing a competitive logistics network for the company: they initiate the process of developing a LND, often on the basis of suggestions from the field; they determine the strategic directions of the firm and possibly develop some ideas for the design of the logistics network; they establish a task force to elaborate their ideas and to develop alternative LNDs; and they take the final decision as to the LND that will be implemented.
In the framework of Chakravarthy and Lorange, the top management plays a similar role. In their framework, the top management concentrates on objectives setting. In this phase the firm's strategic direction is determined. The vision of the chief executive officer and his or her management team should be embedded in these objectives. For each division and business unit in the firm, the top management team negotiates goals that are consistent with these objectives.
The stage of objectives setting is part of the phase of making business choices (particularly the entrepreneurial choices) in our framework.

The task force

The ultimate responsibility of the task force is to develop alternative LNDs, which involves providing support to the top management in working out their objectives and ideas, as well as communicating and coordinating the process with the business units (the field).

The task force is usually made up of logistics, finance and marketing experts. In addition to corporate experts, the task force often includes representatives from the field, to facilitate coordination with the field. Depending on the phase of the design process, other specialists may be involved in the work of the task force. Within the task force often several working groups are appointed whose task it is to explore new options and side constraints for an LND, such as standardization of products and packaging materials and the introduction of EDI.

Sometimes the task force is embedded in the existing organization (e.g., the European logistics department), sometimes a special working group is established which is allocated to the top management team for this special purpose. In paragraph 4.6 we will show two examples.

The phase of 'development of alternative LNDs' in our framework is related to the phase of 'strategic programing' of the framework of Chakravarthy and Lorange. In the phase of 'strategic programing', the strategies identified in the objectives setting stage are developed, the action programes proposed and the expected contributions to the strategic plans evaluated. In their framework, the 'strategic programing' is conducted at the levels 'division', 'business unit' and 'function' of a company, whereas in our framework a specially appointed task force is the main actor in the phase of 'development of alternative LNDs'. Note that the task force often includes a representative of a division or a business unit.

The field

The field consists of all actors involved in the operations. Sometimes the field induces the top management to improve the logistics performance and usually the field is involved in the process of designing a new logistics network. They provide the task force with data on cost rates, demand forecasts, customer locations, etc. Moreover, they assist

in the evaluation of the operational feasibility of the LND, by investigating the requirements for its implementation. This concerns not only budget needs, but also the need for human resources, information technology, administrative processes, etc.
In the case of a multi-business firm, the field can be seen as a combination of the categories 'division', 'business unit' and 'function' in the framework of Chakravarthy and Lorange. The 'budgeting' phase in their framework deals with the budgets required for realizing an LND within the business units and their operational functions. This is comparable to our phase of 'operational feasibility', although we do not focus solely on the financial requirement for implementing an LND.

Both frameworks need to address the issue of communication at the interface between top-down and bottom-up developed proposals, where the strategic decisions are made (Leemhuis, 1985). According to Chakravarthy and Lorange, the purpose of the 'strategic programing' phase is twofold: (1) to forge an agreement between divisional, business unit, and functional managers on the strategic programs and (2) to deepen the involvement of functional managers in the elaboration of the strategies that were tentatively selected in the first stage. Moreover, they see proper communication as a key challenge for both divisional and business managers, although day-to-day tasks can be so demanding that it is difficult to pick up this challenge. In our framework, we introduce the task force as an actor that might solve this problem.

4.3 Scenarios in the framework

Before we embarking on a detailed description of the steps in the new framework, we need to discuss two more topics related to the use of scenarios.

In chapter 3 we saw that the number of external or company scenarios that can be developed may be extremely high. We will now show how to deal with this. Another matter we will discuss is the presentation of scenarios. In chapter 3, we described the scenarios in terms of sets of values of factors, just to illustrate the process of construction. We will now look at how scenarios may be presented as a basis for decision-making.

4.3.1 Number of scenarios

As each scenario is defined by a set of values of factors, it will be clear that a large number of factors and potential values results in a large number of different scenarios. The number of external and company scenarios should be large enough to represent the different futures and to identify an appropriate LND. On the other hand, in order to avoid scenario development from becoming a time-consuming process, resulting in a confusing number of alternative futures with little variation between them, the number should not be too large.
Wack (1985) and Simpson (1992) suggest that an appropriate number of scenarios is achieved by focusing on the few key variables in the strategic issue that is being considered. Of course, only the scenarios in which consistent sets of values of these factors occur, should be considered, but as we have seen in chapter 3, this may still result in a large number of scenarios.

External scenarios

Although in practice relatively large numbers of scenarios need to be studied, it appears that managers generally are able to handle only a limited number of different scenarios at the same time. Different ideas exist as to the number of external scenarios that can be dealt with simultaneously. Referring to his experience with the development of external scenarios for Shell, Wack (1985) states that "six is far too many". The general consensus is that two, three or at most four external scenarios should be considered at the same time. Simultaneous analysis of a larger number of scenarios becomes 'unmanageable', according to Schnaars (1987), and creates 'confusion' among decision makers (Linneman and Klein, 1985). Analysing only two, three or four scenarios at the same time, also has its disadvantages: in the case of two scenarios, a good-bad discussion may result; in the case of three scenarios, the "middle" one is likely to be selected as the most promising one, or managers may be tempted to compromise by planning towards this 'middle' scenario as suggested by Bell (1982); four scenarios seems to be an appropriate number to consider simultaneously.

In order to be able to handle a much larger number of relevant scenarios[1], Porter (1985) proposes to start by the polar, or most widely separated scenarios; they typically result in maximally different alternatives and thus will provide insight into the range of relevant strategic options that are available. Then, step by step, groups of two, three or four other scenarios can be analyzed.

Company scenarios

The literature offers little insight into what would be an appropriate number of company scenarios. In principle, the recommendations regarding the number of external scenarios to be considered simultaneously can also be applied to company scenarios. However, the number of company scenarios may be quite high[2]. So, it will be necessary to structure the process of selecting the company scenarios that will be de-

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[1] In the real-life cases we considered, 15 to 25 external scenarios were developed.

[2] In the real-life cases in which we were involved, some 60 alternative logistics networks were designed and compared.

veloped in detail. Again, we will follow Porter's (1985) advice to start by the polar, or most widely separated, scenarios. Although Porter suggests to continue by developing, step by step, groups of two, three of four scenarios, it is our experience that it is also possible to use somewhat larger groups of four, five or six scenarios. This view is supported to some extent by Eisenhardt (1990), who argues for the simultaneous development of multiple alternatives. Her main argument is that it is easier to analyze multiple alternatives, because comparisons can be made and comparing alternatives sharpens preferences. She also argues that using multiple alternatives speeds up the decision-making process, because it takes less time to make a comparative analysis of a range of alternatives than of just a few. She states that this is related to the difference between fast and slow decision makers in dealing with alternatives: fast decision makers will usually make a quick comparative 'breadth-not-depth' analysis of the alternatives, whereas slow decision makers are more likely to opt for in-depth analyses.

In strategic decision-making concerning a competitive logistics network, too, a fast decision process is preferred. Nevertheless, a 'breadth-not-depth' analysis of the alternatives is unacceptable, on account of the strategic importance of the decision. The MILP model and the DSS SLAM (see also appendix A) which we use in the development of scenarios enable a relatively fast development and thorough 'in-depth' analysis of the important LND part of a company scenario. So, groups of four, five or six company scenarios can be developed in depth simultaneously, which makes it possible to analyze a large number of company scenarios within the limited time available for the decision-making process. In the real-life cases in which we were involved, only a short list of LNDs was selected for final decision-making by the top management.

4.3.2 Presentation of scenarios

The literature also provides few guiding lines for the presentation of scenarios. Simpson (1992) states that "a scenario should be presented in either a qualitative or a quantitative format and may be of varying length ranging from a few paragraphs to 50 pages", which still provides little solid information on which to base the presentation.

Most of the company scenarios with which we dealt in real life covered about six pages. One or two pages would give a brief overview by presenting the factors and factor values of the specific external and company scenario. The next four or five pages would be used for a summary of the external scenario on which it was based, followed by a description of the business choices that had been made and of the proposed LND. The last part would focus on the evaluation of the LND. In section 4.4 we will discuss these topics in greater detail.

In order to distinguish different scenarios they have to be labelled. This is often done hierarchically. The titles of the company scenarios are related to the external scenario on which they are based and refer to the most salient aspect of the LND. For example, we gave the company scenarios based on the external scenario 'United Europe' names such as 'Nationally oriented distribution' (for a scenario in which the logistics network would use a national warehouse in each country) and 'International oriented distribution' (for a scenario with only a few European warehouses in the LND). A group of related scenarios that take the unification of Europe as a starting point might get the label 'United Europe'. Specific scenarios within this group could be labelled 'United Europe, large growth in Southern Europe, nationally oriented distribution' or 'United Europe, medium growth in Southern Europe, internationally oriented distribution'. The literature provides some remarks and guidelines with respect to labelling scenarios. Linneman and Klein (1985) stress the importance of the scenario label: "it often determines how the scenario will be perceived, regardless of the intent". Simpson (1992) argues for the use of provocative yet meaningful scenario titles that create mental pictures all by themselves like 'Star Wars', 'The Empire Strikes Back', etc. Schnaars (1987) advises against the use of probabilities for the labels of scenarios: "Scenarios are possibilities, not probabilities. It is probably best not to assign probabilities to scenarios, but give them labels referring to the main 'theme', which dominates the scenario."

4.4 Steps in the framework

In this section we will work out the global view of the new framework as shown in figure 4.1.
This will be done by distinguishing several phases in the framework, corresponding to the phases of a strategic decision-making process as discussed in chapter 4.4. Figure 4.3 shows the new framework in detail. We will describe the steps in the framework depicted in figure 4.3 by integrating the use of scenarios, the roles of the participants and the contribution of the DSS SLAM and its MILP model. The ultimate goal of the framework is to create the most competitive LND for a company. This is achieved by developing alternative external scenarios, translating them into company scenarios, evaluating and comparing these scenarios (especially their LNDs), and selecting the most competitive LND for implementation. Besides the development and comparison of new LNDs, the existing LND and its underlying business choices are also described and used as a reference for the new LNDs and their underlying business choices. The existing LND is the starting point for the reorganization process. It gives insight into the business improvements that can be made and it shows which investments are needed to achieve

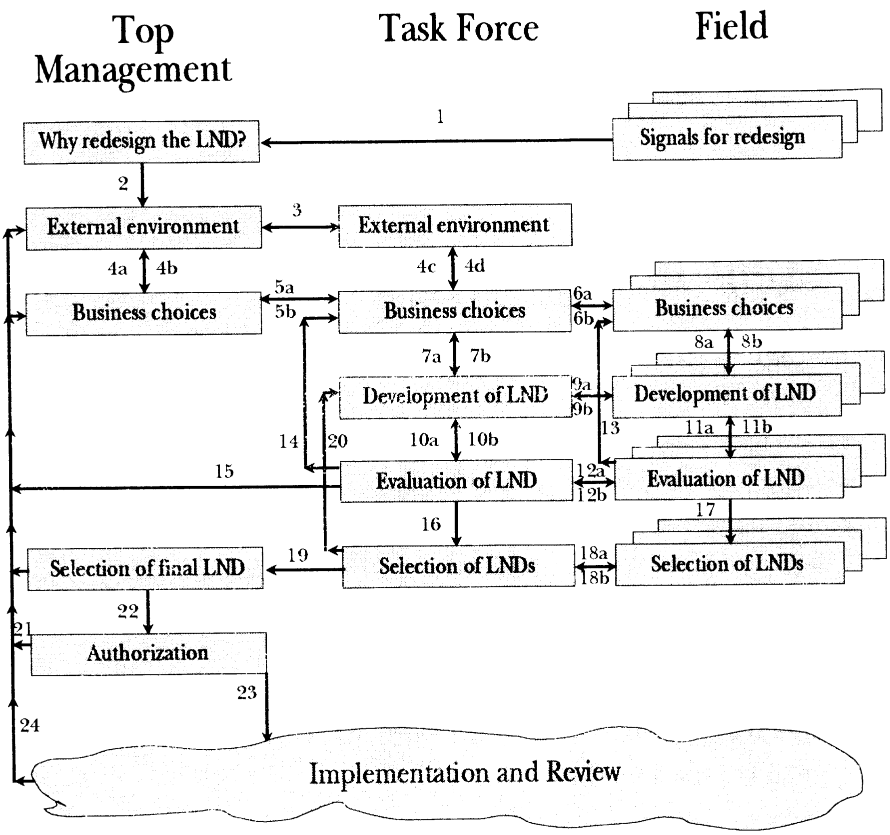


Figure 4.3: A detailed view of a new framework for LND.

these improvements.
Although the existing LND and its underlying business choices are well known to the top management, in the framework they are described in detail, step by step, just as the alternative new LNDs and their underlying business choices.

Below, the steps of the framework are described. Although this is a rather formal description, we emphasize that the factors and values are usually developed incrementally, from a rough idea into very detailed, specific factors and values.
The numbers between brackets in the descriptions of the steps refer to the numbers of transitions in figure 4.3.

Why redesign the LND?

The process of designing an LND usually starts with the identification of opportunities, problems or crises related to the existing logistics network. Top management starts the LND process, prompted by signals from the field (1) or external signals.
In this phase, management information systems are often useful tools to identify and specify the motives for redesigning the logistics network, such as a declining market share, competitors' innovations, increasing costs, declining returns on investments, etc.

External environment

At this stage external scenarios S_{ext} are developed (see chapter 3) (2). The top management gives a preliminary idea of the factors and the ranges of factor values that will play a role in the external scenarios. Information is needed on such issues as market developments, technological innovations, interest rates and political developments. On the basis of this information, experts may extend the required factors and values to describe alternative external scenarios S_{ext} in detail. At this

stage in the process, the task force, of which these experts are members, is installed (3).
To gather the required information, the task force can use executive information systems, research companies and other sources such as information available on the World Wide Web.

The outcome of this phase is a set of external scenarios and a selection of two, three or four widely diverging external scenarios as a starting point for the development of company scenarios.

Business choices
Through business choices, a start is made with the translation of each of the selected external scenarios into one or more company scenarios S_{comp} (4a,c). The focus is on the entrepreneurial choices $\Lambda_{input-LND}$ in which several objectives are set regarding cost reductions, customer service improvements, time limits for the reorganization, etc. (see chapter 3).
Note that also a thorough investigation of the existing situation is needed to gain insight into the starting points for the reorganization process. In this stage, the focus is on the entrepreneurial choices that were made and are still valid in the current situation, denoted by $\Lambda^{o}_{input-LND}$.

Often the top management and the task force first discuss the business choices and especially the entrepreneurial choices in fairly general terms (5a,b). Following this, the task force is asked to elaborate these global settings. To prepare the proper entrepreneurial choices, the task force also cooperates with the field. Together, they investigate the signals from the field (if any) regarding the redesign of the existing LND and they gather data on the existing business situation and options for future entrepreneurial choices (6a,b). Sometimes additional investigations on the external environment are needed (4b,d).

The information needed in this phase concerns existing and forecasted market shares, lead times, cost rates, etc. Again, information systems may help to generate the necessary data.
The result of this phase is a description of previous business choices that led to the existing business situation, $\Lambda^o_{input-LND}$. In addition, for each of the selected external scenarios, one to four sets $\Lambda_{input-LND}$ are developed. This means that a start is made with as many as two to sixteen company scenarios.

Development of LNDs

In this phase (7a), alternative LNDs, specified by $\Lambda_{specify-LND}$, are developed. Moreover, a detailed specification of the present LND, $\Lambda^o_{specify-LND}$, is made. $\Lambda^o_{specify-LND}$ is the reference for all the alternative LNDs that will be developed.

The task force elaborates the top management's guidelines for LNDs. They cooperate with the field, especially in gathering additional data on the existing and potential future LNDs (8a). Sometimes, the field also provides suggestions for alternative LNDs (9a,b).
Note that the top management team does not play a role in these phases of detailed development and evaluation of LNDs. This shows that design of the logistics network is largely delegated to the task force, which underlines the importance of its supportive role.

In the development phase of the framework, the DSS SLAM fulfils an important role. Its first task is to help determine the values in $\Lambda^o_{specify-LND}$ as a reference for the comparison of the $\Lambda_{specify-LND}$'s that specify the alternative LNDs. Using the information provided by

$\Lambda^{o}_{input-LND}$, the MILP model determines the variable logistics costs of the existing logistics network, the lead times and the utilization of the facilities. These figures should reflect the real-life situation. If this is not the case, the data in $\Lambda^{o}_{input-LND}$ should be checked, or adjustments may have to be made to the model. This results in $\Lambda^{o}_{LND-specify}$.

Now, the DSS SLAM and its MILP model can help define the sets $\Lambda_{specify-LND}$ for the alternative LNDs, on the basis of the $\Lambda_{input-LND}$ that are the outcome of the previous phase in the framework. $\Lambda_{specify-LND}$ is developed step by step. The values in $\{D_{flows}, D_{facilities}\}$ are not determined at once, but in a reiterative process. The MILP model takes into account the values in $\Lambda_{specify-LND}$ that have been specified by the task force and provides suggestions for the values of the remaining factors. This process was discussed in detail in section 3.4.2.

In case a set $\Lambda_{input-LND}$ generates an unfeasible solution of the MILP model, changes are needed in the business choices made in the previous phase of the framework (7b, 8b).

Two alternative LNDs that are often developed are the 'green field' alternative and the 'optimized' existing LND. The green field alternative shows an LND which sets no limits on the capacities of the facilities and which does not fix flows of goods or allocations of customers in advance. From the costs perspective, this is often seen as the ideal LND. The 'optimized' existing LND is based on $\Lambda^{o}_{input-LND}$ without the existing quantities of semi-products and finished products flowing between the facilities and without the existing allocation of customers to warehouses. This alternative LND represents the capacities of the existing plants and warehouses.

In the next step (11a), an alternative LND is evaluated. If the evaluation gives rise to modifications, a reiteration of the development phase (10b, 11b) will take place to improve the LND. After several reiterations the LND fits the corresponding $\Lambda_{input-LND}$ and meets the evaluation criteria.

The result of the development phase is that the existing logistics network is described by $\Lambda^o_{specify-LND}$ as a reference for the alternatives $\Lambda_{specify-LND}$ developed in this phase. For each of the sets $\Lambda_{input-LND}$ several sets (1 to 4) $\Lambda_{specify-LND}$ are defined. So, as many as 2 to 64 'set-ups' for company scenarios S_{comp} are developed. These scenarios are evaluated in the next phase; a return-loop to the development phase may be needed to improve them until they meet the evaluation criteria specified in the evaluation phase.

Evaluation of LNDs

In this phase, the $\Lambda_{specify-LND}$'s and their corresponding $\Lambda_{input-LND}$'s developed in the previous phases are evaluated by the task force, often supported by the field (12a,b). Also the existing situation, described by $\Lambda^o_{input-LND}$ and $\Lambda^o_{specify-LND}$ is evaluated.

Figure 4.4 presents the evaluation criteria specified in $\Lambda_{evaluate-LND}$. The first criterion is the *operational feasibility* of the LND. Here, the need for human resources, technological concepts, administrative processes and management control activities of the logistics network and its implementation are investigated (see Ackoff et al., 1984, Anthony, 1992). This results into values of company factors of type c^T, c^A and c^H. A second criterion, based on Broekstra's Consistency Model for Organizational Assessment and Change (1984, 1989; see section 3.2), is the *political feasibility* of a scenario. Broekstra describes the 'political aspect system' of a company as the distribution and use of power and influence across the organization. The feasibility of a proposed LND with respect to this political system is important for its success.
A third aspect of the realization of an LND is the *time schedule*. If the time path set for the implementation is too long, changes in the LND are required.

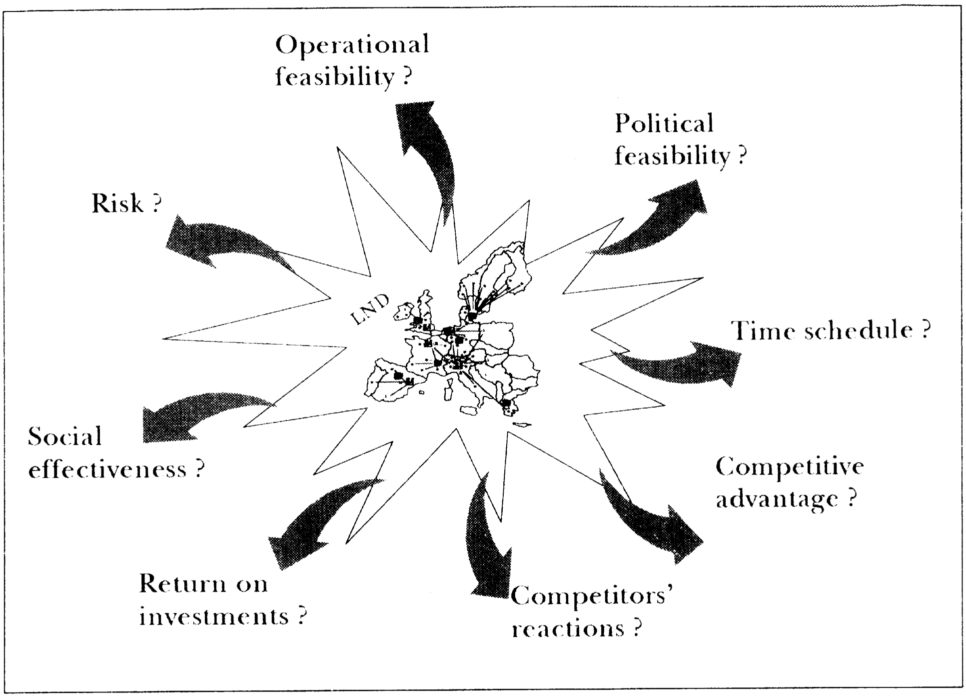


Figure 4.4: Criteria for the evaluation of an LND.

While the operational, political and time aspects are related to the internal implementation aspects of an LND, Porter (1985) focuses on the sources of *competitive advantage* in an LND (e.g., cost advantage, buyer value, technology, first mover advantage) and the *competitors' reactions* to each alternative. These criteria can be seen as belonging to Broekstra's concept of 'organizational health', which in fact is the main evaluation criterion. This concept is often explained as *return on investments*. Expectations concerning the financial returns on investments are based on expected future operational costs of the suggested LND, the long-term investments that are necessary (like new technologies, new buildings etc.) and the costs of the reorganization process. Besides this 'hard' performance, Broekstra also includes 'soft' performance (or *social effectiveness*) in his concept of organizational health. Social effectiveness refers to the complex of the firm's value system, mission, philosophy, behavioral norms, belief systems, climate, etc. This internal cultural system is crucial in attaining effectiveness.

The final evaluation criterion we propose is *risk*. Risk is a function of how poorly an LND will perform if a 'wrong' external scenario occurs (Porter, 1985). Risk also depends on the degree to which a company is tied up, once it has committed itself to an LND by setting its product line, customer service levels, facilities and so on. This means that risk is closely related to the sensitivity of an LND to uncertain future external developments (see chapter 2). In addition, risk depends on the relative probability of the external scenarios: betting on the best external scenario may be the most risky approach. In the evaluation of the risk of an LND, the external scenarios that were not selected for the development of LNDs are also used.
As a result of this evaluation it may be necessary to solve inconsistencies in Λ's (see page 81):

- investigate the LND and adjust $\Lambda_{specify-LND}$ (10b,11b),
- investigate the business choices and adjust $\Lambda_{input-LND}$ (13, 14, 15) or
- investigate the external environment and adjust S_{ext} (15)

This process of adjustment continues for each of the alternative LNDs until the inconsistencies are solved and the evaluation criteria are met.

The evaluation phase is supported by the DSS and its MILP model, especially as regards the evaluation of variable operational logistics costs, use of facilities, deliveries to customers, lead times, etc. Moreover, the

DSS and the MILP facilitate the analysis of the sensitivity of an LND to future changes, for instance in interest rates, transport rates, demand, product ranges, etc.
To assess the operational feasibility of the selected alternatives, field actors are often asked to examine the alternatives and to propose changes. The DSS can assist in this process by showing the effects of the proposed changes and suggesting further adjustments. These suggestions are gathered by the task force and incorporated into the alternatives. Again, the DSS and the MILP model play an important role in combining the field suggestions, showing their effects and evaluating new alternatives. This shows the close relationship between the phases of 'development of LND' and 'evaluation of LND'.

The outcome of the evaluation phase is a series of 2 to 64 company scenarios, that contain LNDs that may be selected for implementation. In this phase, $\Lambda^o_{input-LND}$ and $\Lambda^o_{specify-LND}$ have also been evaluated, resulting in S^o_{comp}. The existing situation, described by S^o_{comp} and its LND^o is used as a reference for comparison in the selection phase.

Selection of the final LND

When for each external scenario several company scenarios (and incorporated LNDs) have been developed, finally one specific LND has to be selected (16, 17). In the previous step, a range of evaluation criteria were presented. In this multi- criteria decision-making problem, the decision dilemma is, according to Porter (1985): "A company does not know which scenario will occur, so it must choose the best way to cope with uncertainty in selecting its strategy, given its resources and initial position". In this strategic decision-making problem, the theory of multi- criteria decision-making, in which all criteria are measured quantitatively, does not apply (see Korhonen et al., 1992). Porter (1985) describes five main approaches to the selection of a scenario. We apply them to the selection of an LND:

- *Bet on the most probable LND*
  Select the LND that is based on the external scenario that is considered to be the most probable.
- *Bet on the 'best' LND*
  Choose the LND in which the most sustainable long-term competitive advantage is established.
- *Hedge*
  Choose a LND that produces satisfactory results under all external scenarios.
- *Preserve flexibility*
  Select the LND that preserves flexibility until it becomes more apparent which external scenario will actually occur.
- *Influence*
  Select a desirable LND that can be brought about by using company's resources.

To these five policies, Mintzberg (1994) added a sixth one:

- *Contingency planning*
  The creation of alternative LNDs to deal with different external scenarios.

In fact this comes close to a mixture of Porter's 'Preserve flexibility' and 'Hedging' approaches.
In the real-life cases in which we were involved, only the 'Bet on the most probable scenario' and 'Contingency planning' approaches were used.

At this stage, a shortlist of about four most- preferred alternative LNDs is made by the task force, sometimes in cooperation with the field (18). The final selection is made by the top management (19).

The DSS SLAM and its MILP model are used in the discussions with the top management team as well as in the cooperation with the field. Using the report facilities, the DSS shows the structure of the designed networks and enables comparison of the evaluation of each LND by the quantitative criteria. The DSS is often used to provide objective information on the alternative strategies. Sometimes, improvements in an LND are needed (20), or reconsiderations of business choices, or investigations in the external environment (21).
If small changes are needed in an LND, the DSS is often used in meetings (even in the top management meetings) to show the effects of the changes instantly.

The 2 to 64 alternative LNDs have to be compared among each other and with LND^o. They may be compared simultaneously, according to Eisenhardt (1990), or they may be divided into smaller groups. In the cases in which we were involved, the LNDs were often grouped according to the external scenario and the business choices $\Lambda_{input-LND}$ they to which they were related. We selected two to four external scenarios and two to sixteen $\Lambda_{LND-input}$ on which to base the LNDs, with a minimum of two groups and a maximum of sixteen LNDs per group.
At the end of this phase of the framework, the final selection of an LND is made.

Authorization
While the final decision with respect to the selection of an LND is often prepared by the task force, the authorization of the decision is usually given by the top of the organization (22). Often the proposal

should be approved by several parties that have the power to enforce modifications or to influence the acceptance process (e.g., trade unions, consumer organizations). Note that a preliminary acceptance by the field is often partly ensured by the composition of the task force and by the interaction with the field during the process.
By approving the final selection of the LND, authorization is given for the implementation of the complete LND, or part of it (23). The selected LND is often first set up for one country or one business unit by way of experiment.

Implementation and Review
On the basis of the experience gained during the implementation, minor or major modifications may be made to the new LND, or the reorganization process may be suspended. In the case of a pilot implementation, the review phase is important for making any changes needed in the LND before further implementations are started. In case of major modifications this may be the start for a new loop in the framework (24).
The review may also focus on the decision process. On the basis of the review, lessons can be learned and future decision processes can be improved.

4.5 Loops in the framework

Mintzberg et al. (1976) distinguish three simultaneously occurring driving forces that affect the routing of the decision-making process through the described steps in the framework:

- The *decision control procedures* guide the way in which the decision process evolves and the allocation of the organizational resources.

- The *decision communication procedures* determine the exchange of information during the decision process. These procedures range from general scanning (exploration) and focused searches for information (investigation) to the distribution of information among the involved parties.
- The *political procedures* represent the way a decision process evolves in an environment of influencing and sometimes hostile forces.

The influence of these three types of procedures on the decision process manifests itself in the form of interruptions, scheduling delays, feedback delays, timing delays and speed-ups, comprehension cycles and failure cycles.
In terms of Mintzberg's 'driving forces', the three parties involved in our framework, their tasks and their interactions belong to the decision control procedures; the management of information exchange during the decision process belongs to the decision communication procedures; the influence of the field, trade unions and consumer organizations may lead to political procedures.

The sequence and number of loops and cycles in the framework strongly depend on the decision situation. Sometimes a large number of development and evaluation steps are needed by the task force to develop a first set of interesting LNDs. In other situations, the field has all kinds of suggestions, ideas or political objections, resulting in several loops between the task force and the field before a compromise is reached on proposals for LNDs that are ready for evaluation by the top management. Sometimes the top management is closely involved in the process and asks for frequent feedback from the task force. Interaction between the task force and the top management may also be prompted by new insights presented by the task force that compel the top management to reconsider its objectives. In paragraph 4.6 we will show some examples of the loops and cycles in the framework, based on real-life cases.

4.6 Applications of the framework

So far we have presented our new framework in very general terms, although it will be clear that it can be applied to the fictitious case of the multinational described in chapter 2. In this paragraph we will show how the framework can be applied to a specific European company in the food industry and a specific European company in the business electronics industry. Both companies are considering a rationalization of their production and distribution strategies in Europe.

4.6.1 An application in the food industry

The company is a large European company producing food products at several locations in the world and selling them worldwide. We will consider the situation in Europe. Forced by shortages in production capacity at some locations and overflows at others, the board has established a task force, named 'European Production Coordination'. This is a multi-disciplinary, cross-organizational task force with no responsibility for operations. Its mission is to show the way towards cost reduction through rationalization of the European production and distribution structure and standardization of products and packaging types. In the design of a new logistics network for this company, 20 plants with a total of 100 production lines, 16 existing and about 25 potential warehouses, 500 customer groups, 15 types of purchased products and 50 different finished product groups are involved. The task force has organized itself in four working groups, focusing respectively on sales forecasting, product standardization, packaging standardization and a new production and distribution structure. We were especially involved in the latter one. The four working groups are coordinated by a coordination team, which reports to the board. Figure 4.5 shows an overview of the framework that emerged from this project.

Numbers of loops and cycles

The start of the process was initiated by the field. The board, the task force and its working groups considered the complete logistics network, whereas each field party considered only their geographical region and product groups of the logistics operations. Several members of the working groups were representatives of the field.

The external scenarios and the business choices were developed simultaneously in three cycles in which the board and the task force were involved.

In the development and evaluation phase, our working group, which dealt with the new production and distribution structure, reported eight times to the tasks force's coordination team. Both in the phase of making business choices and in the evaluation phase, our group consulted with the field twice. The proposals for a new LND were discussed by the board and the task force in four cycles. In our working group, each time the board had suggestions for improvement, we made about three return-loops from the evaluation phase to the development phase. In this loops, not only the LND was improved, but also business choices were adapted or worked out into greater detail.

As a result of the organization of the task force in four working groups, there was a great deal of communication between the coordination team and each of the working groups, among the working groups and between each working group and the field. The coordination team of the working groups met about 15 times.

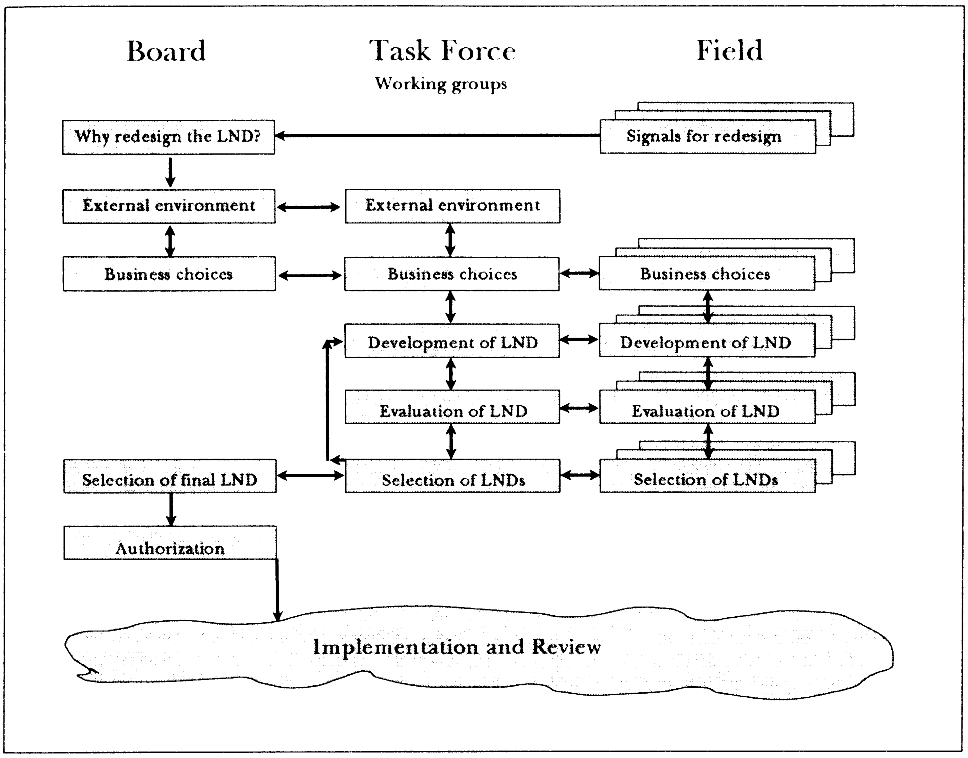


Figure 4.5: Framework for an application in the food industry.

Time needed

The total process from problem identification until authorization of the new LND by the top management took about 18 months. In our working group, we used the DSS SLAM and its MILP model intensively. We needed one month to gather raw data from eight countries and 36 locations and, at a later stage, two months to gather the detailed data we needed. When the data collection was finished, the eight cycles of scenario development that followed took about two weeks each.

Results

The result of this project was a strategy to realize product standardization and packaging standardization for all European countries and a plan for a new production and distribution structure. In this new structure, production and warehousing capacities were reallocated, several plants and warehouses were closed down, a few new warehouses were built, and the product flows from plants to customers were reallocated. The project is expected to lead to a reduction of total variable logistics costs by about 15% on an annual basis.

4.6.2 An application in the business electronics industry

This company produces and sells business electronics products in most parts of the world. In this description, we will consider the European market and the European production and distribution facilities. A request for a large investment in one of the European production plants was the motive for the board to ask the European Logistics Department (ELD) to reconsider the LND in Europe. The ELD's mission was to reduce the total logistics costs by 30% and to reduce the order-to-install lead times from 72 to 24 hours for as many products and markets as possible. We were asked to support the ELD, which is responsible for the operations in Europe, in developing a new LND which would contribute to these objectives.

The company serves about 500 market areas in Europe, which demand five types of products. As the production facilities at three European locations (three plants with each about seven production lines) were fairly new, no new production locations were considered. The company had 16 national warehouses for distribution. A reduction to a few European warehouses was considered and about 10 new potential locations were selected.

Given the complexity of the design problem and the fact that the board had to react soon to the investment request of one of the plants, we discussed with the board the possibility to divide the design process into two phases:
Phase 1: Focusing on cooperation between the three plants with respect to their production and the distribution tasks, while also considering (globally) the deliveries to the customers in the 500 market areas. This should result in a 'top structure' of the LND.
Phase 2: On the basis of the selected 'top structure', redesigning the distribution structure.
This division proved to be very useful, because the top structure turned out to be independent of the alternative distribution structures we considered.
Figure 4.6 shows how the framework was worked out for these two phases of the project.

Number of loops and cycles

After the request of one of the plants for investments in production capacity, the board started the process of designing a new LND. It selected some external trends that should be considered, such as internationalization in transport, increasing transport rates, etc. The board also set the objectives for the total LND in terms of cost reductions and customer service levels. The ELD was asked to work out an LND. They started by designing a 'top structure'. For this part, the framework shows a simple process. In about four loops between development, evaluation and selection a few scenarios were selected. Finally, the board decided on one of these proposals and the implementation

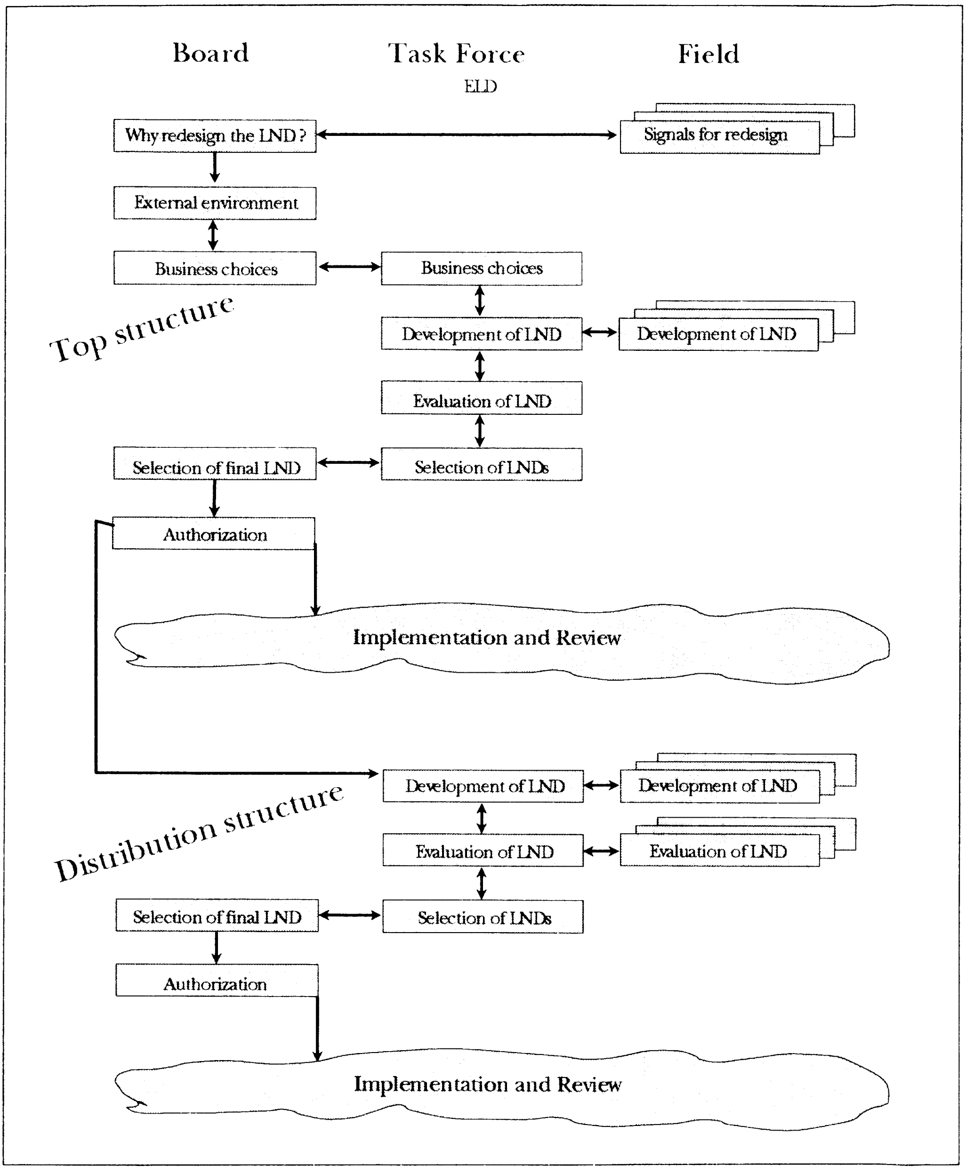


Figure 4.6: Framework for an application in the business electronics industry.

started. There was virtually no involvement of the field in this process, except in some questionnaire surveys to gather data on sales forecasts and cost rates.

The implementation of the 'top structure' and the designing of the distribution structure were started simultaneously. The decision process for the distribution structure was similar to the decision process for the design of the 'top structure', although at the end of the third cycle of designing alternatives by the ELD, extensive checks for feasibility and suggestions for improvement were developed in cooperation with the field. After one more loop between development and selection by the ELD, in which the field suggestions were combined, the final selection and authorization by the board took place.

The 'top structure' and the resulting distribution structure were reviewed in one review process.

Time needed

The total process, from the initiation by the board, which formed the basis for the design of the top structure, to the authorization of the design of the distribution structure took about nine months. The design of the 'top structure' took about three months; the design of the distribution structure about six months. The amount of time needed for data gathering was one month for the global data for the top structure and another two months for the more detailed data for the distribution structure. The development of scenarios took two weeks for each of the eight cycles. The checks for feasibility in the field took about one month.

Results

The result of this project was a plan for a rationalized production and distribution structure: product flows between the three plants were introduced, plants were given responsibility for distribution related in a specific geographical area and the number of warehouses was reduced from 16 national to five European warehouses. The original request for a large investment, needed to double the capacity of one of the plants, was not granted. In fact, it was decided to reduce this plant by half!

The final result of these changes was a reduction of the order-to -install lead time from 72 to 24 hours and a variable logistics cost reduction of 10% per year. The other 20% cost reduction that was needed, was achieved through a strong reduction of fixed costs, realized mainly by reducing the number of warehouses.

4.6.3 Evaluation of the applications

In both applications, the framework was utilized, although in widely different ways. In the food company, the top management and the field were strongly involved. In the consumer electronics company, board involvement was low, although it was the board that took the main decisions, without checking in advance the ideas of the field (in the case of the top structure). In this company, the ELD was responsible for the operations (unlike the task force in the first case) and therefore took responsibility for the scenarios they developed. In the first case, there was no centralized operational responsibility and therefore the decision process was much more complicated than in the second case.

In both applications, the data gathering process was time-consuming: it took about one month to gather the raw data for the identification and some initial analyses and another two months to collect detailed data for the most important elements of the new logistics network. In the next chapter we will discuss the issue of data gathering, with a particular focus on the level of detail needed.

4.7 Evaluation

In this chapter we completed our framework for LND.
We will now make some concluding remarks on the use of the DSS in the framework. Moreover, we will consider the framework in the light of some theoretical views of strategy development.

4.7.1 DSS in the framework

In this chapter and in chapter 3 we discussed the support of the DSS SLAM and its MILP model in the development of company scenarios and, especially, alternative LNDs. Moreover, several times we referred to the support of management information systems in general. Table 4.1 gives an overview of this support. These results largely fit in with the findings of Sabherwal and Grover (1989), extending them however with the support for scenario development and comparative analyses.

Decision-making phase	Computer-based Support Dimensions			
	Scope	Form	Level of support	Data/Model
Identification	Broad, superficial	Qualitative, soft	Decision structuring	Data retrieval and analysis
Development	Narrow, specific	Specific qualitative, also quantitative data	Set-up and improvement of alternatives	Model based
Evaluation	Narrow, specific information per alternative	Quantitative	Assessing alternatives	Model based, data retrieval and analysis
Selection	Narrow, specific information per evaluation criterion	Quantitative	Comparing alternatives	Model based, data retrieval and analysis

Table 4.1: Computer-based support in the three phases of decision-making in the framework.

In this chapter we showed that the DSS SLAM and its MILP model are used intensively by the task force. The top management uses the reports prepared with support of the DSS. In the field, the DSS is mainly used to show the effects of proposed changes.

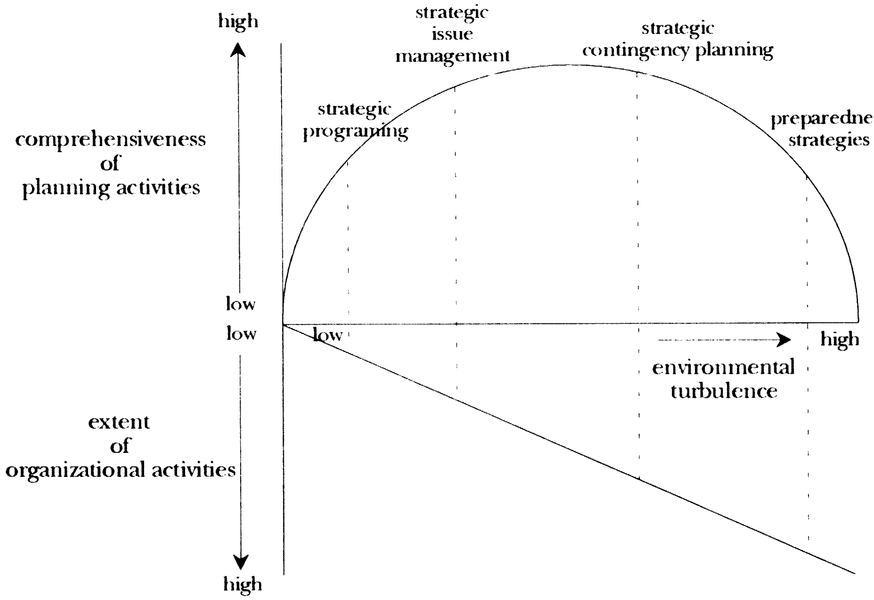
4.7.2 The framework as a strategic planning tool

Mintzberg (1990) distinguishes ten schools of thought for strategy formation. These schools fall into three groupings:

- *Prescriptive schools*
  These schools are more concerned with how strategies should be formulated than with how are formulated in practice.
- *Descriptive schools*
  The main focus of this type of school is how companies formulate strategies in practice.
- *Configurational school*
  This school clusters the strategy-making processes, the contents of strategies, and the structures or contexts. In fact, this school is a combination of the other two schools.

In our view, the use of scenarios and the different possible flows through the framework show the episodic character of the framework, which would mean that it belongs to the configurational school of strategy formation.

Volberda (1992) also presents an interesting classification of modes of strategy (see figure 4.7). He suggests that, due to high environmental turbulence, planning activities become less comprehensive, but organizational activities extend in order to get more strategic mileage out of the organization in case of strategic surprises (see also Wack, 1985).



Strategic programing : extrapolation of trends without changing the organization
Strategic issue management : besides programs, also focusing on relevant issues and initiating activities in line with these issues
Strategic contingency-planning : developing plans for every possible change and transforming the organization in order to anticipate possible developments
Preparedness strategies : decreasing planning activities, and increasing organizational activities in order to get more strategic mileage out of the organization in case of strategic surprises

Figure 4.7: Different modes of strategy (Volberda, 1992).

The tools we used and developed have their roots in strategic programing, strategic issue management and strategic contingency planning, but we think they are very useful in preparedness strategies because of their power to analyze thoroughly *many* scenarios for their results.

Chapter 5

Aggregation of data

5.1 Introduction

In the previous chapters, the question of the appropriate level of detail of data needed in LND decision support was raised several times. For many years, the use of aggregated data was defended on the grounds that the optimization models used in the decision support systems could not be solved with detailed data, on account of the size of the models. Moreover, in many cases detailed data were simply not available. Today, detailed data are more generally available, even electronically. Also, major improvements have been made in the procedures for solving optimization models. However, there are situations where the above-mentioned reasons for using aggregated data are still valid. We will discuss the reasons for aggregating data in section 5.2.1.

In this chapter we will consider the problem of finding the appropriate level of detail of data needed for the design of a logistics network. The main categories of data qualifying for aggregation are products and customers. Large quantities of data are needed to specify these individually (see tables 2.1 and 2.2). In the MILP model developed in chapter 2, we have already aggregated the demand of each customer by the criterion 'time': the demand $d_{fp,c}$ of a customer was defined as 'the total demand of customer c for products fp during a time period of one year'. In this chapter we will also aggregate individual customers into customer groups and see how several levels of aggregation affect the quality of the information provided by the optimal solutions of the MILP model presented in chapter 2.

As may be expected, information loss occurs if, instead of detailed information, aggregated data are used. On the other hand, Mirchandani and Francis (1990) argue that "due to the statistical law of large numbers, the more aggregated the customer representation, the more accurate the estimates of the aggregated customer demands".

This chapter will focus on the development of upper bounds on the error in the minimum total variable logistics costs that may be introduced by aggregating customers. These upper bounds are very helpful in deciding, at an early stage of the decision process, on the appropriate level of aggregation of customers needed for the design of a logistics network.

5.2 Main concepts and previous research

5.2.1 Main concepts in aggregation

The concepts presented in this paragraph are not only valid for LND processes, but more generally for decision processes supported by the use of optimization models. In these processes, the support of the optimization models can be divided into three steps (see figure 5.1). In the first step, the relevant data available within the company are gathered, which results either in detailed data or aggregated data. In the next step, model calculations are made, yielding solutions for the mathematical problem formulations. Finally, these solutions are translated into reports for use in decision support. In this process, aggregation or disaggregation can take place prior to or after the model calculations. This results in seven alternative concepts of aggregation, as shown in figure 5.1. We will now discuss these concepts, focusing on the main reasons for using aggregated data and showing under which circumstances a concept is appropriate:

Availability of data as a motivation for aggregation

When starting a decision-making process, the level of detail of available or easily accessible data differs for each problem situation. The scenarios developed in our framework, which were described in chapter 3, are often based on data representing future expectations regarding, for instance, markets, demand and cost rates. These data are usually not available at every level of detail.
Even historical data are not always available at a detailed level. For example, Magee et al. (1985) state that recognizing individual customers is unfeasible in many companies and that this alone constitutes a valid reason to aggregate customers into customer groups. In the last decade the intensive use of electronic information systems in administrative environments has improved the availability and accessibility of detailed data. On the other hand, it is increasingly uncommon for companies to standardize these data, as a consequence of decentralization trends whereby responsibilities for information management are devolved. Moreover, in electronic information systems detailed data are often stored only for a few months, after which they are replaced by aggregated data. So, in practice it often remains a time-consuming and costly process to gather valuable detailed data to support the decision-making process. Eisenhardt (1990) also refers to this aspect when she states that the search for detailed data slows down the decision process.

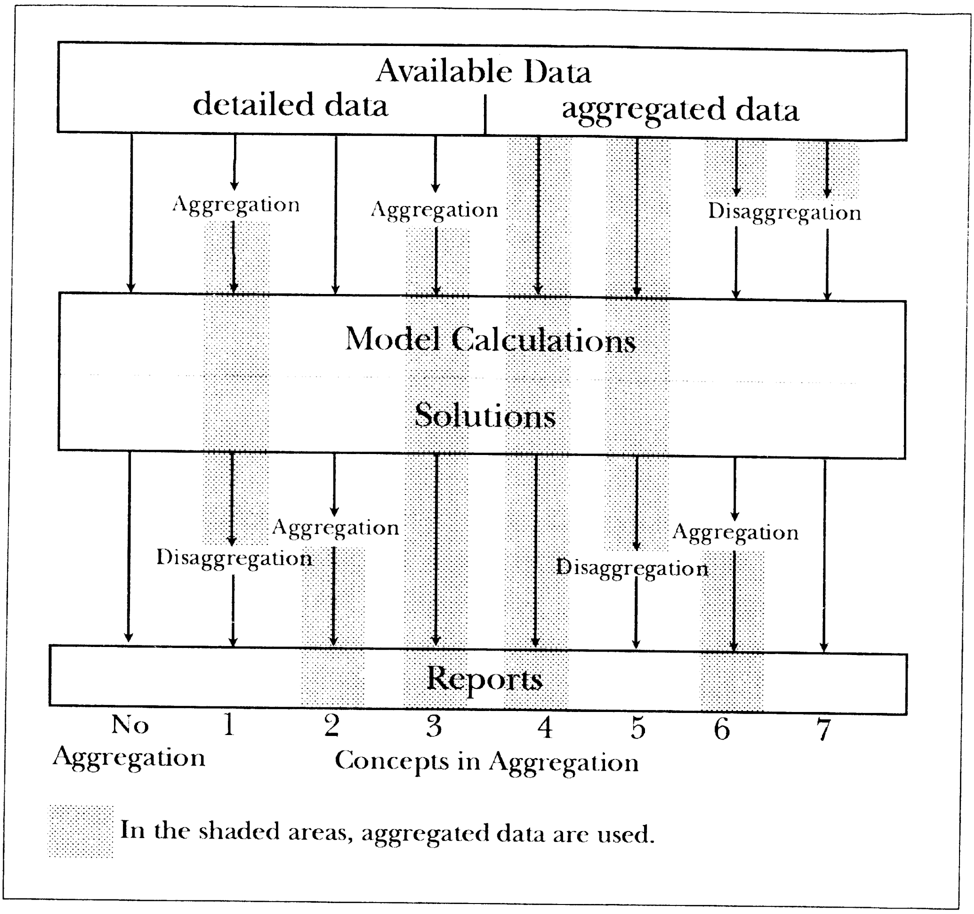


Figure 5.1: Main concepts in aggregation.

On the basis of these arguments, we conclude that the lack of easily accessible data is often an important reason for gathering data at an aggregated level (see concepts 4, 5, 6 and 7 in figure 5.1).

Solvability of optimization models as a motivation for aggregation

A second reason for using aggregating data is that it reduces the size of an optimization model. Ballou (1992) states that the use of aggregated data reduces the amount of computer memory required, as well as the amount of time and effort needed to find a solution. As computer hardware and software are getting cheaper and more powerful by the day, this statement would seem to lose some of its relevance. Moreover, improved methods and the invention of new solution procedures enhance the possibilities for solving larger optimization problems (Geoffrion and Powers, 1995). On the other hand, however, as we discussed in chapter 3, there is a trend to develop increasing numbers of scenarios. This requires shorter computation times, which lends support to Ballou's argument for using aggregated data. According to Zipkin (1994), an ongoing process in taking place, in which computers become more and more powerful, while the models they are required to support become more and more complicated. These models will require more computer memory and will take more time to be solved. This trend, too, supports Ballou's argument.

Bender (1985) and Ananthanarayanan (1987) give another reason to make the model calculations with the help of aggregated data: "the limitations on the ability of humans to understand large complex systems".

So, the classical reasons for using aggregated data in order to reduce computation times and the required amount of computer memory, are still valid (see concepts 1, 3, 4 and 5 in figure 5.1).

Level of decision-making as a motivation for aggregation

The required level of detail of information is often related to the level of decision-making. For example, the board level in our framework will generally be more interested in aggregated information on the outcomes of a scenario (see concepts 2, 3, 4 and 6 in figure 5.1). At the field level, however, line managers base their decisions on more detailed information (see concepts 1, 5 and 7 and 'no aggregation' in figure 5.1). As for the task force, the level of detail they are interested in generally depends on the level of detail of the scenarios they are considering. When a company scenario is evaluated on the basis of aggregated reports, the changes in scenario factors and input data of the model are often also described at an aggregated level (see concepts 4 and 6 in figure 5.1). In addition, the choice for a particular level of detail of data to work with is based on personal preferences, which are often related to the position one holds in a company.

Table 5.1 presents an overview of the relationships between the reasons for using aggregated data and the use of aggregation concepts presented in figure 5.1.

Motivation for aggregation	**Concept for aggregation** (see figure 5.1)						
	1	2	3	4	5	6	7
No detailed data available / accessible				x	x	x	x
Model, based on detailed data, cannot be solved - lack of computer memory - too time-consuming	x		x	x	x		
Level of decision-making	x	x	x	x	x	x	x

Table 5.1: Relation (x) between motivations for aggregation and the use of concepts for aggregation.

In the LND decision processes in which we were involved, we often found that it was very time-consuming to gather detailed data and that many scenarios had to be developed under high time pressure. More specifically, in the cases we discussed in chapter 4, we used aggregation concept 4 in the food industry project and also in the design of the top structure of the business electronics logistics network. For the design of the distribution structure for the business electronics company, we needed more detailed analyses, especially at the customer level, so we used aggregation concept 1.

5.2.2 Previous research on aggregation

A great deal of research has been conducted on aggregation concept 1 in figure 5.1. The objective pursued in this research is to solve the model on the basis of detailed data, by first optimizing the model using aggregated data, and then disaggregating the results into an approximation of the solution of the original problem (see Shapiro and Heskett (1984), Ananthanarayanan (1985), Shetty and Taylor (1987), Aderohunmu and Aronson (1991), Rogers et al. (1991), etc.).
We will consider the following question with respect to aggregation:
What is the appropriate level data aggregation for the calculations of the optimization model, if decision support is solely based on the results of this aggregated model?
We will determine the appropriate level of aggregation by balancing the availability of the data or the time needed to gather data and the potential errors in the information used for decision-making.

Several authors provide indications as to the appropriate aggregation level of customers into customer groups for LND problems (see table 5.2), without explaining, however, what criteria they use to determine this level. Moreover in most of the examples in table 5.2 neither the type of problem, nor the dimensions of the logistics network are described.
Ballou and Masters (1991) extended the insights into the appropriate aggregation level by conducting several experiments, taking into account the sizes of the shipments and the number of potential ware-

Region	Type of Products	Number of customers	Number of customer groups	Proposed by
USA	hospital supplies	unknown	127	Geoffrion and Graves (1974)
USA	food	unknown	121	Geoffrion (1974)
USA	consumer products	unknown	120	House (1985)
USA	consumer products	unknown	80 - 150	Bender (1985)
USA	consumer products	unknown	200 +	Ballou (1992)
Canada	consumer products	unknown	20 - 40	Bender (1985)
Western Europe	consumer products	unknown	60 - 120	Bender (1985)
USA	industrial products	unknown	30 - 50	Bender (1985)
Canada	industrial products	unknown	10 - 20	Bender (1985)
Western Europe	industrial products	unknown	20 - 40	Bender (1985)
Belgium	beer	24,000	650	Gelders et al. (1987)
several	several	unknown	100 to 200	Ballou and Masters (1991)
unknown	unknown	unknown	200	Klincewicz (1985)

Table 5.2: Overview of examples of aggregation levels in LND problems.

houses in the logistics network. Their findings indicate that is generally appropriate to use between 100 and 200 customer groups. They conclude:

> ...In general, 100 clusters is too few for only a few facilities in a network .... The use of 200 clusters is reasonable for locating up to 25 facilities. Above that number, the number of clusters in a location analysis should be increased substantially. ...

However, in 1992, Ballou reported a study in the USA in which customers of consumer goods had to be allocated to warehouses. This time, he found that the appropriate number of customer groups was

200 or more. Note that this conclusion also differs from the aggregation levels recommended by Bender (1985) and House (1985) for LND for consumer products in the USA. Bender recommends 80 to 150 customer groups; House suggests 120.
It will be clear that, on the basis of these examples, it is difficult to draw conclusions as to the appropriate aggregation level of customers.

Up to now, all insights into the appropriate level of aggregation of customers in the design of logistics networks, have come from emperical studies. However, most of these studies fail compare results reached through calculations based on aggregated data and results based on detailed data.
In order to determine the appropriate aggregation level, the examples do not make use of indicators for the difference in total costs to be expected when customer groups are used instead of individual customers. Nevertheless, many researchers have worked on the development of upper bounds on this difference (see Geoffrion (1976), Evans (1979), Zipkin (1980a,b) and Ballou (1992)). The upper bounds they provide are theoretical; unfortunately, no emperical evidence is available on their quality. In section 5.4 we will discuss this previous research, extend the theoretical error bounds and show some experimental results.

5.3 Criteria for and effects of customer aggregation

5.3.1 Criteria for customer aggregation

When aggregating customers into groups, there are several factors to consider. A logical approach is to aggregate customers into one group, if they are located in the same geographical area.

Within these geographical areas, several criteria for aggregation can be used (see also Bender, 1985):

- *Sales volume*
  Analysis of the contribution to the total sales volume can identify those customers that account for the bulk of the volume shipped. This indicates a first aggregation level (i.e. demand level) separating the customers into 'small' customers and 'large' customers, on the basis of their individual sales volume. Now we can aggregate the small customers into groups in at least two ways: within each geographical area, the small customers are aggregated into one group, or each small customer is aggregated into a group together with the nearest large customer.

- *Products*
  The products demanded by a customer can also be used as a criterion for aggregation. Customers demanding a highly comparable set of products are eligible for aggregation into the same group. This can be a useful criterion if, for instance, there are safety regulations for transporting certain products or if products are only supplied from a few locations.

- *Service requirements*
  In chapter 3, we already discussed the close relationship between an LND and the level of customer service (especially the customer order lead time) that can be offered. From this point of view it is often useful to group customers according to the service level to be offered.

- *Transport modes*
  If the decision on the appropriate transport mode for supplying the customers is an important issue in the design of the logistics

network, then the options to supply the customers by different types of truck, train, plane or ship become an important aggregation criterion: customers that can be supplied by the same transport mode, can be aggregated into one customer group. It will be clear that customers that cannot be supplied by the same transport mode should not be aggregated into one customer group.

- *Marketing distribution channels*
  If different customers are served through different distribution channels (e.g., agencies, importers, wholesalers, retailers, dealers), then in principle aggregation is only meaningful within each channel.

It will be clear, that combinations of these criteria are also possible. In this thesis we focus on the clustering of customers located within the same geographical area and with a total sales volume below a certain level. In most of the cases in which we were involved, we did not aggregate small customers into a group together with the nearest largest customer, due to distribution requirements: within each geographical area, the small customers were often supplied by one truck driving one route from one warehouse. The large customers were usually supplied individually with full truck loads.

We define the differentiating demand level as the aggregation level, denoted by a. To investigate the effects of customer aggregation, detailed data on individual customers ($d_{p,c}$ and $\tau_{p,w,c}$) are needed. For the fictitious consumer electronics company presented in chapter 2, these detailed data are not available, but in a specific case study concerning the production and distribution of food in Italy we had access to these detailed data (see also table 2.1). In this chapter we will use this case study for the analysis of the effects of customer aggregation.

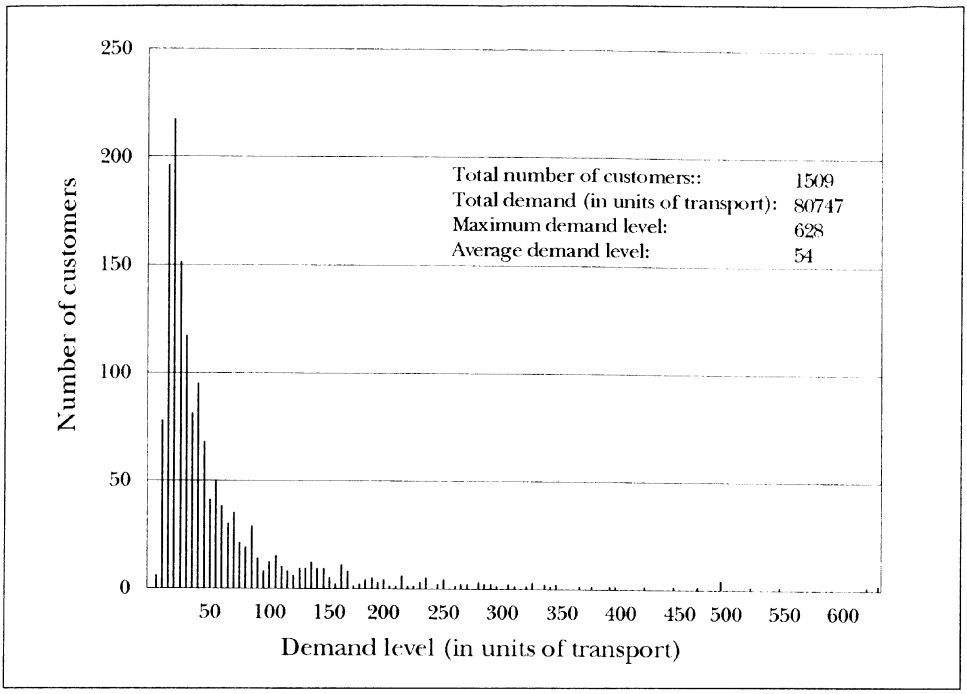


Figure 5.2: Analysis of sales volumes of a food production and distribution company in Italy.

Figure 5.2 shows an analysis of the sales volumes for this case.
Table 5.3 shows the number of customer groups at several levels of aggregation for this case and also for a case concerning the production and distribution of hospital supplies in Europe (see also table 2.1). Note that at aggregation level 628 for the food products and 98 for the hospital supplies, the number of customer groups equals the number of commercial regions. Therefore a higher aggregation level will give the same results.
In the next paragraph we will explain this aggregation procedure in detail.

<table>
<tr><th></th><th colspan="2">Food products
Italy</th><th colspan="2">Hospital supplies
Europe</th></tr>
<tr><td>No. of individual customers</td><td colspan="2">1509</td><td colspan="2">1092</td></tr>
<tr><td>No. of commercial regions</td><td colspan="2">44</td><td colspan="2">15</td></tr>
<tr><td>Total demand</td><td colspan="2">80747</td><td colspan="2">4576</td></tr>
<tr><td>Average demand level</td><td colspan="2">54</td><td colspan="2">4</td></tr>
<tr><td>Maximum demand level</td><td colspan="2">628</td><td colspan="2">98</td></tr>
<tr><td></td><td><i>Aggregation criterion</i></td><td><i>Number of customer groups</i></td><td><i>Aggregation criterion</i></td><td><i>Number of customer groups</i></td></tr>
<tr><td></td><td>Demand $\leq$ 12.5</td><td>1348</td><td>Demand $\leq$ 0.5</td><td>841</td></tr>
<tr><td></td><td>Demand $\leq$ 20</td><td>1049</td><td>Demand $\leq$ 1</td><td>683</td></tr>
<tr><td></td><td>Demand $\leq$ 30</td><td>781</td><td>Demand $\leq$ 2</td><td>477</td></tr>
<tr><td></td><td>Demand $\leq$ 60</td><td>409</td><td>Demand $\leq$ 4</td><td>291</td></tr>
<tr><td></td><td>Demand $\leq$ 100</td><td>241</td><td>Demand $\leq$ 8</td><td>164</td></tr>
<tr><td></td><td>Demand $\leq$ 150</td><td>149</td><td>Demand $\leq$ 15</td><td>93</td></tr>
<tr><td></td><td>Demand $\leq$ 200</td><td>109</td><td>Demand $\leq$ 30</td><td>37</td></tr>
<tr><td></td><td>Demand $\leq$ 628</td><td>44</td><td>Demand $\leq$ 98</td><td>15</td></tr>
</table>

Table 5.3: Examples of aggregation levels in practice.

5.3.2 MILP model, based on customer aggregation

To clarify our ideas on aggregation, we will use a simplified version of the MILP model developed in chapter 2[1]. We will consider a three-level logistics network with production lines, warehouses and customers in which:

- Production and inventory costs at the plants are not considered separately.
- No inter-plant transport can take place.
- No direct deliveries from plant to customer are allowed and no storage areas on the plants are considered.

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[1] In the present chapter we use the relaxation of the MILP model discussed in section 2.6.

- No lower capacities are considered.
- All conversion factors and throughput-times are set equal to 1. This implies that volumes, costs and capacities are expressed in the same transport unit (e.g., cubic metres, kilograms, litres).

However, we expect that the results achieved by using these simplifications can be extended more or less straightforwardly to the more general specification of the MILP model presented in chapter 2. For example, the costs for purchasing, supply, production and inventory at the plants for each finished product can be incorporated into the cost rates of supplying a warehouse from a production line. The direct deliveries from plant to customer can also be dealt with by defining a plant twice, once at the plant level and once at the warehouse level, where the transport costs between that plant and its representation at the warehouse level include internal transportation, handling and inventory costs at the plant.

Taking these simplifications into account, we will now introduce the MILP model based on customer groups, instead of individual customers:

Let us assume that in the detailed problem we have R commercial regions and that there are n customers c for which $\sum_p d_{p,c} > a$. In the aggregated problem, corresponding to aggregation level a, the small customers c within one region and with a demand $\sum_p d_{p,c} \leq a$ are grouped into one customer group g. The n large customers each constitute one single-customer group g. So, in the aggregated problem, there will be $R + n$ customer groups.

The demand $d_{p,c}$ of a customer group g for product p is defined as the sum of the demand of the individual customers c in this group g (see also Evans, 1983):

$$d_{p,g} \quad = \quad \textstyle\sum_{c\in g} d_{p,c} \qquad\qquad \text{for all } p \text{ and } g.$$

The costs of transporting product p from warehouse w to customer group g are related to the costs of transportation $\tau_{p,w,c}$ to the individual customers c in customer groups g as follows:

$$\tau_{p,w,g} = \sum_{c\in g} r_{p,c}\tau_{p,w,c} \qquad\qquad \text{for all } p,\ w \text{ and } g.$$

where $r_{p,c}$ is the transportation costs ratio representing the contribution of transportation costs $\tau_{p,w,c}$ of product p to customer c to the transportation costs of product p to customer group g. We use fixed weight aggregation to define the transportation costs ratio:

$$r_{p,c} = \frac{d_{p,c}}{d_{p,g}} \qquad\qquad \text{for all p and c, where } c \in g.$$

These relationships between detailed and aggregated data are extensions of the relationships used for the single- product problem defined by Geoffrion (1976), Evans (1979) and Zipkin (1980a, 1982) and the relationships for the multi- product situation defined by Evans (1983). Evans defines the transportation costs between warehouses and customers as product-independent.

We will denote the MILP model related to aggregation level a as $MILP^a$. Note that the MILP model based on individual customers is $MILP^o$. We define $MILP^a$ as follows:

Minimize the total variable logistics costs in operations (Z^a):

$$Z^a = \sum_{p,l,w} t_{p,l,w}T^a_{p,l,w} + \sum_{p,w,g} \tau_{p,w,g}d_{p,g}A^a_{w,g}$$

subject to

Input-output balancing at the warehouses:

$$\sum_g d_{p,g} A^a_{w,g} = \sum_l T^a_{p,l,w} \qquad \text{for all } p \text{ and } w.$$

Complete assignment of all customer groups:

$$\sum_w A^a_{w,g} = 1 \qquad \text{for all } g.$$

Capacities of the warehouses:

$$\sum_{p,l} T^a_{p,l,w} \leq upcapw_w \qquad \text{for all } w.$$

Capacities of the lines:

$$\sum_{p,w} T^a_{p,l,w} \leq upcapl_l \qquad \text{for all } l.$$

where

$T^a_{p,l,w}$ = amount of product p to be produced at line l and shipped to warehouse w, $T^a_{p,l,w} \geq 0$; based on the former $TLW_{fp,l,w}$.

$A^a_{w,g}$ = fraction of customer group g supplied from warehouse w, $A^a_{w,g} \in [0,1]$; based on the former $AWC_{w,c}$.

$t_{p,l,w}$ = costs of producing one transport unit of product p at line l, transporting it from line l to warehouse w and handling and storing it at warehouse w; based on the former $pcl_{fp,l} + tclw_{fp,l,w} + hcw_{fp,w} + icw_{fp,w}$.

$\tau_{p,w,g}$ = costs for transportation of one transport unit of product p from warehouse w to customer group g; based on the former $tcwc_{fp,w,c}$.

$d_{p,g}$ = the total demand for product p of customer group g

during the time period considered (in transport units); based on the former $d_{fp,c}$.

$upcapw_w =$ maximum number of transport units that can be stored in warehouse w; based on the former $upcapw_w$.

$upcapl_l =$ maximum part of the total capacity of line l that can be used; $upcapl_l \in [0,1]$.

In this notation a, p, l, w and g represent, respectively, the optional aggregation levels, products, production lines, warehouses and customer groups.

5.3.3 Effects of customer aggregation

In this section we will discuss the effects of aggregating individual customers into groups on the optimal solution of the MILP model. We will do this by comparing the optimal solution of $MILP^o$ to optimal solutions of $MILP^a$ for several aggregation levels a. This comparison should reflect the decline in quality of the information provided by $MILP^a$

One way of comparing the solutions of $MILP^a$ and $MILP^o$ is to look at the difference in total variable logistics costs. This difference $Z^{a^*} - Z^{o^*}$ is named the total cost error. Figure 5.3 shows some experimental results for several instances of the LND problem in the case of the production and distribution of food products in Italy.
As expected, this figure shows that the total cost error increases with the aggregation level. In paragraph 5.4 we will prove that this holds true in more general terms. The increase in the total costs error is explained by the extra costs resulting from assigning customers to a warehouse as a group, instead of assigning them individually, because this may direct a customer to be assigned to another warehouse. Fig-

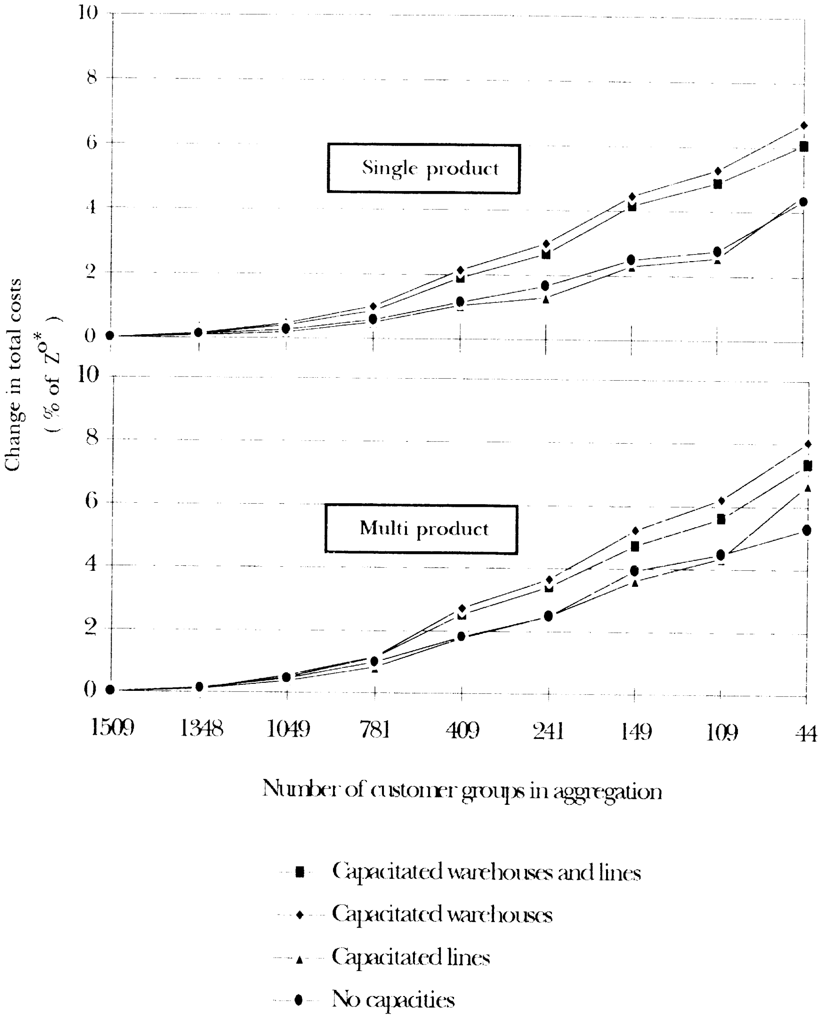

Figure 5.3: Experimental results on the total cost error.

ure 5.3 also shows that in this problem instance the total cost error can rise to a level of 8%. In the situation concerned, this meant about 1 million EURO per year.
The graphs indicate that the total cost error is higher for multi-product problems than for single-product problems. Moreover, in this example the total cost error is the highest in the case of 'capacitated warehouses'. Besides the total cost error, we also investigated the cost errors at the different echelons of the logistics network. It turned out that these errors could rise up to a level of 18%!

A second way to compare the solutions is to consider the structure of the logistics networks. Indicators for the error in the structure are, for example, the utilization of the production facilities and the warehouses and the allocation of customers to the warehouses. Some experimental results on this type of error at different aggregation levels are shown in figure 5.4.
This figure shows that, although the total cost error only indicates a maximum error of about 8%, the changes in the allocations of the customers to the warehouses and the changes in delivery from the warehouses, can increase up to 30%. Moreover, at high aggregation levels, 9 of the 20 warehouses are utilized for different quantities of products. At a specific aggregation level, the MILP model even suggests that one warehouse should be made twice as large as in the solution based on the non-aggregated data!
In other words, not only the cost errors at the different levels of the logistics network, but also the errors in the structure of the logistics network can be more serious than the total cost error indicates. This means that, if the total cost error is used as the only indicator for the aggregation error, one should realize that this may give a too optimistic view of the changes caused by aggregation.

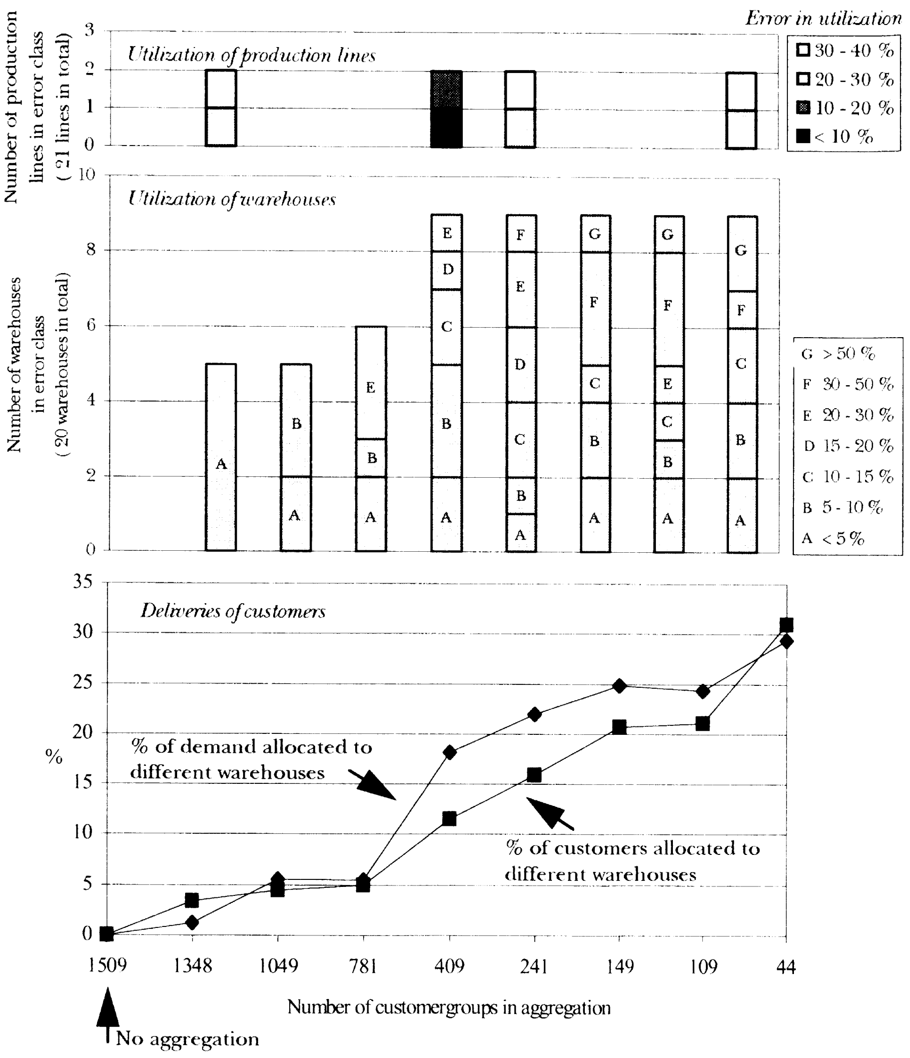

Figure 5.4: Experimental results on the error in the logistics network structure (multi-product situation with limited warehouse capacities as well as limited line capacities).

A third approach is to compare the sensitivity of the optimal solutions of $MILP^o$ and $MILP^a$ to changes in the input data, such as customer demand, cost rates and capacities of warehouses and production lines. These changes may be caused by the variations in the factor values in the company scenarios (see also section 4.4) or by unreliabilities in the input data, such as errors in the demand figures or cost rates.
It may turn out that aggregation problems are generally more stable than models based on detailed information. A first insight may be obtained from the information provided by the solutions of several problem instances $MILP^a$ with respect to reduced costs and shadow prices for the parameters and decision variables of the optimal solution.

On the basis of the experimental findings we presented, we conclude that customer aggregation causes errors in cost levels as well as in the proposed structure of the logistics network. However, in the remainder of this chapter we will only focus on the effect of aggregation on the total cost error. We will develop some tools that provide insight into the expected level of the total cost error and that will help us to determine the appropriate aggregation level.

5.4 Upper bounds on the total cost error

5.4.1 Introduction

In section 5.3 we discussed some insights into the potential errors caused by customer aggregation. We will now focus on the development of several upper bounds on the error in total costs due to customer aggregation.
Before starting to discuss the different types of upper bounds, we will define the total cost error and introduce some notations and properties

that we will need in the derivation of the various upper bounds.

In section 5.3.2 we described $MILP^a$, where $a \geq 0$ is the aggregation level. Note that $MILP^o$ is the MILP model based on individual customers.
With respect to $MILP^a$, we will use the following notations:

$(T^a_{p,l,w}, A^a_{w,g})$	is a feasible solution of $MILP^a$ and
Z^a	is the corresponding value of the objective function,
$(T^{a^*}_{p,l,w}, A^{a^*}_{w,g})$	is an optimal solution of $MILP^a$ and
Z^{a^*}	is the corresponding value of the objective function.

These notations, together with the aggregation definition of $d_{p,g}$ and $\tau_{p,w,g}$ given in section 5.3.2, will be used in the proof of the following lemma:

Lemma 5.1 *For each aggregation level a, the total cost error $Z^{a^*} - Z^{o^*}$ is non-negative.*

Proof. We show that for each feasible solution of $MILP^a$, there exists a feasible solution of $MILP^o$, with the same value of the objective functions Z^a and Z^o. The optimal solution of $MILP^a$ is a feasible solution of $MILP^o$. This implies that $Z^{a^*} \geq Z^{o*}$, which proves the lemma.

Let the set $(T^a_{p,l,w}, A^a_{w,g})$ be a feasible solution of $MILP^a$. Define the set $(T^o_{p,l,w}, A^o_{w,g})$ by

$T^o_{p,l,w}$	$:= T^a_{p,l,w}$	for each p, l, w
$A^o_{w,c}$	$:= A^a_{w,g}$	for each w and each c, where customer group g is such that $c \in g$.

It is obvious that this set $(T^o_{p,l,w}, A^o_{w,c})$ satisfies all constraints of $MILP^o$.
So, $(T^o_{p,l,w}, A^o_{w,c})$ is a feasible solution of $MILP^o$.
Moreover, the corresponding values Z^o and Z^a are equal:

$$\begin{aligned}
Z^a &= \sum_{p,l,w} t_{p,l,w} T^a_{p,l,w} + \sum_{p,w,g} \tau_{p,w,g} d_{p,g} A^a_{w,g} \\
&= \sum_{p,l,w} t_{p,l,w} T^o_{p,l,w} + \sum_{p,w,g} \left(\sum_{c \in g} \frac{d_{p,c}}{d_{p,g}} \tau_{p,w,c} \right) d_{p,g} A^a_{w,g} \\
&= \sum_{p,l,w} t_{p,l,w} T^o_{p,l,w} + \sum_{w,g} \left(\sum_{c \in g,p} d_{p,c} \tau_{p,w,c} \right) A^a_{w,g} \\
&= \sum_{p,l,w} t_{p,l,w} T^o_{p,l,w} + \sum_{p,w,c} d_{p,c} \tau_{p,w,c} A^o_{w,c} \\
&= Z^o
\end{aligned} \qquad \square$$

For a specific type of aggregation procedure, the total cost error even increases monotonously with the aggregation level. This holds for aggregation procedures with the following property:

Property 5.1 *'Extending group property'*
Let us consider an aggregation procedure with the aggregation level as parameter. Let a, b ($a \leq b$) be two aggregation levels. If for each customer group g^a there exists one g^b such that for all $c \in g^a$ holds that $c \in g^b$, then the aggregation procedure has the extending group property.

Note that this property holds for the aggregation procedure we selected in section 5.3.1.

The monotonous increase of the total cost error as a function of the aggregation level a, as suggested in figure 5.3, follows from the following lemma:

Lemma 5.2 *For an aggregation procedure with the 'extending group property', $a \geq b$ implies that $Z^{a^*} \geq Z^{b^*}$, where a and b are aggregation levels.*

The proof follows from exactly the same line of reasoning as the proof of lemma 5.1.

Lemma 5.1 provides the following insight. Suppose we have an upper bound $EB(a)$ on the total cost error for a specific aggregation level a. So, $Z^{a^*} - Z^{o^*} \leq EB(a)$. If Z^{a^*} is known, then Z^{o^*} is an element of the interval $[Z^{a*} - EB(a), Z^{a^*}]$. If Z^{o^*} is known, then Z^{a^*} is an element of the interval $[Z^{o*}, Z^{o^*} + EB(a)]$.
In the following section we will derive several types of upper bounds which can help us to estimate Z^{o*}, without solving $MILP^o$ or to estimate Z^{a*}, without solving $MILP^a$. An estimation of Z^{o^*} or Z^{a^*}, combined with the values of the upper bound $EB(a)$ for several aggregation levels a, offers an insight into the total cost error caused by customer aggregation.

We denote the types of upper bounds we will distinguish by $EB_d^s(a)$, where

- s represents the type of solution needed to calculate the upper bound: an optimal solution of $MILP^a$ (A), an optimal solution of $MILP^o$ (O) or no optimal solution (N).
- d represents the type of data needed: detailed data (*det*) or aggregated data (*agg*).
- a represents the aggregation level for which the upper bound is calculated.

We will first discuss two classical bounds and extend them in section 5.4.4.

5.4.2 The classical bound $EB^N_{det}(a)$

For each aggregation level a, $EB^N_{det}(a)$ can be calculated without solving $MILP^o$ or $MILP^a$. Only detailed data on the demand $d_{p,c}$ of the individual customers and the delivery costs $\tau_{p,w,c}$ from the warehouses to the individual customers are needed. Moreover, data on the delivery costs $t_{p,l,w}$ from lines to warehouses are needed. Since no solution of an MILP problem is needed to calculate this bound, this bound is called an a priori bound.
The result of this bound is an absolute value. This value becomes meaningful if it is related to Z^{o^*} or Z^{a^*} (see figure 5.5):

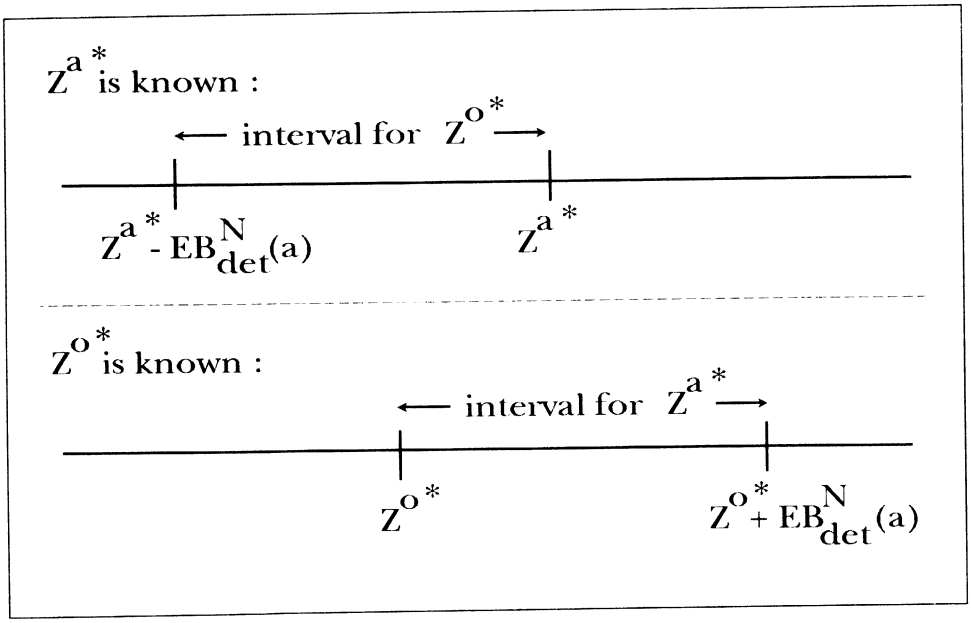

Figure 5.5: Insights from bound $EB^N_{det}(a)$.

if Z^{a^*} is known, an interval for Z^{o^*} is determined by $EB^N_{det}(a)$, which gives bounds on the total cost error caused by aggregation; if Z^{o^*} is

known, an interval for Z^{a^*} is determined by $EB^N_{det}(a)$, which also provides insight into the error that may be caused by aggregation.
Note that these values Z^{o^*} and Z^{a^*} were not needed to calculate $EB^N_{det}(a)$, so at least one of them must be calculated additionally.
Talking about bounds when the solution Z^{o^*} is known might not seem very relevant at first sight. However, we will discuss the practical relevance of these types of bounds in section 5.5.
A point of reference other than Z^{o^*} or Z^{a^*} might be the level of total costs in the existing logistics network of the company.
The bounds developed in this section are extensions of the bounds developed by Zipkin (1980a) and Geoffrion (1976). The nature of the extensions lies in the fact that we consider the multi-product situation and three echelons in the logistics network (see table 5.4).

Type of problem	*Theoretical results on $EB^N_{det}(a)$*
Logistics network design *with customer aggregation*	
Capacitated warehouses and capacitated lines	sp, 3 level, Geoffrion 1976 mp, 3 level, lemma 5.3
Capacitated warehouses and uncapacitated lines	sp, 2 level, Zipkin 1980a sp, 3 level, Geoffrion 1976 mp, 3 level, lemma 5.4
Uncapacitated warehouses and capacitated lines	sp, 3 level, Geoffrion 1976 mp, 3 level, lemma 5.3
Uncapacitated warehouses and uncapacitated lines	sp, 3 level, Geoffrion 1976 sp, 2 level, Zipkin 1980a mp, 3 level, lemma 5.3 mp, 3 level, lemma 5.4
LP in general	Zipkin 1980c Shetty 1987

Table 5.4: Overview of research on $EB^N_{det}(a)$
('sp'= single-product situation, 'mp'= multi-product situation; the number of levels refers to the number of echelons in the logistics network considered).

Zipkin (1980c) and Shetty (1987) considered the effects of aggregation of constraints in linear programing models; we consider aggregation of customers, which implies aggregation of both constraints and variables.

Lemma 5.3 shows an extension involving limited capacity of both warehouses and production lines. Lemma 5.4 shows an extension involving limited warehouse capacity and unlimited production line capacity. It will turn out that these bounds are generalizations of the corresponding single- product bounds of Geoffrion (1976) and Zipkin (1980a).

Lemma 5.3 *Given the multi-product LND problem* $MILP^o$ *defined in section 5.3.2 with limited warehouse capacity as well as limited production line capacities, an a priori upper bound* $EB^N_{det}(a)$ *on the total cost error caused by customer aggregation is described by:*

$$Z^{a^*} - Z^{o^*} \leq 0.5 \sum_p \max_w \left(t_{p,w} \sum_g \sum_{c \in g} \left| \frac{\sum_{p'} d_{p',c} \sum_{c' \in g} d_{p,c'}}{\sum_{c'' \in g} \sum_{p''} d_{p'',c''}} - d_{p,c} \right| \right)$$

$$+ \sum_{p,g} \sum_{c \in g} d_{p,c} \max_w \left(\frac{\sum_{c' \in g} \sum_{p'} d_{p',c'} \tau_{p',w,c'}}{\sum_{c'' \in g} \sum_{p''} d_{p'',c''}} - \tau_{p,w,c} \right)$$

where for each p *and* w*:*

$$t_{p,w} = \max\{t_{p,l,w'} - t_{p,l,w} \mid l \textit{ produces } p\}$$

Proof. The structure of this proof is in line with Geoffrion's proof for the bound $EB^N_{det}(a)$ for the single-product problem with only limited warehouse capacity.
Let us now consider an optimal solution $(T^{o^*}_{p,l,w}, A^{o^*}_{w,c})$ of $MILP^o$, with Z^{o^*} as the corresponding value of the objective function. On the basis of this solution, we construct for a given aggregation level a, a feasible solution $(T^a_{p,l,w}, A^a_{w,g})$ of $MILP^a$ with Z^a as the corresponding value of

the objective function.
Since $Z^{a^*} \leq Z^a$, an upper bound on the total cost error $Z^{a^*} - Z^{o^*}$ is given by $Z^a - Z^{o^*}$.
The proof ends with finding an expression for this upper bound $Z^a - Z^{o^*}$.

A solution $(T^a_{p,l,w}, A^a_{w,g})$ of $MILP^a$ can be found that meets the following characteristics:

$$A^a_{w,g} = \frac{\sum_{c\in g}\sum_p d_{p,c}A^{o^*}_{w,c}}{\sum_{c'\in g}\sum_{p'} d_{p',c'}} \qquad \text{for all } w \text{ and } g.$$

$$\textstyle\sum_l T^a_{p,l,w} = \displaystyle\sum_g d_{p,g}A^a_{w,g} \qquad \text{for all } p \text{ and } w.$$

and

$$\sum_{p,w} T^a_{p,l,w} = \sum_{p,w} T^{o^*}_{p,l,w} \qquad \text{for all } l.$$

Note that in this solution of $MILP^a$, the total production of line l $(\sum_{p,w} T^a_{p,l,w})$ equals the total production of line l in $MILP^o$. In comparison to $(T^{o^*}_{p,l,w}, A^{o^*}_{w,c})$, only a reallocation of the deliveries from the lines to the warehouses is needed to ensure that $\sum_l T^a_{p,l,w} = \sum_g d_{p,g}A^a_{w,g}$ for all p and w.
A solution $(T^a_{p,l,w}, A^a_{w,g})$ that fits these characteristics is a feasible solution of $MILP^a$:

The *complete assignment of all customer groups* follows from:

$$\sum_w A^a_{w,g} = \sum_w \frac{\sum_{c\in g}\sum_p d_{p,c}A^{o^*}_{w,c}}{\sum_{c'\in g}\sum_{p'} d_{p',c'}}$$

$$= \frac{\sum_{c\in g}\sum_p d_{p,c}\sum_w A^{o^*}_{w,c}}{\sum_{c'\in g}\sum_{p'} d_{p',c'}} = 1 \qquad \text{for all } g.$$

Input-output balancing constraints at the warehouses are fulfilled for all p and w, as follows directly from the way we chose $T^a_{p,l,w}$.

Capacity constraints of the warehouses are fulfilled:

$$\begin{aligned}
\sum_{p,l} T^a_{p,l,w} &= \sum_{p,g} d_{p,g} A^a_{w,g} \\
&= \sum_{p,g} d_{p,g} \frac{\sum_{c\in g}\sum_{p'} d_{p',c} A^{o^*}_{w,c}}{\sum_{c'\in g}\sum_{p''} d_{p'',c'}} \\
&= \sum_{p,g}\sum_{c\in g} d_{p,c} \frac{\sum_{c'\in g}\sum_{p'} d_{p',c'} A^{o^*}_{w,c'}}{\sum_{c''\in g}\sum_{p''} d_{p'',c''}} \\
&= \sum_{p,c} d_{p,c} A^{o^*}_{w,c} \leq upcapw_w \qquad \text{for all } w.
\end{aligned}$$

Capacity constraints of the production lines are fulfilled:

$$\sum_{p,w} T^a_{p,l,w} = \sum_{p,w} T^{o^*}_{p,l,w} \leq upcapl_l \qquad \text{for all } l.$$

The fulfilment of the constraints proves that the defined solution $(T^a_{p,l,w}, A^a_{w,c})$ is a feasible solution of $MILP^a$.

Now, the upper bound $Z^{a^*} - Z^{o^*}$ can be estimated as follows:

$$\begin{aligned}
Z^{a^*} - Z^{o^*} &\leq Z^a - Z^{o^*} \\
&= \sum_{p,l,w} t_{p,l,w} T^a_{p,l,w} + \sum_{p,w,g} \tau_{p,w,g} d_{p,g} A^a_{w,g} \\
&\quad - \sum_{p,l,w} t_{p,l,w} T^{o^*}_{p,l,w} - \sum_{p,w,c} \tau_{p,w,c} d_{p,c} A^{o^*}_{w,c}
\end{aligned}$$

We first show how $\sum_{p,l,w} t_{p,l,w}T^a_{p,l,w} - \sum_{p,l,w} t_{p,l,w}T^{o^*}_{p,l,w}$ can be expressed in $A^{o^*}_{w,c}$ and then we show how $\sum_{p,w,g} \tau_{p,w,g}d_{p,g}A^a_{w,g} - \sum_{p,w,c} \tau_{p,w,c}d_{p,c}A^{o^*}_{w,c}$ can be expressed in $A^{o^*}_{w,c}$. The final step is to combine these two expressions and to eliminate $A^{o^*}_{w,c}$, which gives an upper bound $EB^N_{det}(a)$.

The difference $\sum_{p,l,w} t_{p,l,w}T^a_{p,l,w} - \sum_{p,l,w} t_{p,l,w}T^{o^*}_{p,l,w}$ represents the extra costs for deliveries from the lines to the warehouses in $MILP^a$ in comparison with $MILP^o$. These extra costs are caused by the reallocation of line-warehouse deliveries in the aggregated solution. These extra costs can be estimated as follows:

$$\sum_{p,l,w} t_{p,l,w}T^a_{p,l,w} - \sum_{p,l,w} t_{p,l,w}T^{o^*}_{p,l,w}$$

$$= \sum_{p,l,w} t_{p,l,w}\left(T^a_{p,l,w} - T^{o^*}_{p,l,w}\right)$$

$$^2\leq 0.5\sum_{p,w} t_{p,w}\left|\sum_{l}\left(T^a_{p,l,w} - T^{o^*}_{p,l,w}\right)\right|$$

$$^3= 0.5\sum_{p,w} t_{p,w}\left|\sum_{g}\sum_{c'\in g} d_{p,c'}\frac{\sum_{c\in g}\sum_{p'} d_{p',c}A^{o^*}_{w,c}}{\sum_{c''\in g}\sum_{p''} d_{p'',c''}} - \sum_{g}\sum_{c\in g} d_{p,c}A^{o^*}_{w,c}\right|$$

$$= 0.5\sum_{p,w} t_{p,w}\left|\sum_{g}\sum_{c\in g} A^{o^*}_{w,c}\frac{\sum_{p'} d_{p',c}\sum_{c'\in g} d_{p,c'}}{\sum_{c''\in g}\sum_{p''} d_{p'',c''}} - \sum_{g}\sum_{c\in g} d_{p,c}A^{o^*}_{w,c}\right|$$

---

[2] $t_{p,w} = \max\{t_{p,l,w'} - t_{p,l,w}\}$ for each p, w. $t_{p,w}$ represents the highest possible increase in delivery costs in case a product p is delivered to a warehouse w by a different line.
$\left|\sum_l \left(T^a_{p,l,w} - T^{o^*}_{p,l,w}\right)\right|$ represents the changes in product flows in the line-warehouse deliveries. In this sum, each change is counted twice. This clarifies the factor 0.5.

[3] use the definitions of $d_{p,g}$ and $A^a_{w,g}$.

$$= 0.5 \sum_{p,w} t_{p,w} \left| \sum_{g} \sum_{c \in g} A^{o^*}_{w,c} \left(\frac{\sum_{p'} d_{p',c} \sum_{c' \in g} d_{p,c'}}{\sum_{c'' \in g} \sum_{p''} d_{p'',c''}} - d_{p,c} \right) \right|$$

The second part can be estimated as follows:

$$\sum_{p,w,g} \tau_{p,w,g} d_{p,g} A^{a}_{w,g} - \sum_{p,w,c} \tau_{p,w,c} d_{p,c} A^{o^*}_{w,c}$$

$$^{4} = \sum_{p,w,g} \left(\sum_{c \in g} \frac{d_{p,c} \tau_{p,w,c}}{d_{p,g}} \right) d_{p,g} A^{a}_{w,g} - \sum_{p,w,c} \tau_{p,w,c} d_{p,c} A^{o^*}_{w,c}$$

$$^{5} = \sum_{p,w,g} \sum_{c \in g} \frac{d_{p,c} \tau_{p,w,c}}{d_{p,g}} d_{p,g} \frac{\sum_{c' \in g} \sum_{p'} d_{p',c'} A^{o^*}_{w,c'}}{\sum_{c'' \in g} \sum_{p''} d_{p'',c''}} - \sum_{p,w,c} \tau_{p,w,c} d_{p,c} A^{o^*}_{w,c}$$

$$= \sum_{p,w,g} \sum_{c \in g} d_{p,c} \tau_{p,w,c} \frac{\sum_{c' \in g} \sum_{p'} d_{p',c'} A^{o^*}_{w,c'}}{\sum_{c'' \in g} \sum_{p''} d_{p'',c''}} - \sum_{p,w,c} \tau_{p,w,c} d_{p,c} A^{o^*}_{w,c}$$

$$= \sum_{p,w,g} \sum_{c \in g} d_{p,c} A^{o^*}_{w,c} \frac{\sum_{c' \in g} \sum_{p'} d_{p',c'} \tau_{p',w,c'}}{\sum_{c'' \in g} \sum_{p''} d_{p'',c}} - \sum_{p,w,c} d_{p,c} A^{o^*}_{w,c} \tau_{p,w,c}$$

$$= \sum_{p,w,g} \sum_{c \in g} d_{p,c} A^{o^*}_{w,c} \left(\frac{\sum_{c' \in g} \sum_{p'} d_{p',c'} \tau_{p',w,c'}}{\sum_{c'' \in g} \sum_{p''} d_{p'',c''}} - \tau_{p,w,c} \right)$$

Now, we can determine an upper bound on the total cost error:

$$Z^{a^*} - Z^{o^*}$$

$$\leq 0.5 \sum_{p,w} t_{p,w} \left| \sum_{g} \sum_{c \in g} A^{o^*}_{w,c} \left(\frac{\sum_{p'} d_{p',c} \sum_{c' \in g} d_{p,c'}}{\sum_{c'' \in g} \sum_{p''} d_{p'',c''}} - d_{p,c} \right) \right|$$

---

[4] use definition of $\tau_{p,w,g}$.

[5] use definition of $A^{a}_{w,g}$.

$$+\sum_{p,w,g}\sum_{c\in g} d_{p,c}A^{o^*}_{w,c}\left(\frac{\sum_{c'\in g}\sum_{p'} d_{p',c'}\tau_{p',w,c'}}{\sum_{c''\in g}\sum_{p''} d_{p'',c''}} - \tau_{p,w,c}\right) \tag{5.1}$$

$$\leq 0.5\sum_{p}\max_{w}\left(t_{p,w}\sum_{g}\sum_{c\in g}\left|\frac{\sum_{p'} d_{p',c}\sum_{c'\in g} d_{p,c'}}{\sum_{c''\in g}\sum_{p''} d_{p'',c''}} - d_{p,c}\right|\right)$$

$$+\sum_{p,g}\sum_{c\in g} d_{p,c}\max_{w}\left(\frac{\sum_{c'\in g}\sum_{p'} d_{p',c'}\tau_{p',w,c'}}{\sum_{c''\in g}\sum_{p''} d_{p'',c''}} - \tau_{p,w,c}\right) \qquad \square$$

Lemma 5.4 *Given the multi-product LND problem $MILP^o$ defined in section 5.3.2 with limited warehouse capacity and with either unlimited production line capacity or exactly one production line for each product, an a priori upper bound $EB^N_{det}(a)$ on the total cost error caused by customer aggregation is described by:*

$$Z^{a^*} - Z^{o^*} \leq$$

$$\sum_{p,g}\sum_{c\in g} d_{p,c}\max_{w}\left(\frac{\sum_{c'\in g}\sum_{p'} d_{p',c'}(\tau_{p',w,c'} + t^{min}_{p',w})}{\sum_{c''\in g}\sum_{p''} d_{p'',c''}} - (\tau_{p,w,c} + t^{min}_{p,w})\right)$$

where for each p and w:

$$t^{min}_{p,w} = \min\{t_{p,l,w} \mid l \ \textit{produces}\ p\ \}$$

Proof. The proof of this lemma shows is very similar to the proof of lemma 5.3. We will focus on the differences:

Let $(T^{o^*}_{p,l,w}, A^{o^*}_{w,c})$ be an optimal solution of $MILP^o$. Then a feasible solution $(T^a_{p,l,w}, A^a_{w,g})$ of $MILP^a$ can be defined as follows:

$A^a_{w,g}$ same definition as in lemma 5.3

$$T^a_{p,l,w} = \begin{cases} \sum_g d_{p,g} A^a_{w,g} & \text{for all } p,\ w \text{ and} \\ & \text{where } l \text{ is the line corresponding with} \\ & t^{min}_{p,w} = \min\{t_{p,l,w} \mid \text{l produces p}\} \\ 0 & \text{else.} \end{cases}$$

This solution $(T^a_{p,l,w}, A^a_{w,g})$ is a feasible solution of $MILP^a$:

The *complete assignment of all customer groups* can be proved in the same way as in lemma 5.3.

Input-output balancing constraints at the warehouses are fulfilled for all p and w as follows directly from the way we defined $T^a_{p,l,w}$.

The fulfilment of the *capacity constraints of the warehouses* can be proved in the same way as in lemma 5.3.
The fulfilment of the constraints proves that the defined solution $(T^a_{p,l,w}, A^a_{w,c})$ is a feasible solution of $MILP^a$.

In the derivation of the upper bound $Z^{a^*} - Z^{o^*}$, only the first part is different from lemma 5.3:

$$\sum_{p,l,w} t_{p,l,w} T^a_{p,l,w} - \sum_{p,l,w} t_{p,l,w} T^{o^*}_{p,l,w}$$

$$\overset{6}{=} \sum_{p,w} t^{min}_{p,w} \sum_g d_{p,g} A^a_{w,g} - \sum_{p,w} t^{min}_{p,w} \sum_c d_{p,c} A^{o^*}_{w,c}$$

---

[6] In the optimal solution of $MILP^o$, each warehouse is supplied by the cheapest production line.

$$= \sum_{p,w} t^{min}_{p,w} \left(\sum_{g} \sum_{c \in g} d_{p,c} \frac{\sum_{c' \in g} \sum_{p'} d_{p',c'} A^{o^*}_{w,c'}}{\sum_{c'' \in g} \sum_{p''} d_{p'',c''}} \right) - \sum_{p,w} t^{min}_{p,w} \left(\sum_{g} \sum_{c \in g} d_{p,c} A^{o^*}_{w,c} \right)$$

$$= \sum_{p,w,g} \sum_{c \in g} t^{min}_{p,w} d_{p,c} \frac{\sum_{c' \in g} \sum_{p'} d_{p',c'} A^{o^*}_{w,c'}}{\sum_{c'' \in g} \sum_{p''} d_{p'',c''}} - \sum_{p,w,g} \sum_{c \in g} t^{min}_{p,w} d_{p,c} A^{o^*}_{w,c}$$

$$= \sum_{p,w,g} \sum_{c \in g} d_{p,c} A^{o^*}_{w,c} \frac{\sum_{c' \in g} \sum_{p'} t^{min}_{p',w} d_{p',c'}}{\sum_{c'' \in g} \sum_{p''} d_{p'',c''}} - \sum_{p,w,g} \sum_{c \in g} d_{p,c} A^{o^*}_{w,c} t^{min}_{p,w}$$

$$= \sum_{p,w,g} \sum_{c \in g} d_{p,c} A^{o^*}_{w,c} \left(\frac{\sum_{c' \in g} \sum_{p'} t^{min}_{p',w} d_{p',c'}}{\sum_{c'' \in g} \sum_{p''} d_{p'',c''}} - t^{min}_{p,w} \right)$$

Now, we can determine an upper bound on the total cost error:

$$Z^{a^*} - Z^{o^*}$$

$$\leq \sum_{p,w,g} \sum_{c \in g} d_{p,c} A^{o^*}_{w,c} \left(\frac{\sum_{c' \in g} \sum_{p'} t^{min}_{p',w} d_{p',c'}}{\sum_{c'' \in g} \sum_{p''} d_{p'',c''}} - t^{min}_{p,w} \right)$$

$$+ \sum_{p,w,g} \sum_{c \in g} d_{p,c} A^{o^*}_{w,c} \left(\frac{\sum_{c' \in g} \sum_{p'} d_{p',c'} \tau_{p',w,c'}}{\sum_{c'' \in g} \sum_{p''} d_{p'',c''}} - \tau_{p,w,c} \right) \qquad (5.2)$$

$$\leq \sum_{p,g} \sum_{c \in g} d_{p,c} \max_{w} \left(\frac{\sum_{c' \in g} \sum_{p'} d_{p',c'} (\tau_{p',w,c'} + t^{min}_{p',w})}{\sum_{c'' \in g} \sum_{p''} d_{p'',c''}} - (\tau_{p,w,c} + t^{min}_{p,w}) \right)$$

□

The bounds of lemma 5.3 and 5.4 can also be used for multi-product situations with unlimited warehouse capacity.

Of course, the derived bounds $EB^{N}_{det}(a)$ for the multi-product situations can also be applied to single-product situations. In the single-product situation, the derived bound $EB^{N}_{det}(a)$ of lemma 5.4 also holds in case of limited production line capacity, since the single-product version of this bound is independent of the capacity and costs of the line-warehouse trajectory:

Lemma 5.5 *Given the single-product version of the LND problem $MILP^o$ defined in section 5.3.2* [7] *with limited warehouse capacity and limited production line capacity, an a priori upper bound $EB_{det}^N(a)$ on the total cost error caused by customer aggregation is described by:*

$$Z^{a^*} - Z^{o^*} \leq \sum_g \sum_{c \in g} d_c \max_w \left(\frac{\sum_{c' \in g} d_{c'} \tau_{w,c'}}{\sum_{c'' \in g} d_{c''}} - \tau_{w,c} \right)$$

Proof. The proof of lemma 5.4 also holds for this lemma, except the index p is left out and $T_{l,w}^a$ can be specified differently:

Choose $T_{l,w}^a = T_{l,w}^{o^*}$ and define $A_{w,g}^a$ in the same way as in lemma 5.4. It is easy to see that $(T_{l,w}^a, A_{w,g}^a)$ is a feasible solution of the single product version of $MILP^a$
In the derivation of the upper bound in the proof of lemma 5.4, the part $\sum_{l,w}(T_{l,w}^a - T_{l,w}^{o^*}) = 0$. □

Intuitively, this bound can be understood by realizing that, for each customer, the maximum increase in transportation costs caused by aggregation is calculated. This increase is expressed in lemma 5.5 as the maximum difference between the transportation costs $\frac{\sum_{c' \in g} d_{c'} \tau_{w,c'}}{\sum_{c'' \in g} d_{c''}}$ from a warehouse to a customer if this customer is supplied as a member of a customer group and the transportation costs $\tau_{w,c}$ from the same warehouse to the same customer if the customer is supplied individually.
Figure 5.6 shows some experimental results on the bound $EB_{det}^N(a)$ for a multi-product and a single-product situation. In figure 5.3, the specific situation of food production and distribution in Italy with limited warehouse capacity and unlimited production line capacity shows a

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[7] The notation used in section 5.3.2 can easily be translated into a single-product notation by omitting the index p. In this lemma we use the single-product notation.

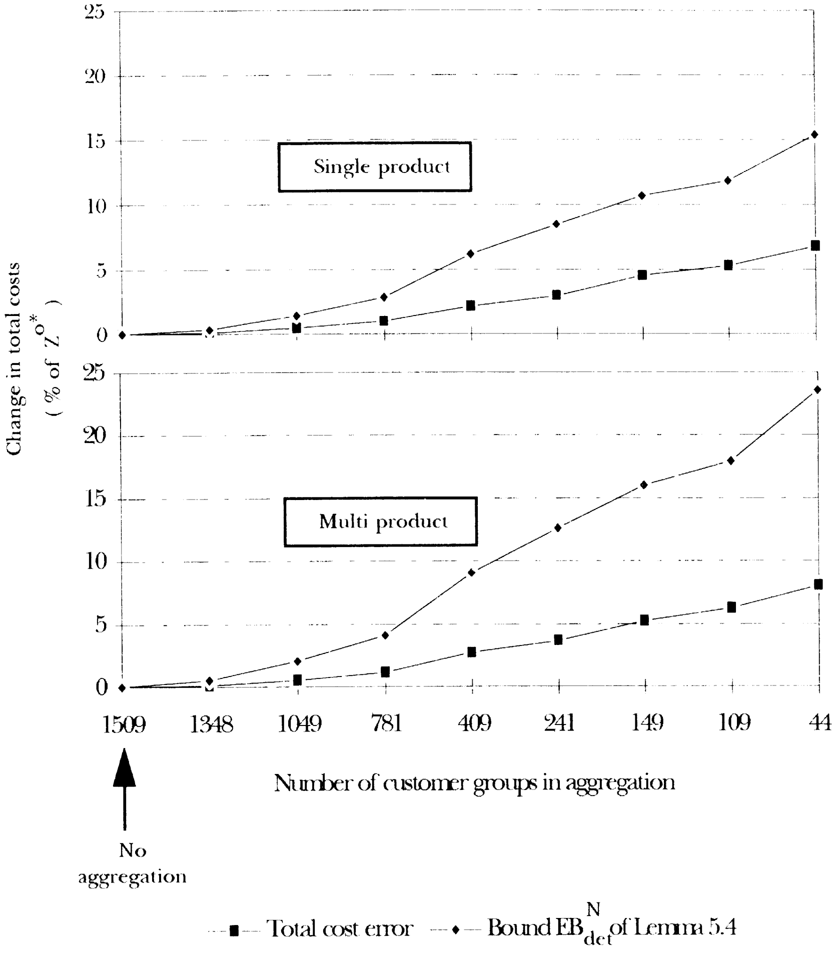


Figure 5.6: Experimental results on error bound $EB^N_{det}(a)$ for a situation with limited warehouses capacity and unlimited production line capacity.

high total cost error caused by customer aggregation. For this situation, we calculated the corresponding upper bound $EB^{N}_{det}(a)$ and related it to Z^{o^*}. Moreover, we show the total cost error (also as a percentage of Z^{o^*}). The graphs show that for these specific problem instances, $EB^{N}_{det}(a)$ provides a loose upper bound on the total cost error.

As we have argued in this section, sometimes Z^{a^*} or Z^{o^*} is needed to obtain useful insights from $EB^{N}_{det}(a)$, so $MILP^a$ or $MILP^o$ has to be solved. This gives the opportunity to use the solutions of $MILP^a$ or $MILP^o$ to determine tighter upper bounds than $EB^{N}_{det}(a)$. This will be done in the next sections.

5.4.3 The classical bound $EB^{A}_{det}(a)$

To calculate this bound, an optimal solution of $MILP^a$ is needed. Moreover, detailed data on the demand $d_{p,c}$ of the individual customers and the delivery costs $\tau_{p,w,c}$ from the warehouses to individual customers are needed. Since a solution of an MILP problem is needed, this bound is called an a posteriori bound. This bound makes it easier to estimate Z^{o^*} as shown in figure 5.7.

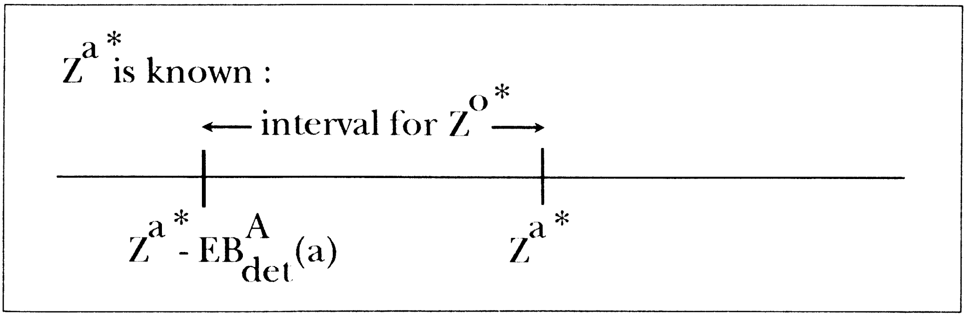


Figure 5.7: Insights from bound $EB^{A}_{det}(a)$.

The a priori bound $EB^N_{det}(a)$ and the a posteriori bound $EB^A_{det}(a)$ are existing types of bounds, which were introduced in the 1970s by Geoffrion (1976) and Evans (1979) respectively. At that time, these bounds were used to find the solution of very large linear programing models, which could not be solved within a reasonable time at that time. A framework of Rogers et al. (1991) shows how these bounds can be used to find a solution for the original detailed problem (see figure 5.8).

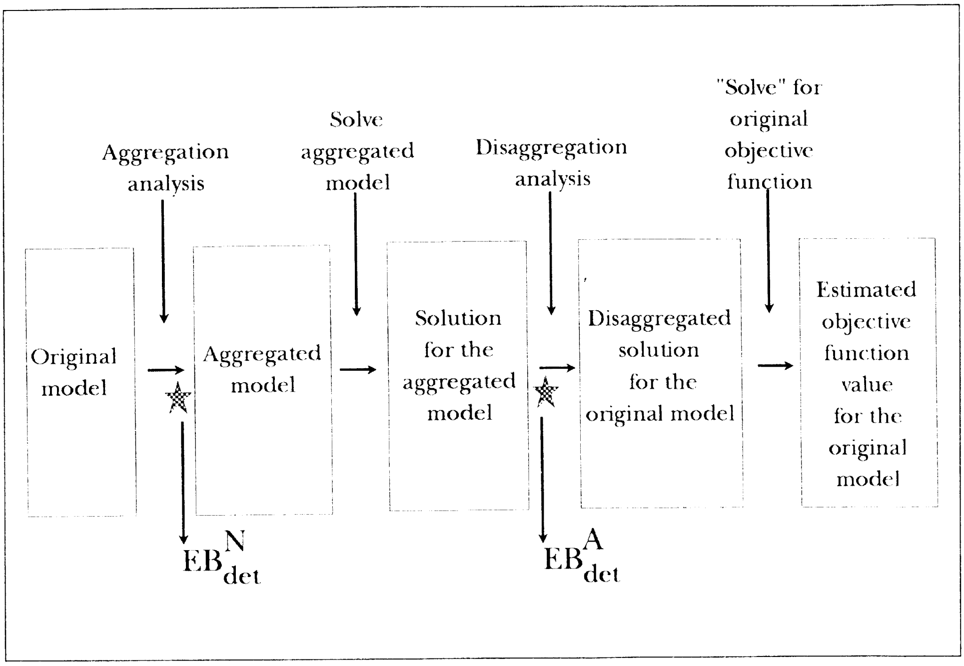


Figure 5.8: Framework for aggregation to find a solution for the original detailed problem (Rogers et al., 1991).

Evans (1983) and Zipkin (1982) extended the work of Evans (1979) on the a posteriori bound $EB^A_{det}(a)$ as shown in table 5.5. They consider a transportation problem and a network flow problem with limited transportation capacity. The logistics network we consider is a three-level problem. Moreover, we have constraints of the assignment type for the delivery to customers by one single warehouse. Note that for the single-product situation these allocation variables are similar to the flow variables in a network flow problem.

Zipkin (1980b and 1980c) also studied a posteriori bounds, based on optimal solutions of an aggregated problem. He derived upper bounds for general linear programing models using aggregation of *either* variables *or* constraints. In our linear programing model of the logistics network problem with customer aggregation, we aggregate constraints *and* variables simultaneously.

In this section, we will develop $EB^A_{det}(a)$ for our three-level, multi-product, capacitated LND problem. The method we will use will be similar to those of Evans (1979), Shetty (1987) and Zipkin (1980a, 1982).

To derive $EB^A_{det}(a)$, we use the optimal dual solution of $MILP^a$ (U^a_l, U^a_w, $U^a_{p,w}$, U^a_g), which is defined as:

U^a_l := the value of the dual variable related to
the capacity constraint of line l
in the primal problem formulation
(non-negative for all lines l).

U^a_w := the value of the dual variable related to
the capacity constraint of warehouse w
in the primal problem formulation
(non-negative for all warehouses w).

$U^a_{p,w}$:= the value of the dual variable related to
the input-output constraint of warehouse w and
product p in the primal problem formulation
(unrestricted in sign for all warehouses w).

U_g^a := the value of the dual variable related to the assignment constraint of customer group g in the primal problem formulation (unrestricted in sign for all customer groups g).

Type of problem	*Theoretical results on* $EB_{det}^A(a)$
Logistics network design with customer aggregation	
Capacitated warehouses and capacitated lines	mp, 3 level,lemma 5.6
Capacitated warehouses or capacitated lines	sp, 2 level, Evans 1979
Uncapacitated lines and warehouses	sp, 3 level, Zipkin 1982 mp, 2 level, Evans 1983 mp, 3 level, lemma 5.6
LP in general	Zipkin 1980b,c

Table 5.5: Overview of research on $EB_{det}^A(a)$ *('sp' = single-product situation, 'mp' = multi-product situation; the number of levels refers to the number of echelons in the logistics network considered).*

Lemma 5.6 *Given the multi-product LND problem* $MILP^o$ *defined in section 5.3.2, with limited warehouse and production line capacities, an a posteriori upper bound* $EB_{det}^A(a)$ *on the total cost error caused by customer aggregation is described by:*

$$Z^{a^*} - Z^{o^*} \leq \sum_{p,c} d_{p,c} \max_{w} \left(-\tau_{p,w,c} - U_w^{a^*}\right) + \sum_g U_g^{a^*}$$

Proof. Let $(U_l^{a^*}, U_w^{a^*}, U_{p,w}^{a^*}, U_g^{a^*})$ be an optimal dual solution of $MILP^a$. First, we will express the unknown value Z^{o^*}, corresponding to the unknown optimal solution (T^{o^*}, A^{o*}) of the original problem, in terms of this optimal dual solution of the aggregated problem. Based on this expression for Z^{o^*}, we will derive an upper bound on $Z^{a^*} - Z^{o^*}$:

$$\begin{aligned}
Z^{o^*} &= \sum_{p,l,w} t_{p,l,w} T^{o^*}_{p,l,w} + \sum_{p,w,c} \tau_{p,w,c} A^{o^*}_{w,c} d_{p,c} \\
&\geq \sum_{p,l,w} t_{p,l,w} T^{o^*}_{p,l,w} + \sum_{p,w,c} \tau_{p,w,c} A^{o^*}_{w,c} d_{p,c} \\
&\quad + \sum_{l} U_l^{a^*} \left(\sum_{p,w} T^{o^*}_{p,l,w} - upcapl_l \right) \\
&\quad + \sum_{w} U_w^{a^*} \left(\sum_{p,c} A^{o^*}_{w,c} d_{p,c} - upcapw_w \right) \\
&\quad + \sum_{g} U_g^{a^*} - \sum_{g} U_g^{a^*} \\
&= -\sum_{l} upcapl_l U_l^{a^*} - \sum_{w} upcapw_w U_w^{a^*} + \sum_{g} U_g^{a^*} \qquad (5.3) \\
&\quad + \sum_{p,l,w} T^{o^*}_{p,l,w} \left(t_{p,l,w} + U_l^{a^*} \right) \\
&\quad + \sum_{p,w,c} A^{o^*}_{w,c} d_{p,c} \left(\tau_{p,w,c} + U_w^{a^*} \right) \\
&\quad - \sum_{g} U_g^{a^*}
\end{aligned}$$

Note that (5.3) represents the value of an optimal dual solution of $MILP^a$. Since this value equals Z^{a^*}, an upper bound can be derived as follows:

$$\begin{aligned}
Z^{a^*} - Z^{o^*} &\leq \sum_{p,l,w} T^{o^*}_{p,l,w} \left(-t_{p,l,w} - U_l^{a^*} \right) \\
&\quad + \sum_{p,w,c} A^{o^*}_{w,c} d_{p,c} \left(-\tau_{p,w,c} - U_w^{a^*} \right) + \sum_{g} U_g^{a^*} \\
&\leq \sum_{p,c} d_{p,c} \max_{w} \left(-\tau_{p,w,c} - U_w^{a^*} \right) + \sum_{g} U_g^{a^*} \qquad \square
\end{aligned}$$

The bound of lemma 5.6 also holds for situations with unlimited capacity on production lines or warehouses. The proof follows with slight adaption from the proof of lemma 5.6

Bound $EB^A_{det}(a)$ is expected to be tighter than $EB^N_{det}(a)$, due to the use of an optimal solution of $MILP^a$ as additional information.

5.4.4 Alternative bounds $EB^A_{agg}(a)$ and $EB^O_{det}(a)$

To calculate the classical bounds $EB^N_{det}(a)$ and $EB^A_{det}(a)$, detailed data $d_{p,c}$ and $\tau_{p,w,c}$ are needed. As discussed earlier, in many practical situations data are only available at an aggregated level. A new type of bound $EB^A_{agg}(a)$ can be introduced by using only aggregated data and an optimal solution of $MILP^a$.
$EB^A_{agg}(a)$ can be used to estimate Z^{o^*} in the same way as $EB^A_{det}(a)$ (see figure 5.9), although it is expected to be a less tight bound, as it uses less detailed data.

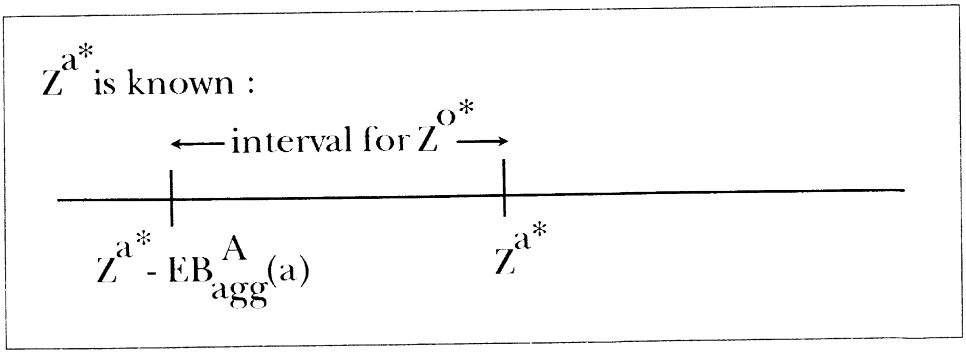


Figure 5.9: Insights from bound $EB^A_{agg}(a)$.

This bound $EB^A_{agg}(a)$ is derived in the following lemma:

Lemma 5.7 *Given the multi-product LND problem $MILP^o$ defined in section 5.3.2, with limited warehouse and production line capacities, an a posteriori upper bound $EB^A_{agg}(a)$ on the total cost error caused by customer aggregation is described by:*

$$Z^{a^*} - Z^{o^*} \leq \sum_g U_g^{a^*}$$

Proof. The upper bound $EB^A_{agg}(a)$ can be derived easily from $EB^A_{det}(a)$:

$$\begin{aligned} Z^{a^*} - Z^{o^*} &\leq \sum_{p,c} d_{p,c} \max_w \left(-\tau_{p,w,c} - U_w^{a^*}\right) + \sum_g U_g^{a^*} \\ &\leq \sum_g U_g^{a^*} \end{aligned}$$

□

The bound of lemma 5.7 also holds for situations with unlimited capacity on production lines or warehouses.

To calculate the a posteriori bounds discussed so far, each time an $MILP^a$ problem has to be solved. To gain insight into the appropriate aggregation level, bounds need to be calculated for several aggregation levels a. An alternative way is to calculate $MILP^o$ and use its optimal solution (and detailed data $d_{p,c}$ and $\tau_{p,w,c}$ and data $t_{p,l,w}$) to calculate upper bounds on the total cost error for several aggregation levels a. The new type of upper bound is named $EB^O_{det}(a)$ (see figure 5.10). Following this procedure, estimations for Z^{a^*} can be made for several aggregation levels a. See again section 5.5 for the practical relevance of these types of bounds.

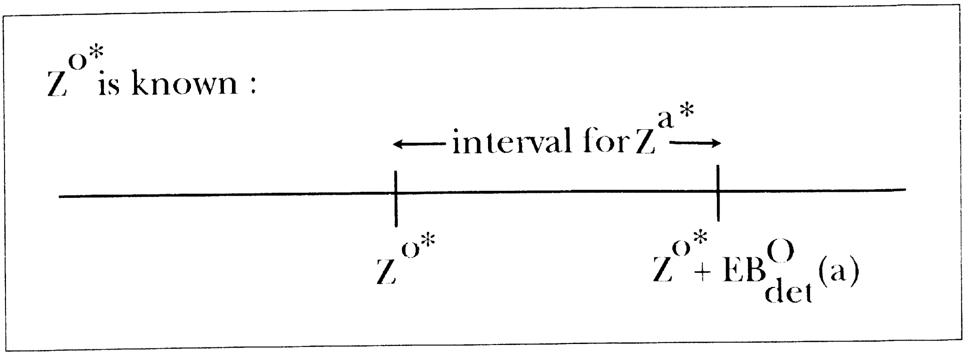


Figure 5.10: Insights from bound $EB^O_{det}(a)$.

The bound $EB^O_{det}(a)$ is derived for several situations in the following lemma's:

Lemma 5.8 *Given the multi-product LND problem $MILP^o$ defined in section 5.3.2 with limited warehouse capacity as well as limited production line capacity, an a posteriori upper bound $EB^O_{det}(a)$ on the total cost error caused by customer aggregation is described by:*

$$Z^{a^*} - Z^{o^*} \le 0.5 \sum_{p,w} t_{p,w} \left| \sum_{g} \sum_{c\in g} A^{o^*}_{w,c} \left(\frac{\sum_{p'} d_{p',c} \sum_{c'\in g} d_{p,c'}}{\sum_{c''\in g} \sum_{p''} d_{p'',c''}} - d_{p,c} \right) \right|$$

$$+ \sum_{p,w,g} \sum_{c\in g} d_{p,c} A^{o^*}_{w,c} \left(\frac{\sum_{c'\in g} \sum_{p'} d_{p',c'} \tau_{p',w,c'}}{\sum_{c''\in g} \sum_{p''} d_{p'',c''}} - \tau_{p,w,c} \right)$$

where for each p and w:

$$t_{p,w} = \max\{t_{p,l,w'} - t_{p,l,w} \mid l \textit{ produces } p\}$$

Proof. This bound follows directly from the proof of lemma 5.3. Expression 5.1 in this proof is the last expression that uses $A^{o^*}_{w,c}$. So, it can be used as a bound of type $EB^O_{det}(a)$. □

Lemma 5.9 *Given the multi-product LND problem $MILP^o$ defined in section 5.3.2 with limited warehouse capacity and with either unlimited production line capacity or for each product exactly one production line, an a priori upper bound $EB^O_{det}(a)$ for the total cost error caused by customer aggregation is described by:*

$$Z^{a^*} - Z^{o^*}$$

$$\leq \sum_{p,w,g} \sum_{c \in g} d_{p,c} A^{o^*}_{w,c} \left(\frac{\sum_{c' \in g} \sum_{p'} d_{p',c'} \left(\tau_{p',w,c'} + t^{min}_{p',w} \right)}{\sum_{c'' \in g} \sum_{p''} d_{p'',c''}} - \left(\tau_{p,w,c} + t^{min}_{p,w} \right) \right)$$

where for each p and w:

$$t^{min}_{p,w} = \min\{t_{p,l,w} \mid l \textit{ produces } p\}$$

Proof. This bound follows directly from the proof of lemma 5.4. Expression 5.2 in this proof is the final expression using $A^{o^*}_{w,c}$. So, it can be used as a bound of type $EB^O_{det}(a)$. □

The bounds of lemma 5.8 and 5.9 can also be used for multi-product situations with unlimited warehouse capacity.
A similar bound for the single-product situation is:

Lemma 5.10 *Given the single-product version of the LND problem $MILP^o$ defined in section 5.3.2* [8] *with limited warehouse capacity and limited production line capacity, an a priori upper bound $EB^O_{det}(a)$ on total cost error caused by customer aggregation is described by:*

$$Z^{a^*} - Z^{o^*} \leq \sum_{g} \sum_{c \in g} d_c A^{o^*}_{w,c} \left(\frac{\sum_{c' \in g} d_{c'} \tau_{w,c'}}{\sum_{c'' \in g} d_{c''}} - \tau_{w,c} \right)$$

---

[8] The notation used in section 5.3.2 can easily be translated into a single-product notation by omitting the index p. In this lemma we use this single-product notation.

Proof. Just as in the proof of the previous lemmas in this section, this bound, too, follows directly from the proof of the corresponding bound $EB^N_{det}(a)$ in lemma 5.5. □

Figure 5.11 shows experimental results on the bound $EB^O_{det}(a)$ as a percentage of Z^{o^*}. Moreover, the graphs show the total cost error as a percentage of Z^{o^*}. The experimental results on EB^N_{det} are also listed in figure 5.11. The graph shows that for these problem instances $EB^O_{det}(a)$ provides a tight upper bound on the total cost error.

5.5 The use of bounds in LND

During the design process of a logistics network, many alternatives have to be evaluated: there may be a substantial number of scenarios to be considered and for a specific scenario several sensitivity analyses need to be performed.

In a situation where detailed data are available and a large number of closely related input sets $\Lambda_{input-LND}$ have to be calculated in a short period of time, it may be too cumbersome to calculate an optimal solution of $MILP^o$ for each input set. In that case, a useful approach could be to determine in advance one aggregation level for all related input sets. This aggregation level can be based on an analysis of one or a few representative input sets $\Lambda_{input-LND}$. This level would be expected to be valid for the other related input sets. For this approach, bounds of the type $EB^N_{det}(a)$ can be used, although this type is expected to give a loose upper bound. The bound $EB^A_{det}(a)$ is assumed to be more accurate, but in order to calculate $EB^A_{det}(a)$ for different aggregation levels, each time a problem instance of $MILP^a$ has to be solved. By putting some effort into solving $MILP^o$ once for the few representative input sets, the bound $EB^O_{det}(a)$ can be calculated for each specific aggregation level that is being investigated. $EB^O_{det}(a)$ is expected to be the tightest

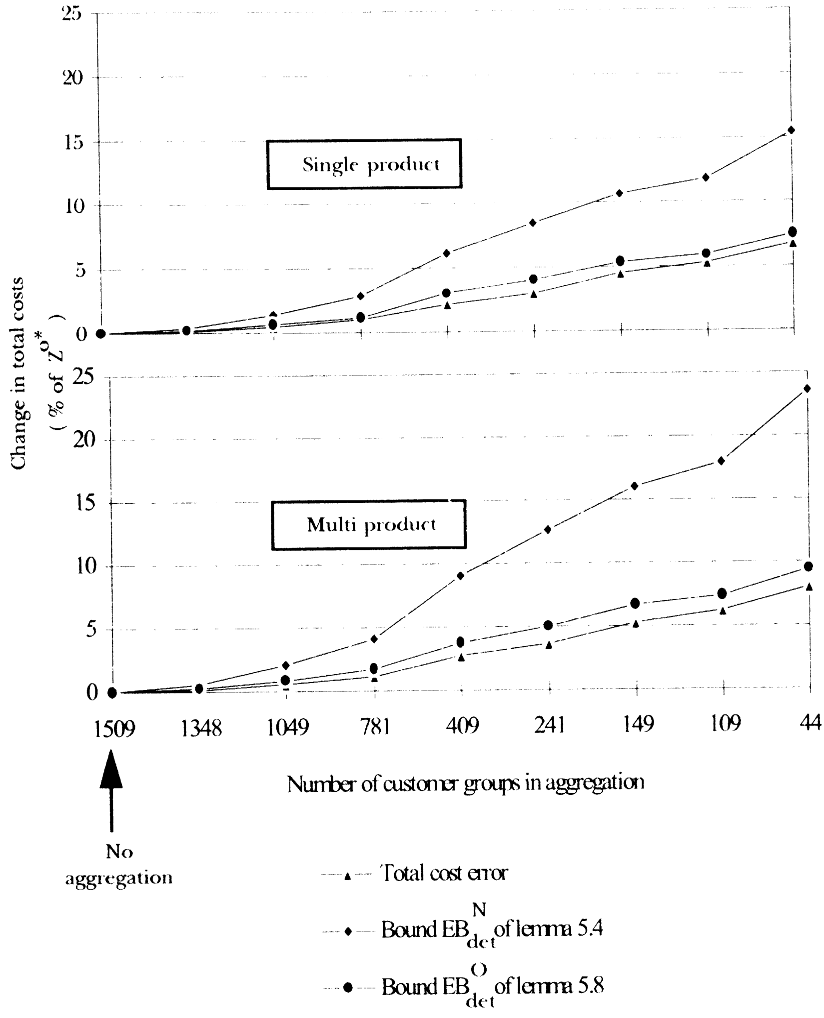


Figure 5.11: Experimental results on error bound $EB^O_{det}(a)$ *for a situation with limited warehouses capacity and unlimited production line capacity.*

upper bound.

As mentioned before, often only aggregated data are available. In those situations one wants to be sure that the use of aggregated data does not lead to network designs that are far from optimal at the operational, more detailed level. In these situations, the bound $EB^A_{agg}(a)$ may give insight into the potential size of error.

If this bound shows a high error bound, one may decide to estimate detailed data. Such estimates may be based on an investigation of a specific geographical region or on information gained from experts within the organization, such as sales managers or transport managers. On the basis of these estimated detailed data, the upper bounds $EB^N_{det}(a)$, $EB^A_{det}(a)$ and $EB^O_{det}(a)$ can be used as explained above for the situation where detailed data are available.

Figure 5.12 summarizes the use of the different type of bounds.

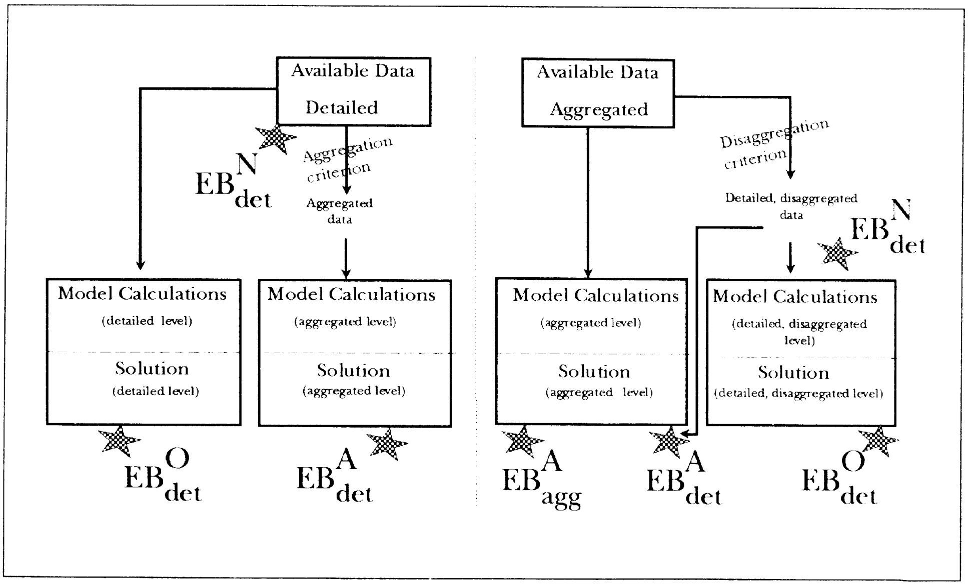


Figure 5.12: Use of different types of upper bounds.

All four types of bounds on the total cost error can be used at the beginning of the development phase of the LND decision process, in order to determine an appropriate aggregation level for the calculations with the MILP model used in the DSS SLAM. On the basis of the calculations of the bounds on several aggregation levels and for several sets $\Lambda_{input-LND}$, a particular level of aggregation is chosen. This level is often used for the development of several alternative LNDs, but it may need to be changed during the development process, because a higher level of detail is needed for more specific analyses, for instance, for the distribution in a specific geographical region. When the aggregation level needs to be changed, again the bounds on total cost error are helpful.

Another reason to use the bounds during the development phase is that the selected aggregation level is based on error bounds calculated for only a few sets $\Lambda_{input-LND}$. During the development process, it is worthwhile to check whether these error bounds still hold for the $\Lambda_{input-LND}$ that is being considered at a particular moment. If not, the aggregation level may have to be adjusted.

5.6 Evaluation

In this chapter, we discussed the effects of customer aggregation on the optimal solutions of $MILP^o$ and $MILP^a$. Since experimental results show that customer aggregation may lead to a high total cost error, we discussed how to select the appropriate aggregation level. For the selection of the appropriate aggregation level, it is often not sufficient to focus on the total cost error alone, because this may conceal high cost errors at specific levels in the logistics network. Moreover, high errors may occur in the utilization of facilities and the supplying of customers.

We developed several types of upper bounds on the total cost error that may be useful in determining the appropriate aggregation level. We presented extensions on two classical bounds, introduced two alternative bounds and discussed their added value in determining the appropriate aggregation level.

This chapter offers many opportunities for further research.
To gain insight into the quality of the different types of bounds, more empirical data are needed for the bounds EB_{det}^{A} and EB_{agg}^{A}, as well as for $EB_{det}^{N}(a)$ and $EB_{det}^{O}(a)$, especially for the situation with limited capacities on both warehouses and production lines.
Moreover, empirical data are needed on a large number of data sets $\Lambda_{input-LND}$. In section 5.5, it was stated that the error bound calculated from a specific data set $\Lambda_{input-LND}$ may represent an upper bound on the total cost error for other sets $\Lambda_{input-LND}$ that are needed for the development of an LND, but this has to be checked during the LND development process. Empirical data on a large number of sets of $\Lambda_{input-LND}$'s may provide insight into the influence of characteristics of $\Lambda_{input-LND}$ (e.g. capacitated or uncapacitated warehouses, the proportion between the delivery costs from lines to warehouses and the delivery costs from warehouses to customers), on the tightness of the bound.
Finally, the effects of aggregation on the utilization of facilities and the allocation of customers to warehouses should be investigated in greater detail.

Clearly, this chapter is a call for further research on data aggregation in strategic LND decision problems as well as research into the consequences of data aggregation for other types of decision problems in strategic decision making.

Chapter 6

Conclusions

6.1 Summary of findings

In this thesis we addressed several issues related to the central question of "How to design a competitive logistics network for a specific industrial company?" A logistics network is comprised of the flows of products and the facilities needed to deliver the products to the customers at the required service levels.
Challenged by new markets, globalization, mergers, technological innovations, environmental consciousness etc. companies inevitably need to adjust their logistics networks. However, redesigning a logistics network may entail a complex strategic decision process involving many alternatives, many participants, many decision criteria and huge numbers of data.

In this thesis we offered several insights to facilitate this complex process. We presented a framework that structures the decision process on the design of a logistics network. These are the main contributions of the thesis:

- Integration of the use of quantitative models and DSSs into strategic decision-making processes through the use of scenarios
- Extension of existing structured approaches to strategic decision making, resulting in an approach involving multiple participants
- Deepened insight into the possibilities of aggregating unwieldy numbers of detailed data into more easily managable sets of aggregated data

Our findings are based on various theoretical concepts and on observations and applications from real-life situations in several industrial companies.
The concepts for strategic decision making we used come from Mintzberg et al. (1976) and Simon (1977). We elaborated Porter's (1985) approach to scenario development, drawing on the Consistency Model of Organizational Assessment and Change developed by Broekstra (1984, 1989). The multi-participant aspect of strategic decision making was brought in from a framework proposed by Chakravarthy and Lorange (1991). To extend existing insights into the possibilities of aggregating huge numbers of detailed data into smaller numbers of aggregated data, we mainly built on the findings of Geoffrion (1975, 1976, 1977) and Zipkin (1980a, 1980b, 1980c, 1982).
A blend of the real-life logistics network design processes in which we were involved is reflected in the case description in chapter 2, the applications of the scenario approach in chapter 3, the applications of the framework developed in chapter 4 and the experimental results on the aggregation of customers presented in chapter 5.

In chapter 1 we promised to deal with a number of specific topics in the field of LND. Let us now briefly look at how successful we have been:

- The *integration of production and distribution* into a total supply chain instead of focusing on either distribution or production networks as subject of the decision process. In chapter 2 we described a logistics network design problem of a fictitious European company selling, producing and distributing a wide range of consumer electronics products on the European market. The company has to take decisions on the number, locations and sizes of plants, suppliers and warehouses; it also has to allocate the flows of the semi-products and finished products to the various echelons of the logistics network and to settle the allocation of the customers to the warehouses. While considering the decision situation in detail, we developed an MILP model to support the development and evaluation of alternative logistics networks (see chapters 3 and 4). The MILP model focuses on minimization of total variable logistics costs while also taking account of other aspects, such as customer service.

- The structured development of *external and company scenarios* (chapter 3). Given the strategic character of the design of a logistics network, we showed how external trends can be represented in external scenarios and how these external scenarios can be translated into company scenarios offering different views of a company's future development. Each company scenario includes an alternative design of a logistics network. This design is prepared with the support of the MILP model that we developed and incorporated into a DSS. The company scenarios are evaluated on the basis of their potential for competitive advantage, costs, sensitivity to future change and internal aspects, such as political and operational feasibility needed to implement the new network. The structured approach to building these scenarios makes it easier to concentrate on the development of the most important scenarios. By adopting this approach it is less likely that scenarios with interesting aspects or alternatives are overlooked.

- The development of a *stepwise approach* to decision processes involving *multiple participants* (chapters 3 and 4). The classical approach to strategic decision making distinguishes several useful phases (identification, developments, selection and authorization). We extended this approach, based on the observation that many strategic decision processes, such as the design of a logistics network structure, involve several parties at different stages in the decision process. This multi-participant approach makes the decision process more transparent and contributes to its effectiveness and its efficiency.

- The support of a *DSS* in the various phases and for the various participants in the decision process (chapters 3 and 4). Since many scenarios and alternative logistics networks are elaborated during the design process and since various parties have to deal with these alternatives, a DSS is very helpful in supporting the development, evaluation and analysis of the alternatives. The DSS we developed does not only focus on distribution or production aspects of the logistics network, but also takes account of the total supply chain from supplier to customer.

- Bounds offering insight into the effects of *aggregation of data* (chapter 5). As a consequence of the complexity of logistics network design and the number of parties that are involved in the design process, huge quantities of data from different departments in the company are needed to design reliable alternative logistics networks. It is often too time-consuming and economically inefficient to gather all these data at a detailed level for each possible scenario. Moreover, the level of detail required may depend on the stage of the design process.

We used mathematical concepts and insights in data aggregation which were originally developed to solve large optimization problems with very detailed data. Using a simplified version of the MILP model developed in chapter 2, we made some first steps in applying these concepts to real-life situations where insight is sought into the potential total cost error caused by data aggregation.

We developed some upper bounds on the total cost error to determine the appropriate level of aggregation of customer data. When these upper bounds have been calculated for several levels of aggregation, a trade-off can be made between the potential total cost error introduced by each aggregation level and the effort needed to gather and process the corresponding detailed data. The upper bounds we developed improve the intuitive approach common in practice to choose an aggregation level for customer data.

The framework developed in this thesis enables logistics networks to be designed more effectively and more efficiently, which enhances the competitive advantage of the companies for which the logistics network is created. In the practical situations we were involved in, it turned out that this could result in savings in the total variable logistics costs amounting to about 10% to 15% annually, while improving customer service. This results are in line with the results Geoffrion and Powers (1995).

6.2 Topics for further research

6.2.1 Improvement of the framework

The framework we developed is based on several theoretical concepts, combined with experiences and observations from real-life logistics network design processes. As illustrated in chapter 4, the framework worked quite well in some practical situations. However, in order to further improve the framework, it should be applied to other real-life case studies in different branches, to other sizes of companies, to non-European companies, etc. Also, other new theoretical concepts could be incorporated to refine the framework. We distinguish three main areas for improvement:

Steps and participants
Based on insights gained from more real-life case studies, refinements may be made with respect to the steps and the participants in the framework. Maybe this will result in a differentiation of the framework, for instance per branche, per size of company, per decision culture of a company or per geographical region. In each of these frameworks, depending on the specific situation, the number of steps may differ. Also the number of participants may vary and their roles can be defined or adjusted in accordance with their field and level of expertise. On the basis of these further studies, new insights may emerge and more precise guidelines for the steps and participants in logistics network development constructed.

Scenarios
With respect to the use of scenarios, the factors that are considered may differ per branche, per size of company, per decision culture of a company or per country. A specification of these factors for each cate-

gory of companies will help to improve the use of scenarios.

One aspect in the development of scenarios that needs to be improved is the description of the incremental growth of scenarios. Scenarios are developed step by step, from a global level at the outset to a detailed level at the end. During this process, new factors in the scenarios emerge, existing factors are described at a more detailed level or are split into new factors. A formal description of this incremental growth may also help to improve the use of scenarios.

Integration of tactical and operational aspects

In this thesis we dealt with logistics network design as a strategic problem. To validate proposals for alternative logistics networks, we recommended cooperation with people at the operational level (the field) to determine the feasibility of alternatives in daily operations. Often simulation models are useful tools to provide insights into the operational feasibility of the suggested logistics network designs.

An interesting topic for research would be to investigate the possibility of integrating the strategic, tactical and operational aspects of the logistics network design problem into quantitative models and to examine how DSSs containing these hierarchical models can further improve the decision process.

Examples of topics we did not cover in the MILP model developed in this are: return flows, multi-transport modes, fixed costs, routing, production scheduling, stock levels, capacity planning of machines and human resources, multi-period planning, technological concepts, administrative processes, control activities, etc.

Some of these elements might be integrated into our MILP model, others might be incorporated into separate models. Of course it is also possible to use quantitative models other than MILP models. If separate models are used, they should be clearly connected and produce consistent outcomes. Mourits (1995) and Van Bruggen et al.

(1993) made some first steps towards such an integration of separate models for logistics network design. Also, some general guidelines on the integration of strategic, tactical and operational aspects in strategic planning have already been developed (Radford, 1988, Hax and Majluf, 1991). A combination of the optimization models and the general guidelines may lead to new opportunities to further improve strategic decision making supported by DSSs.

In addition to research aimed at the further refinement of our LND framework, we believe it would also be worthwhile to investigate the added value of the framework if applied to other problem areas in strategic planning and decision making (of course in combination with other quantitative models).

6.2.2 Improvements in data aggregation

Aggregation criteria
In this thesis we focused on the aggregation of customer data. However, it would also be interesting to look at the effects of aggregation of product data (see Remijnse, 1995) and the aggregation of both product and customer data.

With respect to the aggregation of customers, we focused on the clustering of small customers into one group, while the large customers each constituted one single customer group. Investigations on other procedures such as clustering of small customers into a group together with the nearest large customer seem worthwhile. Comparison of the errors resulting from this new aggregation procedure and the procedure we used would be of particular interest. Moreover, within the aggregation of customers not only their total demand, but also their demand per product, their service requirements, the transport modes and the marketing distribution channels that can be used are interesting criteria for grouping customers.

Experimental results on the effects of aggregation

We have conducted some experiments to explore the effect of customer aggregation on the total cost error and on changes in the logistics network structure. These experimental results were based on six problem instances of one case study. It will be clear that extensions are needed. Also, experimental results on the sensitivity of the optimal solution of $MILP^o$ and $MILP^a$ to changes in the input data may provide new insights in the effects of aggregation.

Bounds on the total cost error

The bounds on the total cost error we developed are based on an MILP model that is a simplification of the MILP model developed for the case of the consumer electronics company in chapter 2. Eliminating the simplifications will change the formulas for the upper bounds we developed. The suggestions made in section 6.2.1 regarding extensions of our MILP model of chapter 2 will also affect the upper bounds we developed. Both these aspects offer new research opportunities.

Since the experimental results on the bounds $EB_{det}^{N}(a)$ and $EB_{det}^{O}(a)$ were based on only two problem instances from one case study, another topic for further research would be to extend the experimental results on the bounds we developed. Also, it would be worthwhile to investigate experimental results on the bounds $EB_{det}^{N}(a)$ and $EB_{det}^{O}(a)$. This could solve the question as to which relationships exist between the quality of the different types of bounds and the problem instance that is used (e.g., capacitated warehouses or lines, levels of customer demand, geographical spread of customers, etc.).

6.2.3 Integration of goods flows and information flows

In chapters 2 and 3 we discussed some trends that challenge companies to redesign their logistics networks. One major development is the customization of demand. This asks for a flexible, but well-planned and well-controlled process from the ordering stage through production and distribution to delivery. Planning and control strongly depend on the information flows within the logistics network. This starts with the orders placed by customers, for instance in a traditional shop, through tele-shopping or at a call center. This information should be distributed efficiently among the participants in the logistics network, in order to ensure that the right activities are initiated at the right moment. Finally the product should be delivered according to the customers' specifications.

In this thesis we assumed that the information processes ran smoothly, without causing delay in the process from ordering to delivery. However, we implicitly dealt with problems in the information processes. For example, one criterion used in the evaluation of an LND was its operational feasibility; if problems, for instance in information processing, were expected, the LND could be adjusted. The lead times incorporated in our MILP model are particularly useful to take account of any extra time that might be needed for information processing.

We also dealt with information aspects at a global level in the factors of the external and the company scenarios.

The framework we developed provides a structure for the design of logistics networks in which information aspects are incorporated, although refinements are needed. Extensions of the framework with respect to the integration of goods flows and information flows may lead to new challenges and requirements for LNDs - a promising area for further research.

Bibliography

Aaker, D.A., 1984, *Developing Business Strategies*, John Wiley & Sons, New York.

Ackoff, R.A., Gharajedeghi, J., Finnel, E.V., 1984, *A Guide to Controlling your Corporation's Future*, John Wiley & Sons, New York.

Aderohunmu, R.S., Aronson, J.E., 1991, The Solution of Multiperiod Network Model with Bundle Constraints by Aggregation, *Working Paper Series april 1991*, School of Management, State University of New York, Binghamton, NY 13902-6000.

Aikens, C.H., 1985, Facility location models for distribution planning, *European Journal of Operational Research*, Vol. 22, pp. 263-279.

Ananthanarayanan Venkatraman, I., 1987, *Analysis of aggregation and disaggregation structures in production and distribution*, Ph.D. Dissertation, Georgia Institute of Technology.

Anthony, R.N., 1992, *The Management Control Function*, The Harvard Business School Press, Boston, Massachusetts.

Ballou, R.H., 1992, Measuring Transport Costing Error in Customer Aggregation for Facility Location, *Working Paper*, Weatherhead

School of Management, Case Western Reserve University, Cleveland.

Ballou, R.H., Masters, J.M., 1991, A Survey of Commercial Grade Warehouse Location Models, *Annual Conference Proceedings, Volume I*, Chicago, IL: Council of Logistics Management, pp. 145-180.

Bell, D., 1982, Potential Contribution to Decision Analysis, *Decision Sciences*, Vol. 13, pp. 534-540.

Bender, P.S., 1985, Logistic System Design in Robeson, J.F. and House, R.G. (eds), *The Distribution Handbook*, Free Press, New York, pp. 143-256.

Benders, J.F., Van Nunen, J.A.E.E., 1983, A Property of Assignment Type Mixed Integer Linear Programming Problems, *Operations Research Letters*, Vol. 2, No. 2, pp. 47-52.

Beulens, A.J.M., Kolen, A.W.J., Niekamp, E.G., 1988, A Decision Support System for a Location-Allocation-Routing Problem, *OR Proceedings 1987*, University of Ulm.

Bloemhof, J.M., Salomon, M., Van Wassenhove, L.N., 1994, On the coordination of product and by-product flows in two-level distribution networks: Model formulations and solution procedures, *European Journal of Operational Research*, Vol. 79, pp. 325-339.

Boumans, P.P.W., 1991, *A DSS for production and distribution planning, based on database management and linear programming*, Master Thesis, Technical University Eindhoven.

Bowersox, D.J., 1992, *Logistical Excellence, it's not business as usual*, Digital Equipment Corporation, Burlington.

Bowersox, D.J. et al., 1995, *World Class Logistics: the challenge of managing continuous change*, Council of Logistics Management, Oak Brook, Illinois.

Brandeau, M.L., Chiu, S.S., 1989, An overview of representative problems in location research, *Management Science*, Vol. 35, pp. 645-674.

Broekstra, G., 1984, MAMA: Management by Matching, a Consistency Model for Organizational Assessment and Change in Trappl, R. (ed), *Cybernetics and Systems Research 2*, Elsevier Science Publishers B.V., North Holland.

Broekstra, G., 1989, *Het creëren van intelligente organisaties*, Eburon, Delft, the Netherlands, (in Dutch).

Bunn, D.W., Salo, A.A., 1993, Forecasting with scenarios, *European Journal of Operational Research*, Vol. 68, pp. 291-303.

Cairncross, F., 1992, How Europe's Companies Reposition to Recycle, *Harvard Business Review*, March-April, pp. 34-45.

Central Planning Bureau, 1992, *Scanning the future: a long-term scenario study for the world economy 1990-2015*, Sdu Publishers, The Hague, the Netherlands.

Chakravarthy, M., Lorange, P., 1991, *Managing the Strategy Process, A framework for a multi-business firm*, Prentice-Hall International Editions, London.

Cohen, M.A., Fisher, M., Jaikumar, R., 1989, International Manufacturing and Distribution Networks: a Normative Model Framework, in: Ferdows, K. (ed), *Managing International Manufacturing*, Elsevier Science Publishers B.V., North-Holland, pp. 67-93.

Cook , R.L., Burley, J.R., 1985, A Framework for Evaluating International Physical Distribution Strategies, *International Journal of Physical Distribution and Materials Management*, Vol. 15, No. 4, pp. 26-38.

Cooper, J., Browne, M., Peters, M., 1991, *European Logistics -Markets, Management and Strategy-*, Blackwell Publishers, Oxford.

Cooper, M.C., Innis, D.E., Peter, P.D., 1992, *Strategic Planning for Logistics*, Council of Logistics Management, Oak Brook, Illinois.

Copacino, W., Rosenfield, D.B., 1985, Analytic Tools for Strategic Planning, *International Journal of Physical Distribution & Materials Management*, Vol. 15, No. 3, pp. 47-61.

Current, J., Min, H., Schilling, D., 1990, Multi-objective analysis of facility location decisions, *European Journal of Operational Research*, Vol. 49, pp. 295-307.

Drezner, Z., 1995, *Facility Location, A survey of applications and methods*, Springer-Verlag, New York.

Duran, F., 1987, A large mixed integer production and distribution program, *European Journal of Operational Research*, Vol. 28, pp. 207-217.

Eisenhardt, K.M., 1990, Speed and Strategic Choice: How Managers Accelerate Decision Making, *California Management Review*, Spring, pp. 39-54.

European Trends, Journal on key issues and developments for business, The economist Intelligence Unit, London.

Evans, J.R., 1979, Aggregation in the Generalized Transportation Problem, *Comput. & Ops Res.*, Vol. 6, pp. 199-204.

Evans, J.R., 1983, A Network Decomposition/Aggregation Procedure for a Class of Multi-commodity Transportation Problems, *Networks*, Vol. 13, pp. 197-205.

Fine, C.H., Hax, A.C., 1985, Manufacturing Strategy: A Methodology and an Illustration, *Interfaces*, Vol. 15, No. 6, Nov.-Dec., pp. 28-46.

Gelders, L.F., Pintelon, L.M., Van Wassenhove, L.N., 1987, A location-allocation problem in a large Belgian brewery, *European Journal of Operational Research*, Vol. 28, pp. 196-206.

Geoffrion, A.M., 1975, A Guide to Computer-Assisted Methods for Distribution Systems Planning, *Sloan Management Review*, Vol. 16, No. 2, pp. 17-41.

Geoffrion, A.M., 1976, Customer Aggregation in Distribution Modelling, *Working Paper No. 59*, Management Science Study Centre, University of California, Los Angeles.

Geoffrion, A.M., 1977, A Priori Error Bounds for Procurement Commodity Aggregation in Logistics Planning Models, *Naval Research Logistics Quarterly*, Vol. 24, No. 24, pp. 210-212.

Geoffrion, A.M., Graves, G.W., 1974, Multi-commodity Distribution System Design by Benders Decomposition, *Management Science*, Vol. 20, No. 5, pp. 822-844.

Geoffrion, A.M., Powers, F.P., 1995, Twenty years of strategic distribution design: an evolutionary perspective, *Interfaces*, Vol. 25, Sept.-Oct., pp. 105-127.

Godet, M., 1987, *Scenarios and Strategic Management*, Butterworths, London.

Hagdorn, L., Warffemius, P., 1995, Decision Support Systems for Strategic Planning in Logistics -an overview-, working paper, forthcoming in *Management Report Series of the Rotterdam School of Management*, Erasmus University Rotterdam, The Netherlands.

Haq, A.N., Vrat, P., Kanda, A., 1991, An integrated production-inventory-distribution model for manufacturers of urea, *International Journal of Production Economics*, Vol. 39, pp. 39-49.

Hax, A.C., Majluf, N.S., 1991, *The strategy concept and process*, Prentice Hall International Editions, London.

House, R.G., 1985, A Small Scale Facility Location Model, *Working Paper Series WPS 78-21*, College of Administrative Science, The Ohio State University.

Huss, R.W., Honton, E.J., 1987, Scenario Planning - What Style Should You Use?, *Long Range Planning*, Vol. 20, No. 4, pp. 21-29.

Klincewicz, J.G., 1985, A Large Scale Distribution and Location Model, *AT&T Technical Journal*, Vol. 64, No. 7.

Korhonen, P., Moskowitz, H., Wallenius, J., 1992, Multiple criteria decision support - A review, *European Journal of Operational Research*, Vol. 63, pp. 361-375.

Leemhuis, J.P., 1985, Using Scenarios to Develop Strategies, *Long Range Planning*, Vol. 18, No. 2, pp. 30-37.

Linneman, R.E., Klein, H.E., 1985, Using Scenarios in Strategic Decision Making, *Business Horizons*, Jan.-Febr., pp. 64-74.

Magee, J.F., Copacino, W.C., Rosenfield, D.B., 1985, *Modern Logistics Management: Integrating Marketing, Manufacturing and Physical Distribution*, John Wiley & Sons, New York, pp. 328-330.

Malaska, P., Malmivirta, M., Meristö, T., Hansén, S.-O., 1984, Scenarios in Europe - Who uses them and why?, *Long Range Planning*, Vol. 17, No. 5, pp. 45-49.

Maljers, F.A., 1995, *Strategische Allianties*, Erasmus University Rotterdam, Rotterdam School of Management, the Netherlands, (in Dutch).

Mason, M.H., 1994, Scenario-based Planning: Decision Model for the Learning Organization, *Planning Review*, March-April 1994, pp. 6-11.

Meristö, T., 1989, Not forecasts but multiple scenarios when coping with uncertainties in the competitive environment, *European Journal of Operational Research*, Vol. 38, pp. 350-357.

Mintzberg, H., 1990, Strategy Formation: Schools of Thought in Frederickson, J.W. (ed.) *Perspective on Strategic Management*, Harper Business, New York, pp. 105-236.

Mintzberg, H., 1994, *The rise and fall of strategic planning*, Prentice Hall International.

Mintzberg, H., Raisinghani, D., Théorêt, A., 1976, The structure of "Unstructured" Decision Processes, *Administrative Science Quarterly*, Vol. 21, June, pp. 246-275.

Mirchandani, P.B., Francis, R.L., 1990, *Discrete Location Theory*, John Wiley & Sons.

Mourits, M., 1995, *Design of a Distribution Planning Support System*, Ph.D. Thesis, Technical University Delft, The Netherlands.

O'Laughlin, K.A., Cooper, J., Cabocel, E., 1993, *Reconfiguring European Logistics Systems*, Council of Logistics Management, Oak Brook.

Porter, M.E., 1985, *Competitive Advantage*, The Free Press.

Radford, K.J., 1988, *Strategic and tactical decisions*, Springer-Verlag, University Press of Canada, Ontario.

Remijnse, M. E., 1995, *Aggregatie in logistieke simulatiemodellen*, TNO-report FEL-95-S116, The Hague, The Netherlands, (in Dutch).

Rogers, D.F., Plante, R.D., Wong, R.T., Evans, J.R., 1991, Aggregation and Disaggregation Techniques and Methodology in Optimization, *Operations Research*, Vol. 39, No. 4, July-August.

Rushton, A., Saw, R., 1992, A Methodology for Logistics Strategy Planning, *The International Journal of Logistics Management*, Vol. 3, No. 1, pp. 46-62.

Sabherwal, R., Grover, V., 1989, Computer Support for Strategic Decision -Making Processes: Review and Analysis, *Decision Sciences*, Vol. 20, pp. 54-76.

Salomon, M. et al., 1996, Distributielogistiek en retourstroomoptimalisatie, *Tijdschrift voor Inkoop en Logistiek*, to appear, (in Dutch).

Schnaars, S.P., 1987, How to Develop and Use Scenarios, *Long Range Planning*, Vol. 20, No. 1, pp. 105-114.

Schoemaker, P.J.H., 1991, When and How to Use Scenario Planning: A Heuristic Approach with Illustration, *Journal of Forecasting*, Vol. 10, pp. 549-564.

Schoemaker, P.J.H., 1993, Multiple Scenario Development: Its Conceptual and Behavioral Foundation, *Strategic Management Journal*, Vol. 14, pp. 193-213.

Schwartz, P., 1991, *The art of the Long View*, Doubleday, New York.

Shapiro, R.D., Heskett, J.L., 1985, *Logistics Strategy -cases and concepts-*, West Publishing Company, St Paul Minnesota.

Shetty, C.M., Taylor, R.W., 1987, Solving Large-Scale Linear Programs by Aggregation, *Comput. & Ops Res.*, Vol. 14, No. 5, pp. 385-393.

Simon, H.A., 1977, *The New Science of Management Decision*, Prentice-Hall, New Jersey.

Simpson, D.G., 1992, Key Lessons for Adopting Scenario Planning in Diversified Companies, *Planning Review*, May-June, pp. 10-48.

Sridharan, R., 1995, The capacitated plant location problem, *European Journal of Operational Research*, Vol. 87, pp. 203-213.

Thierry, M. et al., 1995, Strategic Issues in Product Recovery Management, *California Management Review*, Vol. 37, No. 2, pp. 114-135.

Van Bruggen, L., Gruson, R., Salomon, M., 1993, Restructuring the distribution structure of gasoline products for a large oil company, *Management Report Series, Rotterdam School of Management*, No. 132.

Van Nunen, J.A.E.E., Benders, J.F., 1981, Een decision support systeem voor lokatie en allokatie problemen bij een drankenconcern, *Informatie*, Vol. 23, No. 11, pp. 669-742, (in Dutch).

Van Nunen, J.A.E.E., Beulens, A.J.M., Benders, J.F., 1984, On solving assignment type mixed integer linear programming problems within decision support systems, *Wissenschaftliche Zeitschrift der Technische Hochschule Leipzig*, Vol. 8, No. 2, pp. 89-95.

Van de Ven, A.D.M., Ribbers, A.M.A., 1993, International Logistics: A Diagnostic Method for the Allocation of Production and Distribution Facilities, *The International Journal of Logistics Management*, Vol. 4, No. 1, pp. 67-81.

Van der Hoop, J.H., 1992, The single European market: optimizing logistics operations in post-1992 Europe, in Christopher, M. (ed.) *Logistics, The Strategic Issues*, Chapman & Hall, London, pp. 260-267.

Volberda, H.W., 1992, *Organizational Flexibility: Change and Preservation, A Flexibility Audit & Redesign Method*, Ph.D. Dissertation, University of Groningen, Faculty of Business Administration, The Netherlands.

Von Reibnitz, U., 1988, *Scenario Techniques*, Mc Graw-Hill Book Company GmbH, Hamburg.

Vos, G.C.J.M., 1993, *International Manufacturing and Logistics, A Design Method*, Ph.D. Dissertation, Eindhoven University of Technology, The Netherlands.

Wack, P., 1985, Scenarios: uncharted waters ahead, *Harvard Business Review*, Sept.-Oct., pp. 73-89.

Waterman Jr, R.H., Peters, T.J. and Phillips, J.R., 1980, Structure is Not Organization, *Business Horizons*, June, pp. 14-26.

Wheelen, T.L. and Hunger, J.D., 1995, *Strategic Management and Business Policy*, Addison Wesley.

Wilson, I., 1992, Teaching Decision Makers to Learn from Scenarios: A Blueprint for Implementation, *Planning Review*, May-June, pp. 18-23.

Zipkin, P.H., 1980a, Bounds for Aggregating Nodes in Network Problems, *Mathematical Programming*, Vol. 19, pp. 155-177.

Zipkin, P.H., 1980b, Bounds on the Effect of Aggregating Variables in Linear Programs, *Operations Research*, Vol. 28, No. 2, pp. 403-418.

Zipkin, P.H., 1980c, Bounds for Row-Aggregation in Linear Programming, *Operations Research*, Vol. 28, No. 4, pp. 903-916.

Zipkin, P.H., 1982, Transportation Problems with Aggregated Destinations when Demands are Uncertain, *Naval Research Logistics Quarterly*, Vol. 29, No. 2, pp. 257-270.

Zipkin, P.H., 1994, personal correspondence.

Appendix A

Software for LND

This appendix gives an overview of eleven well-known DSSs for LND. These DSSs present an optimized network (several criteria are possible), taking account of the data and constraints defined by the decision maker. SLAM is the DSS we developed and used for the real-life LND projects in which we were involved (see Boumans, 1991 and Van Nunen and Benders, 1981). We also used SLAM to obtain the experimental results on data aggregation presented in chapter 5. For a more detailed comparison and explanation of the DSSs we refer to Hagdorn and Warffemius (1995). The comparison is based on the information the software suppliers were able or willing to give to us.

The eleven DSSs we consider are strongly structured for the design of logistics networks. We will not consider the new generation of software developments tools, such as AIMMS, which provide meta languages to develop optimization models and data structures in a very efficient and effective manner. Given the rapid development of these tools, they may well become a serious competitor for the strongly structured DSSs we are considering.

We will compare the eleven DSSs by the following criteria:

- *Logistics focus*
  - Layers
    Which layers (e.g., customers, plants, warehouses, suppliers) in the logistics networks does the DSS distinguish?
  - Customer service requirements
    Can the DSS handle customer service requirements (e.g. maximum delivery times, delivery frequencies)?
  - Modes of transport
    Can the DSS deal with different modes of transportation (e.g., truck, train, vessel, plane)?
  - Route planning
    Is route planning part of the LND problem considered by the DSS?
- *Applicability*
  - Maximum problem size
    How many different suppliers, production plants, products, warehouses and customers can be defined?
  - Capacity constraints
    Can the DSS deal with constraints on maximum capacities of plants, warehouses etc.? Can it deal with minimum utilization requirements?
- *Scenarios*
  - Comparison of scenarios
    Does the DSS facilitate comparison of alternative LNDs?

- *Evaluation criteria*
  - Costs
    What kind of cost factors (e.g., transportation costs, handling costs, inventory costs, production costs) can be handled by the DSS? Can the DSS deal with fixed costs?
  - Other criteria than costs
    Does the DSS present evaluation criteria other than costs (e.g., utilization rates)?
  - Presentation of results
    How does the system present the results (e.g., numerical reports, text reports, graphs or maps)? Are the reports standardized or does the system allow for the definition of customized presentations?
- *Model*
  - Optimization
    Which optimization methods does DSS use? What are the possible objectives of optimization?
  - Heuristic methods
    What heuristic methods does the DSS use? What are the possible objectives of the heuristic methods?
- *Data*
  - Types of data needed
    What kind of input-data are needed for the DSS?
  - Aggregation
    Is it possible to create product groups or customer groups and what are the selection criteria for such a classification?
  - Storage
    Are the data stored in a (relational) database?

Characteristics ----------------- DSS	Logistics focus			
	Decision support	Customer service	Modes of transport	Route planning
CAPS	Number, size, location and mission of plants and warehouses	Maximum delivery time Assignment restrictions Minimum stock level Regional boundaries	Truck Train Plane Vessel	A route planning software package can be integrated into the system
LOCATE	Number, size, location and mission of plants and warehouses Inventory policies	Customer service restrictions can be placed in the model	Several modes of transport can be treated	Not included
LOPTIS	Number, size, location and mission of plants and warehouses	Delivery options Minimum stock levels Single sourcing (experimental version)	Not considered	Not included
NETWORK	Number, size, location and mission of all facilities between sourcing and demand	Maximum driving distance for deliveries Preassignments for warehouse to customer deliveries	Mixed transport modes can be treated	Not included
OPTISITE	Location and mission of warehouses	Who is allowed to deliver who Maximum driving distance for deliveries	Several modes of transport can be treated	Not included
PHYDIAS	Number, size, location and mission of plants and warehouses	Delivery times Order completeness	Truck Train Plane Vessel	Route planning software packages are separate, but can communicate with the DSS
SAILS	Number, size, location and mission of plants and warehouses	Unique sourcing Preferred sourcing	Truck Train Plane Vessel	Not included
SITELINK	Number, size, location and mission of all facilities between sourcing and demand	Delivery times	Twelve modes of transport can be defined	Not included
SLAM	**Number, size, location and mission of all facilities between sourcing and demand**	**Delivery times** **Optional deliveries** **Single sourcing**	**Truck** **Train** **Plane** **Vessel**	**Not included**
SLIM	Number, size, location and mission of all facilities between sourcing and demand	Forced sourcing	Several modes of transport can be treated	Not included
STRADIS	Location of production Size, resourcing and siting of depots Fleets size Vehicle mix	Optional deliveries Minimum stock level Maximum delivery times	Truck Train Vessel	Not included

Figure A.1: Comparison of 11 DSSs for LND (part 1 of 4).

Characteristics ---------------- DSS	**Applicability**		**Scenarios**
	Maximum problem size	Capacity constraints	Comparison of scenarios
CAPS	50 products 500 sources/plants 500 warehouses 5000 demand centres	yes, upper and lower bounds for facilities	yes, via several charts
LOCATE	60 products 35 sources/plants unlimited nr of warehouses 200 demand centres	yes, upper and lower bounds for facilities and transportation	yes, via several charts
LOPTIS	No limits	yes, upper and lower bounds for facilities and transportation	no
NETWORK	60 products 30 plants/vendors 20 regional warehouses 40 field warehouses 200 customers / demand centres	yes, only upper bounds for facilities and transportation	no
OPTISITE	60 products 50 plants/sources 50 warehouses unlimited number of demand centres	yes, upper and lower bounds for warehouses	no
PHYDIAS	No limits	yes, upper and lower bounds for facilities	yes, via several standard reports
SAILS	75 products 25 plants/sources 100 warehouses 275 demand centres	yes, upper and lower bounds for facilities	yes, via several standard reports
SITELINK	234 products 99 suppliers /vendors + production plants + plant warehouses + distribution centres + local warehouses 1296 demand centres	yes, upper and lower bounds for facilities and transportation	yes, via a standard report
SLAM	**No limits**	**yes, upper and lower bounds for facilities**	**yes, via custom made reports**
SLIM	99 products 99 suppliers + plants 99 warehouses 999 markets	yes, upper and lower bounds for facilities	yes, via several bar charts and tables
STRADIS	No limits	no	yes, via several standard reports

Figure A.2: Comparison of 11 DSSs for LND (part 2 of 4).

Characteristics ----------------- DSS	Evaluation criteria		
	Costs	Other criteria than costs	Presentation of results
CAPS	Transportation Production Purchasing Handling and inventory Fixed costs for facilities Taxes	Goods flows Utilization of facilities Delivery times	Text and numerical Tables Charts Graphs Maps It is possible to customize the reports
LOCATE	Transportation Production Purchasing Handling and inventory Fixed costs for facilities	Goods flows Utilization of facilities Delivery times	Numerical Graphs Maps
LOPTIS	Transportation Production Purchasing Handling and inventory Fixed costs for facilities Selling price for products	Production volumes Shipping volumes Warehouse utilization Customer service	Several types of standard reports It is possible to create user-defined reports
NETWORK	Transportation Production Purchasing Handling and inventory Fixed costs for warehouses Selling price for products	Goods flows Utilization of plants Utilization of warehouses Inventory levels Customer service	Numerical Graphs Maps
OPTISITE	Transportation Production Purchasing Handling and inventory	Goods flows Utilization of facilities Customer service	Text and numerical Tables Bar charts Graphs Maps It is possible to add custom-made reports
PHYDIAS	Transportation Production Purchasing Handling and inventory Fixed costs for facilities Selling price for products	Goods flows Utilization of facilities Delivery times	Text and numerical Tables Charts Graphs Maps It is possible to create user-defined reports
SAILS	Transportation Production Purchasing Handling and inventory Fixed costs for facilities	Goods flows Utilization of facilities Delivery times	Text and numerical Tables Histograms Graphs Maps It is possible to customize the reports
SITELINK	Transportation Production Purchasing Handling and inventory Several types of fixed costs	Goods flows Utilization of facilities Delivery times	16 standard reports Export to spreadsheet software Export to mapping software The standard reports can be customized
SLAM	**Transportation** **Production** **Purchasing** **Handling and inventory**	**Goods flows** **Utilization of facilities**	**Text and numerical** **Tables** **Graphs** **Maps** **Export to spreadsheet software** **It is possible to customize the reports**
SLIM	Transportation Production Purchasing Handling and inventory Fixed costs for facilities Costs for reorganization of Selling prices of products	Goods flows	Text and numerical Tables Charts Graphs Maps It is possible to customize the reports
STRADIS	Transportation Production Handling and inventory	Goods flows Utilization of facilities	Text and numerical Graphs Maps It is possible to customize the level of detail in the reports

Figure A.3: Comparison of 11 DSSs for LND (part 3 of 4).

Characteristics DSS	Model		Data		
	Optimization	Heuristic methods	Types of data needed	Aggregation	Storage
CAPS	A mixture of optimization and heuristic methods are used to minimize time, distance, total costs or a combination.		Customers Orders Vehicles Sources Cost rates	Products Customers: Criteria are defined by the user	Relational database
LOCATE	Minimization of total costs or maximization of total profit, using linear optimization methods	n.a.	Customer demand Locations Capacities Cost rates	Products	Package specific database
LOPTIS	Minimization of total costs or maximization of total profit, using mixed integer and linear programming	n .a.	Raw material costs and availabilities Production rates Bills of material Cost rates Customer demand Inventory requirements	No aggregation functions	Hierarchical database
NETWORK	Minimization of total costs or maximization of total profit, using linear programming	n.a.	Allocation of vendors to plants Capacities Cost rates Product values Customer demand	Customers	Relational database
OPTISITE	A mixture of optimization and heuristic methods are used to minimize total costs		Customer demand Warehouse data Source data Geographic barriers	No aggregation functions	Package specific database
PHYDIAS	Maximization of profit or market share of minimization of total costs is reached by linear, non-linear and mixed integer programming models	n.a.	Customer demand Cost rates Constraints Distances	Products Customers: Criteria are defined by the user	Relational database
SAILS	Cost minimization by using mixed integer programming	n.a.	Cost rates Customer service limits Customer demand Shipments history data Socio economic indices	Products: Criterion is stock codes Customers: Criterion is geographical area	Package specific database
SITELINK	Minimization of total costs or maximization of total profit, using mixed integer and linear programming	n.a.	Customer demand Cost rates Geographical barriers	Products: User assigns products to product families Customers: User specifies the clusters: maximum demand, maximum number of customers	Relational database
SLAM	Minimization of total costs by using linear programming	A heuristic method is used to round non-integer values (only a few can occur) to integer values	Customer demand Cost rates Capacities Product specification	Products: Product families are defined, based on the production process Customers: Criteria are demand levels and geographical area of the customers	Relational database
SLIM	Minimization of total cost or maximization of revenue, using mixed integer programming	n.a.	Customer demand Products Cost rates	Products	Package specific database
STRADIS	n.a.	Heuristics are used to find low total cost solutions, making trade-offs between production, warehousing, transport and inventory costs and service levels	Customer demand Cost rates	Products: Criteria are location of production, handling characteristics, distribution channel Customers: Criteria are geographical area and service requirements	Package specific database

Figure A.4: Comparison of 11 DSSs for LND (part 4 of 4).

Appendix B

An MILP model for LND

This appendix summarizes the MILP model for LND developed in chapter 2. It also explains in detail the property of a solution of the LP relaxation of the MILP problem, that only a small number of non-integer values for decision variables may occur (Benders and Van Nunen, 1983).

B.1 Description of the model

Decision variables

$TSL_{sp,s,l}$ = quantity of semi-finished product sp to be delivered from supplier s to production line l.

$TLP_{fp,l,p}$ = quantity of finished product fp to be produced at production line l and shipped to the finished products storage area of plant p.

$TLW_{fp,l,w}$ = quantity of finished product fp to be produced at production line l and shipped to warehouse w.

$TPW_{fp,p,w}$ = quantity of finished product fp to be stored at the plant storage area p for distribution to warehouse w.

$APC_{p,c}$ = 1 if customer c is supplied direct from the storage area of plant p,
0 otherwise.

$AWC_{w,c}$ = 1 if customer c is supplied from warehouse w,
0 otherwise.

In this notation, sp, fp, s, p, l, w and c represent respectively the optional semi-finished products and parts, finished products, suppliers, plant storage areas, production lines, warehouses and customers.
The decision variables of type TSL, TLP, TLW and TPW represent the quantities that are supplied or produced on a yearly basis. The decision variables of type APC and AWC reflect the allocation of customers to storage areas of the plants or to warehouses. For each customer, the allocation holds for the whole product range demanded by this customer.

Objective

Minimize total variable logistics costs in operations (Z):

$$Z \quad =$$

Purchasing costs:

$$\sum_{sp,s,l} (pcs_{sp,s} + tcsl_{sp,s,l} trconvsp_{sp}) TSL_{sp,s,l} +$$

Production costs:

$$\sum_{fp,l} pcl_{fp,l} (\sum_{p} TLP_{fp,l,p} + \sum_{w} TLW_{fp,l,w}) +$$

Costs for transportation from lines to plants and warehouses :

$$\sum_{fp,l} (\sum_{p} tclp_{fp,l,p} trconvfp_{fp} TLP_{fp,l,p} +$$

$$\sum_{w} tclw_{fp,l,w} trconvfp_{fp} TLW_{fp,l,w})+$$

Costs for handling and stock keeping at storage areas of plants:

$$\sum_{fp,l,p} hcp_{fp,p} TLP_{fp,l,p}+$$
$$\sum_{fp,p} icp_{fp,p}(\sum_{w} intstockp_{fp,p} TPW_{fp,p,w}+$$
$$\sum_{c} thrputp_{fp,p} d_{fp,c} APC_{p,c})+$$

Costs for transportation from plants to warehouses and customers:

$$\sum_{fp,p}(\sum_{w} tcpw_{fp,p,w} trconvfp_{fp} TPW_{fp,p,w}+$$
$$\sum_{c} tcpc_{fp,p,c} trconvfp_{fp} d_{fp,c} APC_{p,c})+$$

Costs for handling and stock keeping at warehouses:

$$\sum_{fp,w,c} (hcw_{fp,w} + icw_{fp,w} thrputw_{fp,w}) d_{fp,c} AWC_{w,c}+$$

Costs for transportation from warehouses to customers:

$$\sum_{fp,w,c} tcwc_{fp,w,c} trconvfp_{fp} d_{fp,c} AWC_{w,c}$$

Subject to

Complete assignment of customers:

$$\sum_{w} AWC_{w,c} + \sum_{p} APC_{p,c} = 1 \qquad \text{for all } c.$$

Appendix B

Input-output balancing at the warehouses:

$$\sum_l TLW_{fp,l,w} + \sum_p TPW_{fp,p,w} = \sum_c d_{fp,c} AWC_{w,c} \qquad \text{for all } fp, w.$$

Input-output balancing at the finished product storage area of the plants:

$$\sum_l TLP_{fp,l,p} = \sum_w TPW_{fp,p,w} + \sum_c d_{fp,c} APC_{p,c} \qquad \text{for all } fp, p.$$

Input-output balancing at the production lines:

$$\sum_s TSL_{sp,s,l} = \sum_{fp} prconv_{sp,fp}(\sum_w TLW_{fp,l,w} + \sum_p TLP_{fp,l,p}) \text{ for all } sp, l.$$

Capacities of the warehouses:

$$locapw_w \leq \sum_{fp}(stconvw_{fp,w} thrputw_{fp,w}(\sum_l TLW_{fp,l,w} + \sum_p TPW_{fp,p,w})) \\ \leq upcapw_w \qquad \text{for all } w.$$

Capacities of the storage areas of the plants:

$$locapp_p \leq \sum_{fp} stconvp_{fp,p}(\sum_w TPW_{fp,p,w} intstockp_{fp,p} + \\ \sum_c APC_{p,c} d_{fp,c} thrputp_{fp,p}) \leq upcapp_p \qquad \text{for all } p.$$

Capacities of the production lines:

$$locapl_l \leq \sum_{fp}(\frac{\sum_w TLW_{fp,l,w} + \sum_p TLP_{fp,l,p}}{capl_{fp,l}}) \leq upcapl_l \qquad \text{for all } l.$$

Capacities of the suppliers:

$$locaps_{sp,s} \leq \sum_{l} TSL_{sp,s,l} \leq upcaps_{sp,s} \qquad \text{for all } sp, s.$$

Explanation of the abbreviations (in alphabetical order)

$capl_{fp,l}$ = maximum quantity of finished products fp that can be produced by production line l during the time of one year, when it is used completely for producing finished products of type fp.

$d_{fp,c}$ = the total demand for products fp ordered by customer c during the time period of one year.

$hcp_{fp,p}$ = costs for handling one unit of finished product fp in the storage area of plant p.

$hcw_{fp,w}$ = costs for handling one unit of finished product fp in warehouse w.

$icp_{fp,p}$ = inventory costs for one unit of finished product fp in the storage area of plant p during one time period.

$icw_{fp,w}$ = inventory costs for one unit of finished product fp in warehouse w during one time period.

$intstockp_{fp,p}$= intermediate stock time, representing the number of periods needed to combine the goods flows from the various production lines (also from other plants) for distribution to the warehouses.

$locapl_l$ = minimum fraction of the total capacity of the production line l that must be used; $locapl_l \in [0, upcapl_l]$.

$locapp_p$ = minimum number of storage units (e.g. square metres, pallets) to be used at the finished product storage area of plant p.

$locaps_{sp,s}$ = smallest total quantity of semi-products sp that must be ordered within the time period of one year by all plants from supplier s.

$locapw_w$ = minimum number of storage units (e.g. square metres, pallets) to be used in warehouse w.

$pcl_{fp,l}$ = production costs of one unit of finished product fp at production line l.

$pcs_{sp,s}$ = purchasing costs of one unit of semi-product sp from supplier s.

$prconv_{sp,fp}$ = the number of units of semi-product of type sp that are needed for the production of one unit of finished product of type fp.

$stconvp_{fp,p}$ = number of storage units needed for one unit of product fp in the storage area of plant p.

$stconvw_{fp,w}$ = number of storage units needed by one unit of product fp in warehouse w.

$tclp_{fp,l,p}$ = costs for transportation of one transport unit of finished product fp from production line l to the storage area of plant p.

$tclw_{fp,l,w}$ = costs for transportation of one transport unit of finished product fp from production line l to warehouse w.

$tcpc_{fp,p,c}$ = costs for transportation of one transport unit of finished product fp from plant p direct to customer c.

$tcpw_{fp,p,w}$ = costs for transportation of one transport unit of finished product fp from plant p to warehouse w.

$tcsl_{sp,s,l}$ = costs for transportation of one transport unit of semi-product sp from supplier s to production line l.

$tcwc_{fp,w,c}$ = costs for transportation of one transport unit of finished product fp from warehouse w to customer c.

$thrputp_{fp,p}$ = throughput time, representing the number of periods of stock that are needed to meet the demand for product fp of customers who are served direct from plant p (i.e., without an intermediary warehouse).

$thrputw_{fp,w}$ = throughput time, representing the number of periods of stock that are needed to meet the demand for product fp by customers who are served by warehouse w.

$trconvfp_{fp}$ = number of transport units needed to transport one unit of finished product fp.

$trconvsp_{sp}$ = number of transport units needed to transport one unit of semi-product sp.

$upcapl_l$ = maximum fraction of the total capacity of the production line l that can be used; $upcapl_l \in [locapl_l, 1]$.

$upcapp_p$ = maximum number of storage units available at plant p.

$upcaps_{sp,s}$ = maximum total quantity of semi-products sp that can be delivered within the considered time period to the plants by supplier s.

$upcapw_w$ = maximum number of storage units available in warehouse w.

B.2 Property of the relaxation of the model

It usually takes a long time to find an optimal solution for an instance of the MILP model defined above. This is especially caused by the large number of integer 0-1 variables of type APC and AWC. Benders and Van Nunen (1983) showed that for generalized assignment problems,

an optimal solution of the linear programing relaxation of this problem contains only a small number of non-unique assignments. This means that the solutions of the relaxed LP model, which can be solved much faster, are very useful for the MILP model itself.
We will show that the result of Benders and Van Nunen (1983) can be translated to the MILP model we defined.

The linear programing relaxation of the MILP model as described in chapter 2 and summarized in the first part of this appendix, is obtained by redefining the decision variables of type AWC and APC as follows:

$APC_{p,c}$ = fraction of the demand of customer c for each product to be shipped from plant p to customer c. The fraction is a value in the interval [0,1].

$AWC_{w,c}$ = fraction of the demand of customer c for each product to be shipped from warehouse w to customer c. The fraction is a value in the interval [0,1].

Using the results of Benders and Van Nunen (1983) the following lemma holds:

Lemma B.1 *For any basic feasible solution of the relaxation of the MILP problem described in appendix B.1, in which every warehouse or plant storage area stores every finished product and every line produces every finished product, the number of non-unique assignments is less than or equal to the total number of fully occupied warehouses, plant storage areas, production lines and suppliers plus the total number of exactly satisfied lower bounds on the capacity of warehouses, plant storage areas, production lines and suppliers.*

Proof. Consider any basic feasible solution of the relaxed problem in which every warehouse or plant storage area stores every finished product and every line produces every finished product.

Let C_1, C_2 be the number of uniquely and non-uniquely assigned customers respectively.
Clearly, $C_1+C_2 = C$, where C represents the total number of customers.

Let κ be the average number of warehouses and plant storage areas over which a non-uniquely assigned customer is splitted.

Denote by UW_1, LW_1, UP_1, LP_1, UL_1, LL_1, US_1, LS_1 the number of non-zero slack activities for the exactly satisfied upper bounds on the capacities of the warehouses, plant storage areas, production lines and the suppliers.

Let UW_2, LW_2, UP_2, LP_2, UL_2, LL_2, US_2, LS_2 be the number of exactly satisfied lower bounds on the capacities of the warehouses, plant storage areas, production lines and suppliers.
Clearly,

$$\begin{aligned}
W &= UW_1 + UW_2 \\
W &= LW_1 + LW_2 \\
P &= UP_1 + UP_2 \\
P &= LP_1 + LP_2 \\
L &= UL_1 + UL_2 \\
L &= LL_1 + LL_2 \\
S &= US_1 + US_2 \\
S &= LS_1 + LS_2
\end{aligned}$$

where
W, P, L, S represent the total number of warehouses, plant storage areas, production lines and suppliers respectively.

Appendix B

Let FP, SP represent the total number of finished products and semi-products respectively.

If every warehouse and plant storage area stores every product, then at least
$FP * W + FP * P$ variables $TLW_{fp,l,w}$, $TPW_{fp,p,w}$ and $TLP_{fp,l,p}$ are non-zero.
Moreover, if every production line produces every product, then at least $SP * L$ variables $TSL_{sp,s,l}$ are non-zero.
So, in the situation where every warehouse and plant stores every product and every production line produces every product, the number of non-zero activities is at least

$$FP * W + FP * P + SP * L +$$
$$UW_1 + LW_1 + UP_1 + LP_1 + UL_1 + LL_1 + US_1 + LS_1 +$$
$$C_1 + \kappa C_2$$

which is less than or equal to the maximum number of non-zero activities in any basic feasible solution that equals the total number of constraints:

$$C_1 + C_2 + 2W + 2P + 2L + 2S + FP * W + FP * P + SP * L$$

So, $FP * W + FP * P + SP * L +$

$$UW_1 + LW_1 + UP_1 + LP_1 + UL_1 + LL_1 + US_1 + LS_1 +$$
$$C_1 + \kappa C_2$$
$$\leq$$
$$C_1 + C_2 + 2W + 2P + 2L + 2S + FP * W + FP * P + SP * L$$

or

$$C_2 \leq \frac{UW_2 + LW_2 + UP_2 + LP_2 + UL_2 + LL_2 + US_2 + LS_2}{\kappa - 1}$$

Since $\kappa \geq 2$, we have

$$C_2 \leq UW_2 + LW_2 + UP_2 + LP_2 + UL_2 + LL_2 + US_2 + LS_2 \qquad \square$$

Samenvatting

Beslissingsondersteuning voor Strategische Planning in de Logistiek

- concepten, hulpmiddelen en toepassingen -

Dit proefschrift behandelt het analyseren en ontwerpen van logistieke netwerken voor industriële bedrijven. Een logistiek netwerk bestaat uit de toeleveranciers en de produktie- en distributiecentra, die er voor zorgen dat via onderlinge beleveringen van grondstoffen, halffabrikaten en eindprodukten, de klant uiteindelijk het door hem bestelde produkt op het overeengekomen tijdstip op de juiste plaats geleverd krijgt.

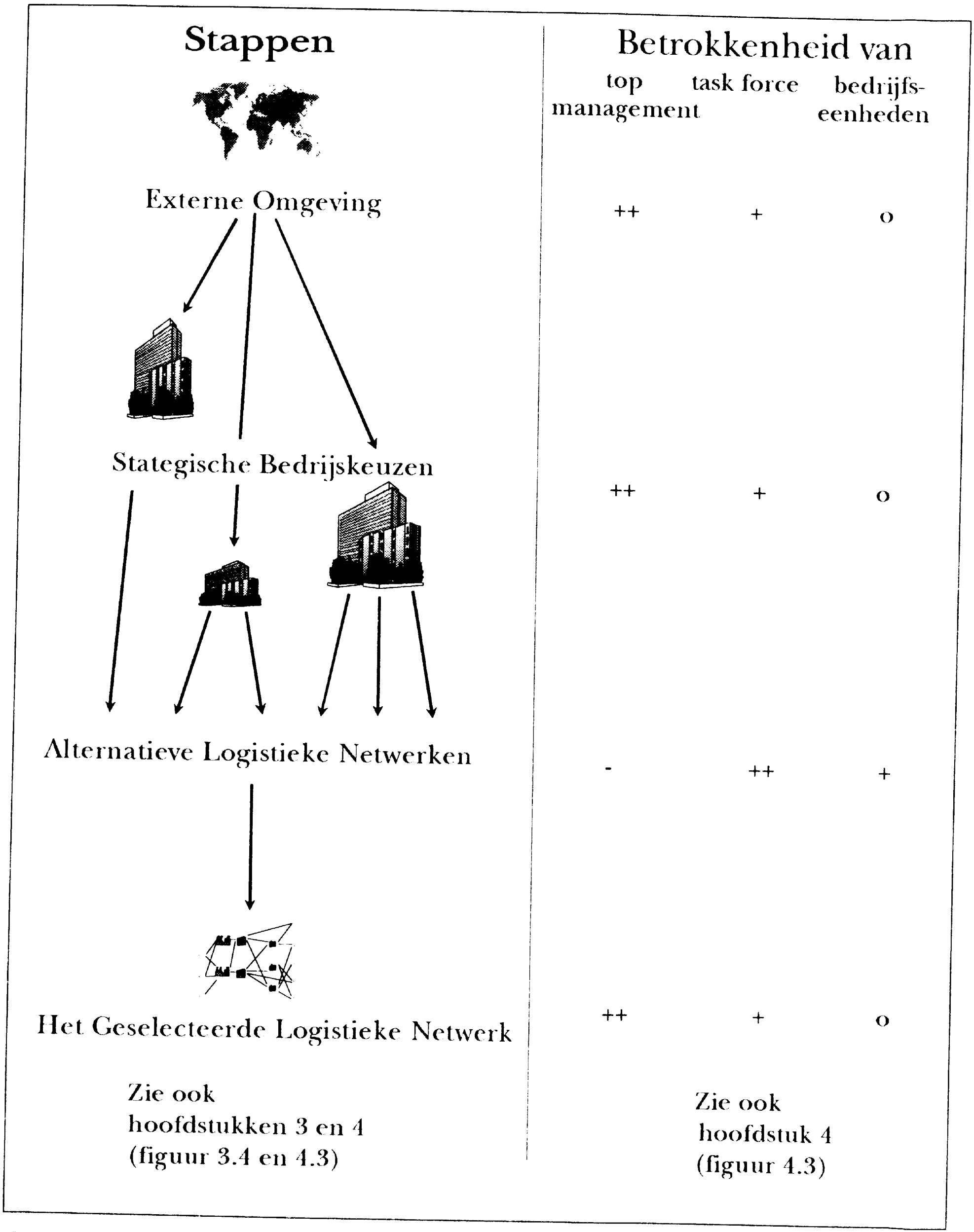
In de turbulente omgeving waarin nieuwe marktgebieden ontstaan en klanten steeds hogere eisen stellen aan de produkten, hun beschikbaarheid en hun levertijden, waarin bovendien de technologie in hoog tempo nieuwe uitdagingen biedt en het milieu grote aandacht verdient, zoeken bedrijven naar mogelijkheden om hun concurrentiepositie te versterken. Een belangrijke bijdrage hieraan wordt geleverd door een logistiek netwerk te creëren dat flexibel in kan spelen op de snel wijzigende omgeving, waarbij uiteindelijk de klant snel en tegen zo laag mogelijke kosten de gewenste produkten ontvangt.
De centrale vraag van dit proefschrift luidt dan ook: "*Op welke wijze kan een logistiek netwerk worden ontworpen voor een specifiek indus-*

trieel bedrijf, zodat haar concurrentiekracht vergroot wordt?" Hierbij wordt vooral aandacht besteed aan de keuze van de locaties, de aantallen en de omvang van de produktie- en distributiecentra, aan de keuze van de toeleveranciers en aan de produktstromen van toeleveranciers, via produktie- en distributiecentra naar de klanten.
Met dit strategische en complexe beslissingsvraagstuk is door de auteur ervaring opgedaan in vele praktijksituaties. In hoofdstuk 2 wordt een fictieve case beschreven die gebaseerd is op deze praktijkervaring.

Gebleken is dat tijdens het proces van het ontwerpen van logistieke netwerken vaak een groot aantal alternatieven ontwikkeld, geanalyseerd en vergeleken wordt. Bij de besluitvorming over het meest geschikte logistieke netwerk voor een bedrijf spelen vele, zowel kwalitatieve als kwantitatieve criteria een rol. Daarnaast zijn een groot aantal bedrijfsonderdelen en vele individuen met verschillende functies in het bedrijf bij dit proces betrokken. Dit alles resulteert in een complex en vaak langdurig traject met vele interrupties en terugkoppelingen.
Het doel van dit proefschrift is om deze complexiteit hanteerbaar te maken en daarmee de efficiëncy en de effectiviteit van het besluitvormingsproces te verhogen, hetgeen uiteindelijk resulteert in verbeterde logistieke netwerken. Hiertoe wordt een framework ontwikkeld voor het ontwerpen van logistieke netwerken.
In dit framework wordt het door veel bedrijven gehanteerde concept van scenarioplanning uitgediept (hoofdstuk 3) en versterkt door de integratie met het gebruik van een Beslissings Ondersteunend Systeem (SLAM), met daarin een kwantitatief optimalisatie (MILP) model (hoofdstuk 2 en hoofdstuk 4). Daarnaast wordt een analyse gemaakt van de fasen in het besluitvormingsproces en de rol van de verschillende partijen daarin. Het ontwikkelde framework wordt in algemene termen opgebouwd en in twee praktijksituaties toegepast (hoofdstuk 4). Figuur 1 geeft een vereenvoudigd overzicht van dit framework.

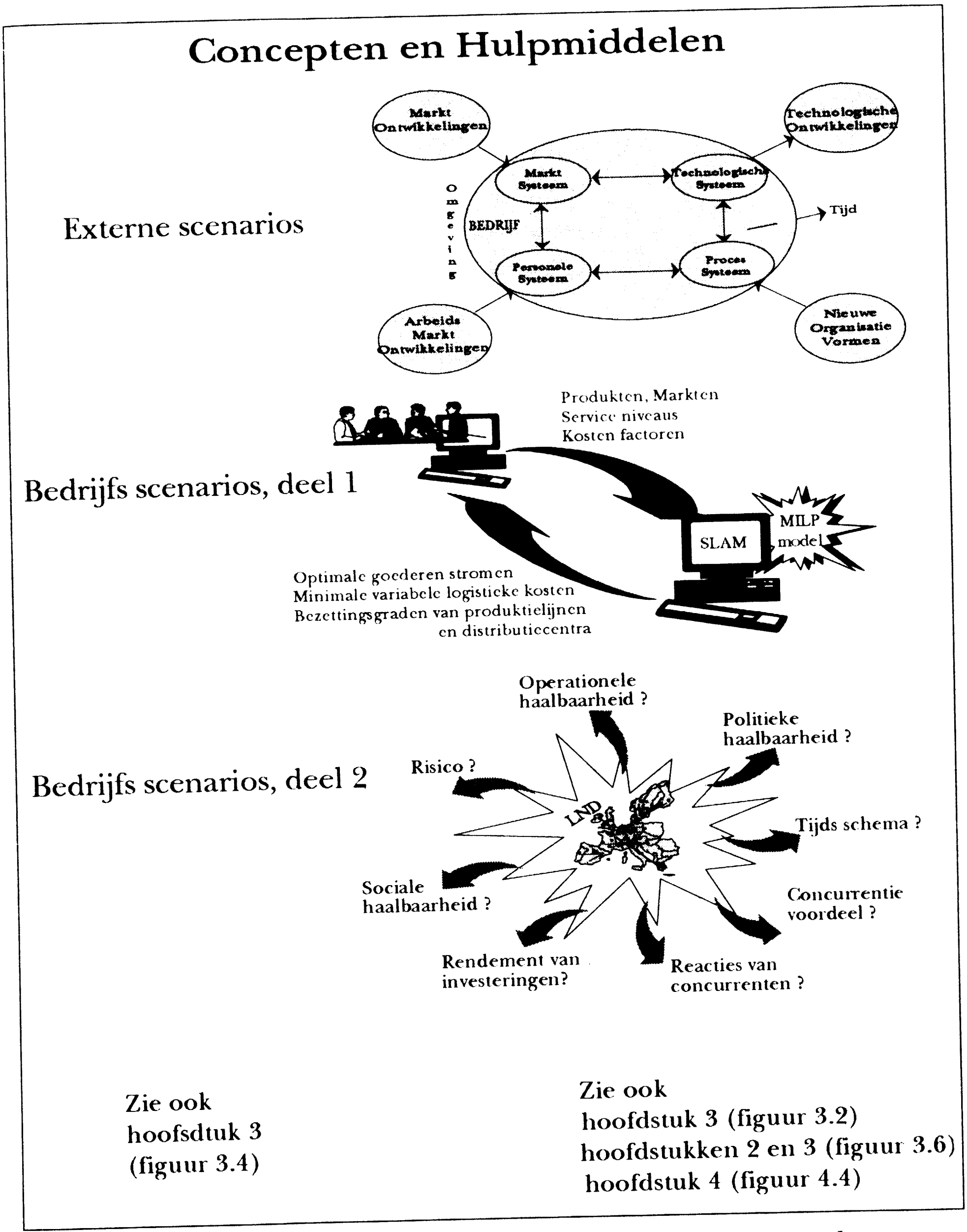
Gezien het strategisch belang van het logistieke netwerk, wordt het initiatief voor het herstructureren van het huidige logistieke netwerk doorgaans genomen op hoog niveau in een organisatie: het topmanagement. Voor het bedenken en uitwerken van alternatieve logistieke netwerken wordt vaak een projectgroep in het leven geroepen: de task force. Deze task force zorgt ook voor de afstemming met de verschillende bedrijfsonderdelen.
In het framework wordt gestart met het in kaart brengen van de externe omgeving. Hierbij worden de van belang geachte trends en ontwikkelingen weergegeven in vier categorieën van externe factoren: marktontwikkelingen, technologische ontwikkelingen, nieuwe organisatievormen en arbeidsmarktontwikkelingen. De waarden die aan deze factoren worden toegekend worden gecombineerd tot consistente combinaties. Iedere reeks van consistente waarden representeert een visie op de toekomst en vormt een extern scenario. Bij het ontwikkelen van externe scenarios zijn vooral het topmanagement en de task force betrokken, waarbij ook vaak experts uit de bedrijfseenheden of van buiten het bedrijf worden gevraagd om hun kennis van een specifiek onderwerp in te brengen.

Deze externe scenarios vormen het uitgangspunt voor de strategische keuzes die betrekking hebben op het logistieke netwerk. Het topmanagement is hier de belangrijkste partij, waarbij de task force ondersteunt door het uitwerken van deze keuzes tot bedrijfsscenarios. De keuzes van het topmanagement zijn onder te verdelen in vier categorieën bedrijfsfactoren die gerelateerd zijn aan de vier categorieën externe factoren en hebben betrekking op de markt, de technologie, het management van de operationele processen en de personele aspecten van het logistieke netwerk. De reeksen van onderling consistente waarden van deze factoren, vormen de alternatieve bedrijfsscenarios.



Figuur 1: Overzicht van het framework en de bijbehorende concepten

Concepten en Hulpmiddelen



Zie ook
hoofsdtuk 3
(figuur 3.4)

Zie ook
hoofdstuk 3 (figuur 3.2)
hoofdstukken 2 en 3 (figuur 3.6)
hoofdstuk 4 (figuur 4.4)

en hulpmiddelen voor het ontwerpen van een logistiek netwerk.

In de praktijk blijkt dat soms wel 20 externe scenarios geselecteerd worden als mogelijk uitgangspunt voor bedrijfsscenarios. Bij ieder extern scenario worden vervolgens enkele bedrijfsscenarios geformuleerd, hetgeen kan resulteren in meer dan 60 alternatieve bedrijfsscenarios.
In ieder bedrijfsscenario worden ook de keuzen met betrekking tot de structuur van het logistieke netwerk vastgelegd. Een waardevol hulpmiddel bij het ontwikkelen van dit grote aantal logistieke netwerken is SLAM, dat op basis van de strategische keuzen over de markt, de produkten en het gewenste serviceniveau, een logistiek netwerk berekent dat met zo laag mogelijke variabele logistieke kosten aan de marktvraag voldoet. Dit gedeelte van het maken van de bedrijfsscenarios wordt doorgaans door de task force geleid, waarbij frequente afstemming met de bedrijfseenheden plaatsvindt. SLAM bewijst hierbij zijn waarde door snel inzicht te geven in de consequenties van wijzigingen in het logistieke netwerk voor de logistieke kosten, de customer service en de bezettingsgraad van fabrieken en distributiecentra.
Deze alternatieven voor een logistiek netwerk voor het bedrijf worden stuk voor stuk, vaak in clusters van vier, vijf of zes geanalyseerd en geëvalueerd op financiële aspecten, de operationele haalbaarheid, het tijdsschema voor de reorganisatie, de personele consequenties, de politieke haalbaarheid en de flexibiliteit om in te spelen op wijzigende externe omstandigheden. Hiermee wordt een beeld gekregen van het strategische voordeel dat behaald kan worden met het betreffende logistieke netwerk. Een selectie van de twee, drie of vier meest interessante logistieke netwerken wordt uiteindelijk voorgelegd aan het topmanagement, zodat zij de definitieve keuze kunnen maken. Vaak wordt gekozen voor een logistiek netwerk dat bevredigende resultaten biedt onder zoveel mogelijk externe scenarios.
In het proces van extern scenario tot logistiek netwerk wordt regelmatig teruggekeerd naar voorliggende stappen om bijvoorbeeld een externe ontwikkeling meer gedetailleerd te beschrijven of een marktstrategie te

heroverwegen. Het ontwikkelde framework biedt een helpende hand bij het structureren van dit proces in deelstappen.

Behalve dat het framework met de bijbehorende concepten en hulpmiddelen gebruikt wordt voor grootschalige herstructurering van logistieke netwerken, is het ook te gebruiken om regelmatig het bestaande logistieke netwerk te evalueren en kleinere aanpassingen uit te werken. Met name SLAM bewijst hier zijn waarde.

Tijdens het proces van het ontwerpen van een logistiek netwerk is zeer veel informatie nodig over markten, produkten, kosten, etc. Het is vaak tijdrovend en in veel situaties ook niet wenselijk, om deze gegevens op een gedetailleerd niveau beschikbaar te krijgen. Er wordt dus vaak met geaggregeerde gegevens gewerkt, met name als het de invoergegevens voor SLAM betreft. Mogelijkheden hiervoor en de eventuele onnauwkeurigheid die hierdoor ontstaat, zijn onderwerp van hoofdstuk 5.
Er worden resultaten van experimenten beschreven die aangeven hoe de uitkomsten van het MILP model van SLAM wijzigen naarmate meer klanten geaggregeerd worden tot klantgroepen.
Het kiezen van het juiste aggregatieniveau kan, behalve op basis van deze experimentele resultaten, ook gebaseerd worden op bovengrenzen van de fouten in de uitkomsten van het MILP model, die veroorzaakt worden door de verschillende aggregatieniveau's. Omdat de totale variabele logistieke kosten een belangrijk beslissingscriterium vormen, worden een aantal bovengrenzen voor deze fout afgeleid. Twee reeds bestaande bovengrenzen worden uitgebreid en twee nieuwe bovengrenzen worden geïntroduceerd.
Deze bovengrenzen worden niet alleen gebruikt om in een vroeg stadium van het ontwerp proces een geschikt aggregatieniveau te kiezen, maar ook om tijdens besluitvorming te controleren of de aggregatie fout niet te ver toeneemt en niet te veel verschilt per scenario. Dit kan im-

mers leiden tot slecht vergelijkbare resultaten en daardoor een foutieve beslissing!

De bedrijfskundige relevantie van het proefschrift is gelegen in de bijdrage die het levert aan het verbeteren van logistieke netwerken en daarmee aan het versterken van de concurrentiepositie van bedrijven. In meer algemene termen is de bijdrage gelegen in de verhoging van de effectiviteit en de efficiency van besluitvormingsprocessen die plaatsvinden in een snel veranderende, complexe omgeving.
Nieuwe elementen in de concepten en hulpmiddelen die hiervoor worden aangedragen zijn:

- De integratie van het gebruik van kwantitatieve modellen en beslissings ondersteunende systemen in het strategisch besluitvormingsproces door middel van het gebruiken van scenario's
- De uitbreiding van bestaande gestructureerde benaderingen voor strategische besluitvorming naar een benadering waarin meerdere partijen een rol spelen
- De verdiepte inzichten in de mogelijkheden van aggregatie van gegevens.

Het proefschrift sluit af met een aantal interessante onderwerpen voor vervolgonderzoek die zich richten op het aanbrengen van verbeteringen in het framework, op het uitbreiden van inzichten in de effecten van data-aggregatie en op het verder integreren van goederen- en informatiestromen in de ontwerpen van logistieke netwerken.

Curriculum Vitae

Lorike Hagdorn was born on April 9, 1960, in The Hague, the Netherlands. In 1978 she obtained her pre-university certificate ('Gymnasium β') at the Rijnlands Lyceum in Oegstgeest. She went on to study Applied Mathematics at the University of Leiden. Her master's thesis was concerned with queuing theory and job scheduling and was written under the supervision of Professor Arie Hordijk. During her studies, she took a subsidiary course in Business Administration at the University of Delft. There she also worked as a research assistant and taught students the basic principles of Calculus, Linear Algebra, Operations Research and Statistics.

After graduating in 1984, she continued this work as an assistant professor. She also supervised students writing their master's theses and conducted research on Decision Support Systems. Research projects in several companies inspired her to switch to a consulting firm in the field of quantitative methods and business informatics in 1986. She started as a consultant and became a project manager and a member of the management team.

In 1989 she started to write her doctoral thesis under the supervision of Professor Jo van Nunen at the faculty of Business Administration of the Erasmus University. She continued her job as a consultant on a part-time basis, now working for Origin and specializing in information management and information technology in logistics. At the Erasmus university, she became an assistant professor in Information Systems and Computer Science, lecturing on Management Support Systems, Logistics and Project Management to first degree students and MBA students. She also supervised students working on their master's theses.

Within the NGI (a Dutch association in the field of informatics), she founded a working group on 'The role of IT in logistics planning and control concepts'. She was an International Logistics representative in the Community of European Management Schools (CEMS). In 1995 she set up a part-time masters program in Business Administration.

Her current research interests focus on the contribution of information management and information technology in logistics networks to the competitive advantage of companies.