Stellingen
van Lóránt Tavasszy, behorende bij het proefschrift
Modelling European Freight Transport Flows.

I.
Vrije internationale uitwisseling van goederen en de benutting van vervoerwijzen zijn in de huidige modelbenaderingen voor het goederenvervoer onvoldoende uitgewerkt.

II.
De in de huidige statistieken ontbrekende gegevens over het internationale goederenvervoer tussen Europese regio’s kunnen geschat worden via de Poissonschatter voor het multimodale distributiemodel.

III.
Bij het op aggregaat niveau modelleren van vervoerwijzekeuze in het goederenvervoer dient de tijdwaardering in plaats van als een gemiddelde waarde hetzij als alternatief-specifiek, hetzij als stochastische variabele te worden gehanteerd.

IV.
Prognosemodellen ontwikkeld voor het personenvervoer zijn na enige aanpassingen ook geschikt voor het geaggregeerd beschrijven van goederenvervoersstromen.

V.
Het effect van gegeneraliseerde transportkosten op de verdeling van goederenstromen over herkomst/bestemmingsrelaties is gelijk voor verschillende vervoerwijzen indien met de tijdwaardering van goederen rekening wordt gehouden.

VI.
Door de verlaging van de internationale barrières voor handel en transport zal het grensoverschrijdende goederenvervoer sterk toenemen.

VII.
Modellen van de routekeuze in het personenvervoer kunnen in aangepaste vorm toegepast worden voor de simultane keuze van haven, vervoerwijze(n) en route in het goederenvervoer.

VIII.
De tot nog toe nauwelijks gevoerde discussie over de effecten van de economische integratie op grensoverschrijdende vervoersstromen is van belang voor de visie van lidstaten op de toekomstige uitwisseling van personen en goederen tussen Europese regio’s.

IX.
De huidige barrières voor internationale handel en transport zijn veel meer gestoeld op eigentijdse protectie van lokale markten dan op historische internationale tegenstellingen.
X.
Het geleidelijk opheffen van de formele barrières voor de internationale uitwisselingen van goederen binnen Europa zal een versterking van de informele barrières tot gevolg hebben.

XI.
Twee eisen ten aanzien van het ontwerp van beleidsondersteunende modellen zijn het voorzien in stuurvariabelen en het beschrijven van de werking van het systeem. Indien aan één van beide niet voldaan is zal dit systeem onbestuurbaar lijken.

XII.
Geografische informatiesystemen verhogen de effectiviteit van het onderzoek naar patronen in verkeers- en vervoersstromen doordat modellen op relatief eenvoudige wijze op verschillende aggregatieniveaus gehanteerd kunnen worden.

XIII.
Om in het politieke debat over het te voeren overheidsbeleid de neuzen één kant op te krijgen kan het nodig zijn om de onderliggende ontwerpprocessen in beperkte mate te doorlopen. De kans is echter groot dat alle neuzen dan de verkeerde kant op staan.
Modelling European
Freight Transport Flows
This thesis is a result of a Ph.D. study performed at the Transportation Planning and Traffic Engineering Section of the Faculty of Civil Engineering of Delft University of Technology from 1991 to 1996.
Modelling European Freight Transport Flows

Proefschrift

ter verkrijging van de graad van doctor aan de Technische Universiteit Delft, op gezag van de Rector Magnificus, Prof. ir. K.F. Wakker in het openbaar te verdedigen ten overstaan van een commissie aangewezen door het College van Dekanen op maandag 30 september 1996 om 16.00 uur

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Preface

The shaping of Europe's transportation system is a fascinating and complex problem. In an era of disappearing barriers we are faced with the need to accommodate freight flows that are structurally changing. The effects of traffic on the economy and the environment call for improvements in infrastructure networks and their utilization; any new perspective, therefore, must involve the possibility of a new balance of freight flows among alternative modes of transport. It requires also proper scales of simplification of reality, however, to describe existing and future patterns of freight movements in Europe.

This thesis aims to strengthen the existing modelling approaches that provide this type of information. Much has been studied and written in recent years on the subject; nevertheless, there always remain areas for innovation. Realizing that there are many other topics in freight transport today that would justify plunges into modelling theory, I focus on the specific integration issues related to the European transport system. Wherever the availability of data permitted it, I added empirical analysis to provide additional insight in the European freight flow patterns. My aim is to assist European policy analysts and planners in formulating medium and long term transportation policy.

The work has benefited from many institutions and individuals. The research was conducted at the Transportation Planning and Traffic Engineering Section of the Delft University of Technology. It resulted from the project "Integrated transport chains in freight transport" which was funded by the Commissie Beek. The work was initiated by Ben Immer and Professor Rudi Hamerslag; I deeply appreciate their commitment and motivating guidance throughout the years.

I also wish to thank my colleagues at the Section, especially James Edward Stada, Sigurd Hauwert and Nanne van der Zijpp, who provided part of the modelling groundwork for this thesis along with many ideas, insights and stimulating discussions. I am indebted as well to other people who have shared their research experience with me during different stages of the project. I thank Professor Piet Bovy for his constructive ideas and comments on the design of the simulative route choice model and on preliminary drafts of this thesis. The multimodal distribution model was specified and tested with Henk Jan Veerman. Early versions of the multimodal route choice model were implemented and tested by Arnoud Burgess and Johan Matton with data kindly provided by NEA in Rijswijk. My greatest thanks, however, go to my friends, my dear family and above all, my wife, Annet.

Delft, March 21, 1996

Lóránt Tavasszy
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1. Background and research approach

1.1 Introduction

The ongoing integration of national economies within Europe has in the course of several decades given a substantial impetus to the exchange of goods across national borders. The concerns and hopes over the economic and environmental impacts of the resulting growth in international transport flows have in recent years been expressed in many studies. The general expectation is that the internal European market, or Single European Market (SEM) will have an additional growth effect on the European economy, with estimates ranging from 2.5% to several times this rate (see e.g. Cooper et al., 1992). A prerequisite for the realisation of this growth, however, is the availability of adequate transportation facilities. European industry has expressed its fear that the insufficient infrastructure will diminish the economic growth potential of the internal market (Round Table of European Industrialists, 1987). An international group of experts in transportation reports for example that "European truckers achieve the same speed as stage coaches in the last century: about 20 km/h." (Group Transport 2000+, 1990); although this clearly does not apply to all transport relations on the continent, it still indicates the lack of speed and efficiency of transport due to bottlenecks in the network. The availability of these facilities for transportation, however, comes at certain costs. Because of the loads and dimensions involved, freight traffic has a strong influence on the costs of infrastructure, in terms of investments,
1. Background and research approach

maintenance and operations (see e.g. ECMT, 1991). If one takes into account the additional effects of pollution, danger, and nuisance, freight transport clearly implies a substantial demand on monetary, environmental and infrastructural resources.

The function of public policy has traditionally been to coordinate the use of these resources. Clearly, the investigation and design of public policy related to transportation also requires analysis at a scale which transgresses regional and national transportation systems. An international planning perspective allows planners to evaluate and improve the worth of the freight transportation system to international trade. Within the context of the future development of the European Union, the role of international trade, and thus the importance of an efficient international transportation system is clear. In addition, a European perspective is also necessary to account for the costs of international freight transport, as in the case of through-transport there is a claim on resources (infrastructural or environmental) not owned by one of the parties that benefits from the trade in question. More and more, this problem results in unilateral restrictions of the amount of through-transport by individual countries. Finally, we must emphasize also that, apart from existing international balances, the European perspective also brings new opportunities in terms of economies in the transportation system which can only be enjoyed when the geographical area that is served is large enough. As an example, the distance over which combined transport becomes cost-efficient still exceeds by far average domestic transport distances (see e.g. NEA, Rutten, 1994). International transport typically involves long distances and may therefore well be suited for the operation of combined transport. In summary, the key feature of a European perspective is that it focuses on international, in addition to national, trade and transportation. Until now, however, transportation policy has been primarily oriented towards these problems at the national level (ECMT, 1995).

Part of the recent criticism (ECMT, 1995) on the existing transport studies of the future development of freight transportation concerns the inadequacy of transport models to provide information on the future development of freight flows. This inadequacy is partly attributed to differences between national modelling approaches. As the differences between models as such are a matter of organization, and not so much of model design, we will not deal with them further. Secondly, however, a number of structural shortcomings in the available models can be identified that relate to the policy issues at the European level. In this study, after specifying the meaning of the word "model", we will focus on this second point.

Each study in which an analysis of alternative policies is performed adopts some kind of description of the actual system and its environment. These descriptions of the real world we call models; they can be either formal (e.g. a graphical, physical or mathematical model) or non-formal (i.e. mental) in nature. Policy makers make extensive use of their personal, mental models in order to make assessments of different policies. This type of model may have many desirable qualities when it comes to policy analysis: it may be powerful, easy-to-use and sensitive to political and social variables. However, it exhibits one disadvantage over formal models: it is not open in the sense that the knowledge contained in this type of model is not easily shared for discussion and evaluation. In this study, we are concerned with formal and quantitative models, the main object of examination being the mathematical models of the freight transportation system. These models
describe the freight transportation system and its behaviour by specific theoretical statements, expressed in mathematical notation.

In an attempt to value the "attractiveness" or "adequacy" of a model for policy use, we observe a model from two perspectives: 1) the resources required to build and use them and 2) the relevance of the insight obtained through the model to policy issues. Note that these two attributes imply a conflict in design requirements in the sense of the necessary complexity of the model. In general, the higher the complexity of the model, the more alternative policies we may be able to analyse; meanwhile, data needs may be insurmountable. These demands are of particular interest within the context of European freight transport. On the one hand, the issues in transportation policy seem to be no less complex or urgent than for domestic transportation; on the other hand, however, the circumstances with respect to the availability of data on European goods flows are far inferior to the conditions to which one has become accustomed on the national or regional level. Considering the fact that certain policy issues are or will shortly be treated in EC policy circles in a more or less decisive manner (e.g. the intention to issue an agreement upon a pan-European infrastructure network), an obvious, and probably inevitable, alternative for modelling is to let the available data dictate the level of complexity at which analyses of the transportation system should take place. This approach towards model design presents an additional difficulty, which is dealt with further in this thesis: freight transportation models have generally been studied less extensively than passenger models. In contrast to passenger transport, the theoretical advances of the past two decades in transportation modelling have found application only to a limited extent and in specific cases (i.e. in specific regions of the world, for particular commodities or sectors of the economy). Furthermore, some modelling approaches heavily rely on data that relate to material flows or cost figures of a specific firm and are, therefore, confidential in nature. By using publicly available data, the practical possibility can be provided to researchers and consultants to apply the proposed models.

In conclusion, the main problem that we intend to deal with in this thesis can be summarized as follows. Existing studies on problems in freight transportation policy at the European level, directed at a quantitative analysis, have been restricted in their scope, mainly due to the limited availability of suitable instruments and data. However, the need for a practicable approach for freight transport modelling seems to be high, given the rate at which strategic decisions are made at the European level. The general research needs that pertain to modelling, (focusing on the research needs that pertain to the presently available data) can be stated as follows:

- the framing of medium and long term problems in European freight transportation policy, in such terms that policy issues can be related to models of the freight transportation system;
- the choice between modelling approaches given the existing nature of the data available at present. Existing modelling approaches should be evaluated in terms of the use they make of the available resources and their applicability to the analysis of different policy issues;
- the design of new models that fill the main gaps in the existing models for freight transportation. Existing modelling approaches ideally should be improved in terms of their relevance to policy issues, while making use of the same data.
1. Background and research approach

1.2 Objective

The main objective of the study is to design and demonstrate a mathematical model of freight transportation in Europe. The intended group of users of this model consists of policy analysts and transportation planners, who advise governments on their medium and long term transportation policy. In order to identify their modelling needs, we will be addressing the following research questions:

- what are the main issues in European freight transportation policy? Given these issues,
- to what extent are existing data and modelling approaches sufficient for studying the effects of policy on European freight transport flows?

As will be shown further on, some policy issues will require a modification of existing modelling approaches. An important part of model design is the testing of the model, i.e. the assessment of the degree it represents reality. The study will therefore also concentrate on the validity of the proposed approaches.

1.3 Assumptions and limitations

The framing of a modelling problem requires us to describe the decision-making context (which we intend to enrich with these models) in a more detailed way. The different aspects of the issues in decision-making related to substance, i.e. the contents of the information that has to be provided, will be treated later in this thesis. At this point, we introduce some assumptions and limitations of the study that delimit the organizational aspects of the decision-making context. These relate to the following issues:

1. use of readily available data
2. the time frame of decisions
3. the type of decision support information

ad 1 use of readily available data

One important factor in choosing the modelling approach involves the use of data. Data are necessary to describe the transportation system and to test whether the results of a model comply with real-world observations. As indicated in the previous section, the availability of data will limit the complexity of the model. In this thesis, we have attempted to use only data that are publicly available during the time of the research. The main reason behind this limitation is the belief that the available data have not been utilised to the extent possible in existing modelling approaches and the view that it would take considerable time to substantially improve on the availability of data on a European scale.
ad 2 time frame

In modelling the transportation system, different perspectives can be taken with respect to the time horizon or time frame. Depending on this perspective, different problems can be studied at different levels of resolution. The perspective taken in this study is that of medium to long term planning, i.e. involving a time unit of one year. The main motivation behind this perspective is that at this time Europe's infrastructure is still in a stage of development that allows for long term changes in the transportation system. Secondly, the growing integration of Europe will affect freight transportation patterns over a long period of time. The facts that these trends have only been studied to a limited extent, and that the infrastructures are to be established politically in the coming years, makes a long term view on Europe that much more important.

ad 3 type of decision support

This thesis is concerned with the design of tools for improved support of public policy in the field of freight transportation. Two types of tools can be distinguished in this respect: descriptive and normative. Descriptive tools aim at reproducing the system 'as is'. Tools of the normative type aim at producing an optimal state of the freight transportation system, by the criteria of the user of the tool itself; this state in general does not correspond with reality. Tools of a descriptive nature intend to reproduce the state of the system as it is or as it could be under changed conditions. Our study concerns these descriptive models of the freight transportation system. In this sense, public policy is aided not in the sense of the determination of optimal decisions according to certain criteria, but in the sense of hypothetical questions projecting scenarios generated by alternate policies.

1.4 Outline of the thesis

The modelling of freight transport in Europe begins with the following three stages:

- the problem oriented analysis, to establish the needs and possibilities for modelling
- the synthesis of the analysis into a frame of reference for new model design
- the design oriented analysis, aimed at the specification, estimation and application of new models for freight transport in Europe

The results of these stages are reported throughout seven chapters of this thesis.

Chapter 2 and 3 deal with problem analysis. They involve identifying the individual aspects of the modelling problem.

Chapter 2 gives an introduction to the context within which modelling should take place, i.e. the policy issues and the data available to describe the freight transportation system. In this chapter,
1. Background and research approach

we aim to answer to our first research question. In Chapter 3, the existing approaches towards modelling freight transport are reviewed. Insofar as the existing modelling approaches are not applicable to an analysis of freight transport flows on a European level, new approaches will be suggested.

In Chapter 4 we summarize the findings of the problem analysis, and propose a solution to some of the problems identified, by introducing an information system that will be the framework for the design of two descriptive models of the freight transportation system. We also focus on the importance of time in choosing among transport alternatives.

Chapter 5 and 6 deal with the design and validation of a new set of models for freight transport flows within Europe.

Chapter 5 derives a multimodal distribution model that allows us to calculate the effects of the European Integration on freight transport. The specification and estimation of the model are discussed in detail; the model is applied to illustrate the changes in freight flows as a result of decreasing border barriers. Chapter 6 proposes a stochastic, multimodal route choice model that can be applied to study the demand for transport chains or intermodal freight services. As an illustration of the model, an estimation is made for the case of the combined choice of port of transshipment and inland mode of transport on a relation between UK and Germany.

Chapter 7 concludes this study with a short summary of the results and implications of the study, along with recommendations for further research and for application of the proposed models at the European level.
2. Issues in European freight transport

2.1 Introduction

The purpose of this chapter is to determine the needs for modelling by making a detailed analysis of the problems, or issues, in European freight transport. Our objective is to model the freight transportation system in such a way that European policy issues specific to the context can be investigated. First a conceptual model is required, in which the different elements of the freight transportation system and freight transportation policy can be introduced. We look upon the freight transportation system and the government as a controller-controlled system relationship, where the government "manages" the system with certain objectives in mind. For this purpose, the government uses resources from the system (which may be of a physical or non-physical nature) to develop and implement policies that might improve its performance. The objective of this study is to develop instruments which enable us to simulate the freight transportation system, in order to provide information about alternative future states of the system. In particular, we will focus on information, regarding the long term effects of policy on freight transport flows and is obtained through mathematical modelling.

In this chapter we describe the components that are of importance to establish the information requirements, and thus the need for modelling the freight transportation system. In the following
section we give a conceptual description of the freight transportation system. In section 2.3, we describe the key issues in European freight transportation policy. We define the inputs and outputs of the freight transportation system that are of interest to government, given the objectives of transport policy. The topic of information for policy support is treated in section 2.4. Here, we characterize the data that are available at the moment on the different components of the freight transportation system, and we confront this with the data needs that have emerged from the identification of policy issues. The chapter concludes with a synthesis of these findings.

2.2 A conceptual model of the freight transportation system

The objective of this section is to introduce a descriptive framework for the analysis of the freight transportation system and of the mathematical models that have been developed to describe this system. This framework should serve as a basis to identify the available models of the freight transportation system and to evaluate these with respect to the existing policy issues and their data requirements. We will call this framework a conceptual model of the freight transportation system, as it is a simplified description, or conceptualization of the large collection of people, objects and processes that constitute the system in the real world.

The general purpose of the freight transportation system is to allow for the availability of goods for production and consumption at various locations, given the available natural resources and needs of suppliers and consumers of goods. Its main function is, as such, facilitating the economy. Within the freight transportation system, we can observe a large number of processes that together enable this necessary function to be fulfilled. These processes themselves consist of many activities that can be observed in the freight transportation system like blending, sorting, storage, packaging and stuffing. In order to describe these processes in a structured way, we will start with the process of decision making within the freight transportation system. The "decision-makers" within the system can be people or organizations; we will describe them in more detail further on in this section.

Choice problems can be described by the set of alternatives that decision makers choose among using a set of policy rules. These alternatives for the different activities in the system are denoted as the "supply side" of the transportation system. They are characterized by service attributes that describe the performance of the system according to criteria of the decision makers. Decision makers are part of the "demand side" of the system, as it personifies the need for goods and services; the decision makers are characterized by the way in which they value the alternatives' attributes and choose among alternative courses of action. Below we look further into the main choices to be made in the freight transportation system. We describe the choice problems, the agents in the system that resolve these problems, and the so-called "processing rules" by means of which alternatives are chosen.
2.2.1 Choice problems

In the above scheme, choice problems are characterized by the alternatives available to the decision maker. The main choices that appear in the literature relate to the following types of alternatives (see e.g. Harker, 1987; Kanafani, 1987; Ortúzar and Willumsen 1994):

1. production and consumption locations
2. the nature and volume of goods to consume
3. the nature and capacity of production processes
4. the location of warehouses
5. product pricing
6. buyers and suppliers
7. the choice of mode(s)
8. the size and frequency of shipments
9. the size of inventories
10. vehicle assignment and scheduling
11. routing between origins and destinations

In order to keep the complexity of the conceptual model within manageable limits, the choices can be grouped into three levels of analysis or "composite" choices, according to the time frame to which they apply:

- **the locational level** describes the land use characteristics or, more specifically, the locations where goods are produced, stored or consumed. The main output of the production and consumption processes is the demand for and the supply of goods at various locations. We can say that the problems typically decided on by producers and consumers are those related to points 1 to 5 in the above list.

- **the relational level** involves the process of spatial distribution of goods between locations of demand and supply, i.e. over origin-destination (O-D) relations. The choices to be considered are the buyer/supplier relationships, the mode of transport, the shipments' characteristics, and the size of stocks to be held at different locations. A decision at the relational level results in a change in the demand for movements of certain goods between locations.

- **the transport operations level** comprises the use of services and facilities for the physical act of transportation. We define the process of transportation generally: it concerns the arrangement of shipments, transportation modes, services and infrastructure in such a way that the demand for movement of goods is satisfied\(^1\). The primary output of transportation is freight traffic on the transportation network, expressed in vehicles per unit of time. The choices considered at

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\(^1\) We thus assume that storage and transshipment is carried out (but not necessarily decided upon) as part of the transportation process.
2. Issues in European freight transport

this level concern the type of vehicle, its schedule and its route of transport\(^2\).

We add the following notes to this specification of the system:

- There are numerous feedbacks between the outputs and inputs of these processes; for example, the congestion phenomenon can involve the link between flows as outputs and infrastructural level of service as an input to the transport operations process. Note that feedbacks are not necessarily limited to one level in the system.

- The structuring of choices according to this model coincides with the well-known four stages of calculation in passenger transport modelling (generation, distribution, mode choice and assignment). It might be argued that this framework leaves many of the behavioural subtleties in the world of decision making uncovered. However, later on, we will show that 1) this framework is fairly adequate to describe a large variety of modelling attempts in this field, including the "behavioural" ones and 2) this framework should be maintained in the design of a model for freight transport within Europe, if one intends to make the maximum possible use of presently available data sources.

In figure 2.1 these levels are pictured in a spatial context\(^3\).

\[ \text{Figure 2.1 Levels of analysis in the freight transportation system} \]

\(^2\) However, in the case of intermodal transports, or transport chains (i.e. multiple modes being used on a door-to-door relation, including transshipment between modes), the two choices can only be treated separately under certain restrictive assumptions. We will return to this issue in Chapter 6.

\(^3\) Ovals indicate locations of production or consumption, arrows indicate flows of goods and lines at the lowest level indicate the network of transport infrastructure and services.
2.2.2 Decision making

The basic unit of decision making is usually an individual or a group of persons within an organization, such as a management team or a firm. In some occasions, producers control the way in which processes at all three levels take place; however, many other configurations of decision makers are possible in the system. The interactions between individuals within decision-making units are usually abstracted in a model, by assuming that these organizations act as if they were individual decision makers. The interactions between decision making units can be abstracted if one assumes that each of these groups acts independently. The decision makers within the freight transportation system as pictured in figure 2.1 are denoted as "agents", and identified by means of the choices that they select. In our conceptual model, the following agents contribute to the flows of goods in the system:

- **Producers** decide on the location and the nature of the production process and the price of the product. Being part of production chains, producers exchange different goods, from natural resources to consumer products.

- **Consumers** decide on the nature and the volume of goods to purchase from producers, and where to buy these goods. As they consume goods, they produce waste, which is transported and further processed or stored. Although consumers provide the final demand for goods, their decisions related to goods movements are limited. However, they mainly concern the relations between retail points and their individual households. As the majority of consumer-related goods movement ("shopping trips") are generally classified as passenger transport, and pertain to transportation on the local scale, we do not include these movements in our model of goods transport.

- **Shippers** decide on the distribution and frequency of goods movements, on the characteristics of the shipments, and on the mode(s) of transport. Their main output is instrumental to the movement of goods, in the sense that they organize freight transport.

- **Carriers** are the agents who perform the transportation activity itself, and in principle operate with one mode of transport. They decide on the operational aspects of the transportation process, such as the assignment of freight shipments to vehicles or the planning of vehicle schedules and routes.

- **Government** provides the legislative and infrastructural framework for the processes in the system.

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4 See e.g. Winston, 1981; McKinnon, 1989; Jeffs, 1990

5 This classification was adapted from Harker (1987), the main difference being that potential carriers are not represented in our model.

6 except if they control all the individual segments of an intermodal transport operation; in that case they are characterized as "intermodal carriers".
2. Issues in European freight transport

Table 2.1 summarizes that part of the conceptual model that pertains to the decision makers in the system and their choice problems.

<table>
<thead>
<tr>
<th>Choice problem</th>
<th>Level</th>
<th>Process</th>
<th>Agent</th>
</tr>
</thead>
<tbody>
<tr>
<td>locations of production and consumption</td>
<td>locations</td>
<td>generation</td>
<td>producer, consumer</td>
</tr>
<tr>
<td>nature and volume of goods to consume</td>
<td></td>
<td>(production, consumption)</td>
<td></td>
</tr>
<tr>
<td>nature and capacity of production processes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>location of warehouses</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>price of the products</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>buyer / supplier relationships</td>
<td>relations</td>
<td>(multimodal)</td>
<td>shipper</td>
</tr>
<tr>
<td>size and frequency of shipments</td>
<td></td>
<td>distribution</td>
<td></td>
</tr>
<tr>
<td>size of inventories</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>choice of mode(s)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>vehicle / load unit assignment and scheduling</td>
<td>operations</td>
<td>(multimodal)</td>
<td>carrier</td>
</tr>
<tr>
<td>routes between origins and destinations</td>
<td></td>
<td>transport</td>
<td></td>
</tr>
</tbody>
</table>

In this thesis, we will focus on the processes that pertain to distribution and transportation, i.e. to the relational and the operations levels. The latter two processes are also known as physical distribution. As we will see further on, the reason for this focus is mostly practical, and results from a general lack of insight into how production and consumption are linked throughout Europe in general, or, more specifically, within international production chains. Unfortunately, the first steps toward gaining some more insight into these patterns, i.e. an inventory of these trade linkages, requires enormous data sampling efforts. Instead, in this study, we will adopt a relatively crude model of the production and consumption processes, and turn our attention towards the distribution of goods and to the way that transportation is organised.

Having described the decision makers and the related choice problems, let us now focus on how decisions are made. Earlier we stated that decision maker produce decisions by means of a number of processing rules. These rules describe the stages in which the decision makers' characteristics (i.e. their preferences) and the characteristics of the choice problem (i.e. the alternatives and their attributes) are processed. Following Timmermans and Borgers (1985), we consider the perception of alternatives, the combination of their attributes into a structure of preferences, and the way that the decision is made accordingly (figure 2.2).
The perception rule determines how alternatives and their attributes are perceived. The perception of alternatives by a decision maker is characterised by

- the choice set, or the subset of (known) alternatives that are available to choose from and
- the nature of the uncertainty involved in the perception, denoting that the decision maker has no exact knowledge of the real value of the attributes of alternatives.

This uncertainty in the value of the alternatives' attributes is an important factor in our conceptual model, as it helps to account for variations in the choices of decision makers. In the following chapter, we will discuss different ways to operationalize the perception rule into mathematical models of choice behaviour. However, it must be realized that there may be other causes of variations as well, which do not relate to variations in the alternatives' characteristics, but rather to factors related to variations in the characteristics of the decision makers themselves. This issue is particularly relevant if a model applies to large groups of decision makers.

The combination rule concerns the combination of the attributes of alternatives into a structure of preferences. Two types of decision making models are possible, depending on whether any trade-offs between attributes are possible. The so-called compensatory models value the alternative
2. Issues in European freight transport

actions by means of one "composite" attribute, called utility. Non-compensatory models involve the evaluation of alternatives on an attribute-by-attribute basis. In our study, we will not deal further with the non-compensatory models of choice. Instead, we assume that decision makers attempt to maximize the profits incurred by their choices. This assumption will be the key to describing the decision criteria for each choice problem, as well as the attributes of the transport alternatives. They will value their attribute according to the effect that a change in it has on their profit.

The decision rule concerns the linkage between the structure of preferences and the decision made. Throughout this thesis, we will assume that 1) the decision makers are consistent in their decisions, i.e. under similar circumstances (i.e. same alternatives, same attributes, same decision-maker) the choice will be the same and 2) choice preferences are transitive, i.e. if alternative A is preferred over alternative B and alternative B over C, alternative A is preferred over C as well.

2.3 Freight transport policy

2.3.1 The policy analysis process

The goals of freight transport policy are very diverse, since, apart from pertaining to the transportation sector itself, may related to, for example, the economy or the environment. In principle, the specific objectives which are of common interest to freight transport policy within a European context are those which are in any way affected by international trade or transport. In order to achieve these objectives, government has a number of instruments that influence the freight transportation system can be influenced. These instruments can be infrastructural, administrative or financial in nature. The actions taken by government to influence the freight transportation system concern the application of these instruments to specific parts of the system, and are denoted as policy measures. As a starting point for the description of policy issues we take the process of the design of these policy measures, usually referred to as policy analysis (see e.g. Patton and Sawicki, 1986 or Dunn, 1994). In this process we distinguish the following main stages of analysis:

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7 The combination rule in this case may be based on the principles of dominance (i.e. a dominant alternative is better for at least one attribute of an alternative, and no worse than any other for all other attributes), satisfaction (alternatives that do not meet a required attribute level are eliminated from the choice set) or lexicographic rules (i.e. the decision maker chooses the alternative that is the most attractive for the most important attribute). Evidently, a combination of these non-compensatory combination rules is also possible. See e.g. Young and Richardson (1982) and Fan (1992) for two models with such a structure.

8 i.e. "transport" in the broad sense of the word; for example, Gwilliam (1993) refers to "international transfer mechanisms", which we have interpreted as involving flows of different nature, including information or pollutants. Further on, we will elaborate on these objectives.
Freight transport policy

- the definition of the problem and its context, the definition of objectives and the identification of a number of possible policy measures.

- the prediction of the impacts of these actions on the system and the environment, at different levels of detail, resulting in a limited number of promising policy measures and insights into their expected impacts.

- the grouping of promising policies into strategies by evaluating the expected impacts of the promising policy measures

Note that the process of policy analysis is in essence a cyclical process and involves numerous possibilities for feedback between the three main stages pictured above. For example, the strategies and their expected impacts will feed into the problem definition phase. Note also that this process implies an "ex ante" investigation of actions, i.e. prior to the implementation of any policy, in contrast to "ex post" analysis, which concentrates on the measurement and investigation of policies which have already been implemented.

The object of research here, in essence, is a tool for impact assessment, the second of the above stages. We can formulate the requirements for modelling from the perspective of policy analysis by defining the "issues" as a combination of inputs and outputs of the impact assessment stage:

1. autonomous developments: on the one hand these define the scope of the analysis in terms of time and geography, on the other hand they picture the external frames of reference (i.e. not directly influenced by transport policy) that are relevant for the analysis.

2. the policy measures that act as input in the impact assessment: depending on the instrument and the way that these are applied, different policy measures will result. The more policy measures we can evaluate, the wider the "policy scope" of the model will be.

3. the impacts to be determined: in general, these impacts of interest are strongly interrelated to the goals and objectives in question. Therefore, later on in this section, we will review the main impacts of transport policy that are pertinent to Europe. Within this stage, our main point of interest concerns a specific type of impact assessment models, namely those by which the effects of certain policy measures can be determined in terms of freight transport flows.

In the remainder of this section, these dimensions of policy issues will be discussed separately.

2.3.2 Objectives and prospects

The objectives of freight transport policy concern both the internal performance of the freight transportation sector and the external performance with respect to its environment. A number of these objectives of freight transport policy at the national level can also be formulated at the
2. Issues in European freight transport

European level, mainly because of their strong relationship to international trade or transport\(^9\). Transport policy objectives of international importance relate to the following outputs of the freight transportation system:

1. efficiency of international movements\(^{10}\)
2. safety and security of transportation
3. damage to the environment
4. effects of freight transport policy on national industry

ad 1 efficiency of international freight movements

The efficiency of international freight movement is reflected by the costs and benefits for the users of the freight transportation system. Alongside the operational and tactical issues related to the ongoing optimization of transport operations (which will be dealt with in more detail further on), several strategic studies show that existing infrastructure capacity will not be sufficient to meet the demands of the projected volumes of freight traffic. Congestion nowadays affects more than 5000 kilometers of the 54000 kilometers of roads of international importance within the European Community (ECMT, 1995). The economic losses due to inadequate infrastructure were estimated to be ECU 4 billion in 1990, and may total ECU 14 billion in 2010 (DHV, 1991). The costs of freight transport are expected to grow further due to increasing congestion. Between 1984 and 1989, international freight transport flows by road within Europe have increased by roughly 50\%, international rail transport by approximately 7\% (ECMT, 1995).

However, the problem of congestion cannot be investigated within the isolated context of international freight transport. It is still passenger transport that dominates network flows; moreover, in general, international transport only accounts for a small proportion. In this study, we refrain from modelling passenger flows and therefore congestion. Note, however, that international freight transport may play an important part in certain areas, especially at sections of the network where this traffic tends to concentrate (e.g. transit traffic through Germany).

In this respect, the expected changes in the existing impediments for goods movement give rise to substantial uncertainty as to how international transport relations will develop. If we take into account geographical imbalances in the present impediments, the alleviation of these hindrances may lead to structural changes in the existing distribution patterns. As these patterns determine the sections of the infrastructure that are used for transportation, insight in the expected changes in patterns is invaluable for infrastructure planning at the European level.

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\(^{10}\) The provision of transport infrastructure is regarded as a policy measure, that may assist in obtaining this objective (see further on in theis thesis).
ad 2 safety and security

The safety (against accidents) and security (against intentional property damage) of transportation is reflected in terms of either vehicle and load security or driver safety. The security aspect causes international transportation to be impeded by e.g. inspections at borders, and thus to be burdened with additional costs when compared to domestic freight movements. In terms of safety, international freight transport is subject to the same locational, or corridor-related access restrictions as domestic transport.

ad 3 environmental protection

The objective of environmental protection is reflected in the contribution of transport to the degeneration of the global environment. Environmental quality is generally measured in terms of 1) pollutants by vehicles and other, indirect producers of transport services (e.g. electricity plants); 2) noise, mostly related to emissions of traffic at the local level; and 3) urban life quality, in the sense of environmental damage caused by traffic and transport which is more difficult to measure, such as visual intrusion of infrastructure. The negative effects of freight transport on the environment in terms of, for example, emission of air pollutants or utilization of energy and noise hindrance, are expected to increase in the future. These are of international importance, mainly because the sources of these negative effects are of foreign origin (the transit of Dutch trucks through Germany, or the transport of pollutants through the atmosphere, for example).

ad 4 national industry

The indirect effects of freight transport policy on national industry are of international importance, due to the fact that the advantages and disadvantages of transport policy may not be experienced equally by different countries. These effects are measured from two perspectives: the sectoral and the regional perspective. With regard to the first, we may consider for example that in order to conform to European technical standards, costs of the implementation of standards will differ among different sectors of the economy. Furthermore, the transportation sector itself has to operate in a cost-effective way, in order to provide transport services at reasonable costs. In contrast with the expected shortage in infrastructure capacity, the capacity available in road and inland waterways equipment overrides the present needs, resulting in low returns of investment in these sectors. The regional perspective concerns the relative advantage of different locations for producing certain goods. Beside the static aspects (differences in degree of development between different regions), transportation policy introduces a dynamic aspect in regional development. (It is conceivable that, as a result of transport policy, markets develop differently for individual regions or countries). Note that, in terms of the conceptual model of freight flows, this objective directly relates to the stage of generation.
2. Issues in European freight transport

Discussion

The scope of modelling in this study is limited to the freight transportation system itself as described in the conceptual model. Thus, we do not deal with models required for an "integrative" policy analysis that involve all the above measures of output. This would require more detailed emphasis on the mechanisms behind other performance measures of the freight transportation system, like models of the economic or the ecological system. In this thesis we will focus on two measures of output of the freight transportation system which are freight transport flows (in terms of a the direction, the composition and the volume of goods moved within a certain period of time) and freight transport performance (i.e. transport flows weighted by transport distance). Using these measures, additional models will be needed to establish other (internal as well as external) impacts of transportation\(^{11}\). As such, the calculation of freight transport flows and freight transport performance as a measure of the usage of the system is relevant for each of these impact categories, from a different perspective. For effects on national industry, the total in- and outward flows give an indication of the activity of a region. The pressure of the freight transportation system on the environment is also strongly related to transport flows (for calculating local annoyance and pollution) or transport performance (for system-wide effects). The calculation of safety and security effects also depends on flows of other traffic participants using the same infrastructure. As indicated, so do the impacts on the efficiency of the transport system, as soon as they concern congestion phenomena. Without considering congestion, however, the efficiency of the system can be evaluated in terms of the costs of the available transport alternatives.

2.3.3 Autonomous developments

Autonomous developments concern the organization of the economy in a wider perspective than freight transport alone. They may be related to e.g. changes in focus on different natural energy resources, the availability of new technologies, or an increasing intensity of global communication. These developments may have a long-term influence on freight transportation, and are not controlled directly by transport policy. Here, we will focus on two developments which can be observed at the level of individual decision makers and at the European level, respectively\(^{12}\). The first concerns structural changes in the way individual decision makers deal with their logistics processes. (The term logistics is, in the present context, equivalent in meaning to the processes and associated choice problems, presented in the three levels of analysis in the conceptual model.) The second concerns the development of the Single European Market, which has also resulted in a number of important policy measures to be implemented within the freight transport system. Below we describe these developments in more detail.

\(^{11}\) see Bayliss (1988) for a range of applications for the calculation of alternative impacts from these measures.

\(^{12}\) For an excellent overview of developments from a global perspective, see OECD (1991).
Freight transport policy

Changes in logistics

At the level of the individual firms, improvements are made in the efficiency of manufacturing, distribution, and transport by means of an ongoing rationalization of the management of goods and information flows (see e.g. Cooper et al., 1992 and Sherlock, 1994). In the last two decades, goods flows on the average have become higher in value. Due to structural developments in consumption patterns (increasing GDP per capita, expansion in the range of goods for sale) industry is gradually moving towards a higher share of high-tech, high value and low volume products. To accomodate these products in an efficient manner, production, distribution and transportation techniques are changing.

Part of the rationalization of goods flows involves the better use of inventory for production and distribution, aiming at a reduction of the required warehouse or distribution center capacity. Apart from the centralization of stockholding, different so-called "requirement planning techniques" are introduced, among them the well known JIT (just-in-time) production\(^\text{\textsuperscript{13}}\). These techniques in general will result in an increased need for transport in terms of a higher share of high frequency, low volume shipments. Due to centralization, the average distance of transport will increase; if one wishes to require certain service levels (in terms of order lead time, for example), additional emphasis will be placed on the speed and the reliability of transport. These developments are strongly related to the realisation of the Internal Market.

The rationalization of information flows concerns the optimization of administrative procedures that accompany goods flows, in terms of factors such as the harmonization of document layouts, the reduction of the number of copies required of the same document, and the automated document production. The impacts of automation, that is the increasing use of computer systems, are twofold. Together with improved administrative procedures, automation means documents can be produced and used more efficiently. On the other hand, as a result of Electronic Data Interchange (EDI), part of the firms' external communication may become "paperless". So, establishment of networks and standards for a common format of messages is a prerequisite for the compatibility of the systems of different users.

The Single European Market

The main development in freight transport at the European level concerns the economic integration of different national economies. The concept of a Single European Market (SEM) aims at elimination of international barriers to the mobility of persons, goods, services, and capital. Figure 2.3 illustrates the background and structure of the SEM policy.

\(^{13}\) See e.g. Cooper et al. (1992) for a discussion of these techniques
2. Issues in European freight transport

Figure 2.3 Background and structure of the SEM policy (adapted from Cooper et al, 1992)

The first column in this figure shows the main types of barriers SEM aimed to remove. Leaving out the differences between countries which are not directly economic in nature, such as cultural and language barriers, and prior to the establishment of SEM in January, 1993, these concern were as follows:

- Physical impediments concern primarily the customs controls. Intra-community movements were subject to transit regulations (to prevent illegal imports or exports) and import and export declarations (for statistical and fiscal purposes). Beside customs issues, transportation between EC member countries was restricted by other physical impediments such as permits for cabotage (transport by a haulier registered in a different country then the country of origin and the country of destination) in road transport.

- Technical impediments concern the standards for industrial and consumer goods. Special technical requirements for various products may exclude or impede the international exchange of products. Consider for example limits in truck size and weight, or the different voltages for the railways of the European countries.
Freight transport policy

- Fiscal impediments concern the large differences in levels of VAT and excise duty for goods and services between member countries. As an indirect impediment for international exchange of goods (and as such of a different nature than the cross-border administration) these fiscal impediments result in geographical imbalances in the prices of goods, directly influencing trade patterns.

These barriers have been removed only to a limited extent since the establishment of the SEM\(^\text{14}\). The potential significance of this development for international trade is illustrated in the well known study for the European Community by Cecchini (see Robinson, 1988, for a summary report). In his study, the major barriers to international goods movements were identified and quantified. The economic consequences of building a Single Market were investigated, indicating that a substantial additional economic growth can be expected due to the European integration.

This quantitative assessment of the magnitude of barriers, however, did not involve an assessment of these barriers to trade and transport systematic to an extent that would allow for forecasts of international imbalances in the growth of intra-EC transportation. Firstly, no explicit geographical perspective had been taken. To a limited extent, however, an identification of the geographical discrepancies between hindrances experienced by export on different relations has occurred. The additional costs per shipment for a border crossing appears to depend on the country to which the trade is related, ranging from ECU 26 (Belgium) to ECU 130 (Italy) for imports, and from ECU 34 (Belgium) to ECU 205 (Italy) for exports. Naturally, the magnitude of these border barriers will differ by the main mode of transport.

This takes us to our second point, namely that in Cecchini's study, the role of the different modes of transport in the formation of barriers (e.g. in these cost figures), and the impact on cross-border flows had not been involved explicitly. Research on these barriers, insofar as it concerns transportation, has not yet taken place from a multimodal perspective. One of the questions that we will deal with in this thesis, is how this process of integration will influence the movement of goods between the regions of the Community, from a multimodal perspective.

2.3.4 Policy measures

Actions

A single policy measure or action can be defined as the application of a resource or instrument available to the government (which, for instance, can be financial, or a set of regulations) to one or more points of intervention in the transportation system. These points of intervention can concern all physical or organizational aspects of freight transport. A further explanation follows.

\(^{14}\) As an example, some recent articles (Versteeg, 1996 and van Schendelen, 1996) point out that, although existing barriers are actually being alleviated, new barriers of an implicit nature are also introduced at the national level which slow down the integration process.
2. Issues in European freight transport

- Land use, production: these measures influence the locational pattern of industry and retail businesses. Together with the production process as a point of intervention, these influence the logistical and physical attributes of goods that are produced or consumed in an area. Consider for example investment bonuses that companies may receive from the government at selected locations. Measures within this category relate to the stage of the generation of freight flows in the conceptual model.

- Infrastructure: this point of intervention concerns the availability and capacity of physical infrastructure. The tactics affect all users of this infrastructure. Consider for example major works like the Channel Tunnel, the Rhine-Main-Danube link, or the Betuwe line.

- Equipment: Through regulation, subsidies and harmonisation, the government can induce changes in the performance (with respect to transport, such as size/weight regulations; or external performance, such as emissions) of equipment.

- Organization of services: this point of intervention constitutes the organization of services provided by the transportation market on the long term (access to the market for new competitors, or the degree of privatisation, for example) and on the short term (time-tables, working hours or opening hours).

- Pricing of services: price-setting for transportation services (as well as other auxiliary services) by carriers or forwarders can be influenced directly through regulations concerning bounds on prices or the prices themselves, and indirectly through measures of, say, a fiscal nature.

- Freight traffic: these, mostly regulatory tactics impose constraints on the behaviour of the users (for instance, speed limits).

The sheer number of possible combinations among different points of interventions and instruments make it cumbersome to perform exhaustive investigations of sets of policy measures. Instead, policy analysts have been concentrating on the identification of packages of policy measures also denoted as "series of measures" (ECMT, 1995) or "strategies" (EAC, 1990); each of these packages is directed to attain objectives that would be outside the scope of one single policy measure.

Strategies

The Strategic Transport Research program of the Commission of the European Communities includes the guidelines for developing trans-European networks within transport infrastructure. These concern the need to enhance the interconnection (related mostly to the infrastructural point of intervention) and interoperability (related mostly to points of intervention that affect services) of national transport networks as well as the connections between central and peripheral areas. Recently, the ECMT has proposed three groups of measures related to these principles and specifically directed at international transport (ECMT, 1995). They concern the following:

1. infrastructural investment and the configuration of international networks
2. operation of multimodal networks
3. travel demand

ad 1. Infrastructural investment and the configuration of international networks

This series of measures related to the addition of new infrastructure. It involves measures concerning firstly the construction of "missing links" in the networks of different modes, including transshipment facilities. Missing links in the European network have been identified earlier by the ECMT (1987). Note that this group of measures may also involve improvements in the quality of local connections to the international network or capacity increases in high-density areas or on specific corridors.

ad 2. Operation of multimodal networks

This series of measures aims at making optimal use of the infrastructure that is available. These concern firstly the issue of multimodality, aiming at a shift of transport flows away from road transport towards other modes. This shift may be achieved by either promoting intermodal transport or achieving a new balance between modes by means of a number of pricing incentives. Secondly, from a unimodal perspective, international transport operations can be streamlined (in terms of the choice of departure time or routing of goods) by means of, for example, actual information on the status of the network or the separated flow of different types of traffic sharing the same infrastructure.

ad 3. Travel demand

This latter category concerns measures directed at diminishing the demand for transport in general. The reduction of transport demand by means of measures of a specifically local nature can be achieved by changes that affect land use and the production or the distribution of goods. The usefulness of international transport demand itself is not questioned at this point, as it is this demand exactly which reflects international economic integration in Europe.

2.4 Information

The main output of the system which we are concerned with in this study, and which has to be provided by the models, concerns freight transport flows. If we want to investigate the effects of policy measures on these flows, it is clear that we have to look at many different variables (and combinations of these variables) and, consequently, at the mechanisms present at each level of
2. Issues in European freight transport

analysis of the transportation system. Given the complexity of the problem we realize that even a systematic analysis can only provide a fragmented view on the needs for information. In this section we will place our findings with respect to policy issues within the framework of the conceptual model, and confront this view with the data that are available to model freight transport flows at the European level.

2.4.1 Required information

So far, the policy issues have been treated in a rather fragmented way, in the sense that the different components (objectives, policy measures and developments) of these issues have been discussed independently from one another. In order to highlight the parts of the conceptual model of the freight transportation system which are important in terms of policy support, we must "rearrange" the different issue components to depict the different issues from the perspective of the designer of mathematical models of the freight transportation system, instead of the policy maker. Recalling the levels of analysis of the freight transportation system, i.e. the locational, the relational and the transport operations level, we can now connect these stages with the components treated.

Multimodal transportation

The way the infrastructure is used will be strongly influenced by the rationalization of inter-industrial flows, for two reasons: firstly, the trend towards improved inventory storage will gradually boost the need for reliable and fast transportation services. Secondly, the availability of information on the possibilities for transport (e.g. in terms of time tables) or the circumstances (e.g. travel times) under which transport has to take place will result in a more accurate perception of the transport alternatives. The most direct effect of the development of the SEM on transportation operations will be the effect of the abolition of border controls on transport costs. As a result, transport prices may fall due to 1) greater vehicle and driver productivity and 2) increased competition between carriers and fewer empty hauls, provided that the additional productivity or profits will be transferred to the users of the services.

In terms of policy measures, the main issues that are relevant to the level of transport operations concern the availability of infrastructure and the use of the existing network capacity. The need to operationalize the quality of transport services appears to focus on two distinct levels of the European transport network: firstly, the freight network is considered at the interregional level as a facility that ties together regional and local networks. Secondly, it concerns the connections of different locations within a region to this interregional network. At both levels, the distinction

15 In RAND (1993) the problem of the sheer number of possible policy measures and effects is referred to as the "curse of dimensionality". A grouping of policy measures and impacts necessary to cope with this problem and similar to the one presented here can be found in Tavasszy (1994). See also (NEA, 1989).
between modes of transport is relevant; not only because of the complementary nature of their functions (e.g. road transport as an access link toward trunk haul by inland waterways), but particularly because of a "modal shift" away from road transport is considered as a favourable result of freight transportation policy. The analysis should therefore be undertaken within a multimodal framework.

Distribution

At the distribution stage, the issue of barriers to international trade and transportation is obvious. As the main principle behind the establishment of the SEM, the free exchange (or, free distribution) of people, goods and capital naturally relate to freight flows. Both in terms of an autonomous development, as well as a part of transport policy, monitoring existing barriers and studying the impacts of their alleviation is a key issue in modelling freight transport in Europe.

Judging from the present literature, there is still a need for more detailed assessment of the effects of the realisation of the SEM on international freight transport flows. This is confirmed by recent studies of European transport. The ECMT reports: "The concept of 'border effects' is rarely mentioned in the literature, despite the fact that the first goal in creating a more cohesive economic area within Europe should effectively be to eliminate them; there has been no real debate over the possible nature of 'border-free' transport in Europe of the kind seen in Germany immediately after reunification" (ECMT, 1995). Therefore, in terms of the issues to investigate, most of the remainder of this thesis focuses on the quantification of these barrier effects and the impacts of their removal.

Generation

The main issue that directly relates to the generation of freight flows at the European level concerns economic development in different regions. It is conceivable that as a result of the developments in logistics and the alleviation of existing constraints within the framework of the SEM new locations will be preferred over the existing ones. The abolition of border controls, for example, will allow for stocks to be held according to the real patterns of production and consumption. In terms of policy measures, local policies aiming at attracting international manufacturers are of particular interest. Although the decision to move the location of production or stockholding mostly entails large investments, these changes will take place over the long term.

2.4.2 Data availability

The process of modelling is strongly dependent on the availability of observations about the outcome of choices within the freight transportation system. The data that are of primary importance to us concern the outcomes of the different types of decisions that were described in
2. Issues in European freight transport

the previous section. Due to budget and time constraints, a compromise typically will be necessary between the level of detail at which the system is modelled, and the magnitude of the area for which data can be gathered. As our general objective is to design a model applicable to freight transport flows on the European level, we have already fixed one of these degrees of freedom, namely the extent of the study area. Next, we determine the level of aggregation of the model.

We can distinguish data that pertain to direct observations (i.e. through surveys) on the level of individual firms and data that are aggregated from these survey results, in terms of sectors of industry, regions or countries. In general, the data that are available on a European scale are aggregate (see table 2.2), although there have been some detailed surveys on a lower aggregation level, in France, Germany, the United Kingdom and the Netherlands. Apart from their limited geographical scope, their applicability on the European level is limited, due to differences in base year and scope of the surveys (see NEA, 1990).

Table 2.2 Typical profile of data availability at different levels of aggregation

<table>
<thead>
<tr>
<th>process</th>
<th>aggregation level</th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>firm</td>
<td>sector(^{16})</td>
<td>region</td>
<td>country</td>
</tr>
<tr>
<td>Production / Consumption</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Distribution</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Multimodal transport</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

where

1 = data readily available for EC + EFTA countries
2 = corridor-related or small-sample surveys have been made in a number of countries (F, NL, D, B in order of sample size), limited availability

If one wants to use data on the freight transportation system at the level of individual firms, throughout Europe, additional surveys are necessary. Given the fact that at present policies are already being implemented on the European level, one can argue that the time span within which impact analyses must be conducted does not leave much time for detailed surveys to be carried out at the European level. An issue that also complicates the collection of data at the firm level is the confidentiality of company records that serve as a basis for producing statistics. Due to the requirement that such data are not to be published by statistics agencies, a large part of the activities of these companies remains unknown.

\(^{16}\) or commodity group
2.5 Conclusions

In this chapter, we have given an outline of the issues in freight transport by first describing the freight transportation system in a conceptual way. Thus we have identified three levels upon which the investigation will be based in this study: the locational level (describing production and consumption), the level of origin/destination relations (describing the process of trade and distribution) and the operations level (describing multimodal transportation). At each of these levels, the issues that are relevant to freight transport policy, and thus must be dealt with in freight transport modelling, can be identified. Based on the above section on the availability of data, we can make a first assessment of the feasibility of modelling different issues with the available data.

As a framework for the identification of the problems or issues in the freight transportation system we have chosen a series of inputs and outputs of the policy analysis process, i.e. objectives and prospects, autonomous developments and policy measures. After describing each of these in detail, we have assessed the implications of these issues for freight transport from a European and international perspective. We can conclude from the above discussion that there is a potentially large set of issues that are of European interest and which are closely related to goods flows. The issues that are distinctive for the European freight transport system all concentrate around the gradual integration of national economies. The main issues that emerged in this discussion were the following:

- Issues related to the operational level of analysis involved 1) rationalization of logistics, 2) new infrastructure and increases in network capacity and 3) the shift between modes, either as part of an intermodal chain or as a unimodal transport alternative for road transport. Both as supplements (offering separate infrastructural capacity) and as complements (offering functional integration of their networks) the role of transport modes should have more emphasis in transportation planning.

- At the level of origin/destination relations, we have seen that there is a need for studies concerning the possible effects of the alleviation of border barriers, not only in terms of its spatial effects, but also in terms of a possible redistribution of flows among modes of transport. Surprisingly, little research has been done on these redistribution effects for the case of freight transport in Europe.

- Related to changes in the generation of goods are changes in the location of production and consumption; in the long term, these may concern relocation of industries to regions that serve as more efficient distribution endpoints.

In the following chapter, we will review the existing approaches towards mathematical modelling in the field. Our perspective will concern the conceptual model of the freight transportation system as described in this chapter. Each of the approaches will be evaluated with respect to its ability to analyse the issues identified and to operate with the presently available data.
2. Issues in European freight transport
3. A review of existing modelling approaches

3.1 Introduction

Despite the importance of freight flows for transportation systems analysis, freight transport modelling has received relatively little attention in the literature. Different approaches have been suggested, with relatively few (published) attempts at real world, large scale applications. In order to obtain some insight into which approach would be best suited to our needs and possibilities, the objective of this review is to illustrate freight modelling approaches and to evaluate them in terms of their applicability to the specific setting of European freight flows. This evaluation will yield recommendations for freight transport modelling in the present research context. Some of these recommendations will be pursued further in this study.

At this point it is useful to elaborate on the scope of the models that will be reviewed. The term “modelling approaches” indicates advances in freight transport modelling theory as well as operational applications of this theory. The review deals with mathematical models of freight transport, presented in the international transport modelling literature; in addition some applications of these models will be discussed. The applications reviewed were limited to two Dutch approaches towards modelling European freight flows for which the documentation was readily available. These applications were examined in an earlier project with respect to their
3. A review of existing modelling approaches

applicability in a policy analysis for freight transport for the Dutch government (Tavasszy, 1994). Here we describe the characteristics of these applications that are related to the calculation of freight flows.

The following section deals with the criteria for the classification of modelling approaches. Theoretical approaches and some practical applications are described in sections 3.3 to 3.5. The implications for modelling freight transport within Europe are discussed in section 3.6; the conclusions of this chapter are presented in section 3.7.

3.2 Classification

Different classifications for existing modelling approaches have been given by a number of authors (see e.g. Blauwens, 1980; Harker, 1987; Kanafani, 1983; Ortuzar & Willumsen, 1994). We will depart from our definition of the freight transportation system offered in the previous chapter. Just as the conceptual model is an abstraction of the real world towards the part of the economy of interest, mathematical models are abstractions of a conceptual model. In our view, each modelling approach can be considered as a treatment of one or more choice problems of an agent in the system, by means of certain processing rules.

The general guideline for classification that we have adopted in this chapter concerns abstractions of the conceptual model in terms of:

1. the level of analysis considered
2. the characteristics of the choice process and
3. the aggregation level of modelling

ad 1 levels of analysis

Our first criterion concerns the the choice problems treated, by differentiating between the three main levels of analysis in the system. We distinguish models of the levels generation, distribution and network assignment. As they only deal with part of what we defined as the freight transportation system we call these models partial models (also referred to as sequential models). In order to build a model of the freight transportation system which covers all the three levels of analysis we will either need 1) a sequential application of partial models, assuming the outcomes of the different levels to be independent or 2) integrative models, where we need assumptions regarding the interaction between the different levels. As the first category considered the same mechanisms in the system as the partial approaches, we will not discuss it separately. In addition to the partial models, we will focus on integrative models (also called simultaneous models) that consider interactions between one, two or all three levels of analysis. We may for example assume that the costs of transport on an O-D relation are the same for the routing and the distribution decisions. Particularly if there are strong interactions between the demand and supply side of the
system (e.g. in the case of congestion) these interactions become important. Usually it is assumed in these cases that the system moves toward at a state of equilibrium, where none of the users can change its decision without suffering.

ad 2 choice models

Secondly, we categorize the models according to the assumptions made concerning the processing rules in the decision making process. In this review we only consider compensatory choice models, i.e. with a structure that assumes trade-offs between attributes. The criterion we will use here to distinguish between alternative modelling approaches is that of dealing with uncertainty. Firstly, we distinguish deterministic and probabilistic choice models. Within the category of probabilistic choice models, we make a further categorization, regarding the source of the uncertainty. Consider the attractiveness (in terms of utility, or here: profit, see section 2.2.2) of choosing alternative \( i \):

\[
U_{ua} = \sum_i w_u^i X_a^i + \varepsilon_{ua}
\]

(3.1)

where

\( U_{ua} \) = attractiveness to user \( u \) of choosing alternative \( i \)
\( w_u^i \) = weight or preference of user \( u \) attached to the \( k \)-th attribute
\( X_a^i \) = \( k \)-th attribute of alternative \( a \)
\( \varepsilon_{ua} \) = error term indicating variation in attractiveness of alternative \( a \) for user \( u \)
\( u \) = index for user
\( a \) = index for alternative
\( i \) = index for attribute

Depending on whether the variations in the attractiveness of alternatives are associated with the alternative itself, the user's preferences, or both, we can find the following approaches towards probabilistic choice modelling:

1. models with homogeneous preferences, assuming that the users' preferences are deterministic, i.e. \( w_u^k \) is not a random variable. Adapting our notation by underlining random variables, the following functions may result:\(^1\):

\[
U_{ua} = \sum_i w_u^i X_a^i + \varepsilon_{ua}
\]

(3.2)

\(^1\) See for an interesting exploration of the relation between these two functions Mirchandini and Soroush (1987).
3. A review of existing modelling approaches

\[
U_{ua} = \sum_i w_u^i X_a^i + \varepsilon_{ua}
\]  

(3.3)

From these alternative functions, the latter is usually applied in traditional choice modelling approaches in transportation. Depending on the further assumptions regarding the stochastic attributes of the random error term, different models result. If we assume that the distributions of the error terms of the different alternatives are identically, independently and Gumbel distributed, we obtain the logit type choice model. Choice models where we assume that the error terms are not necessarily dependent and normally distributed are denoted as probit models. Uncertainty regarding differences between travellers in terms of the value they place on attributes of alternatives is included implicitly in the error term of the utility function, together with other sources of uncertainty.

2. the taste variations approach: here we assume that variations in choice behaviour originate only from the phenomenon of decision makers placing different values upon an attribute of an alternative. The resulting functions can be denoted as follows (again, underlining random variables):

\[
U_{ua} = \sum_i w'_u X'_a
\]  

(3.4)

This phenomenon is also referred to as "taste differences" or "heterogeneous preferences". As we will see later, there is renewed interest for these models. However, as will be shown, the fact that these models do not account for variations in the attractiveness of alternatives due to reasons other than the users' preferences results in problematic behaviour of the models, in a way which is comparable to deterministic models.

3. models with a random error term and heterogeneous preferences: this model accounts for uncertainty in the utility of an alternative due to differences between individuals' preferences, in addition to uncertainty from other sources. The resulting attractiveness functions are now a combination of the previous two possibilities:

\[
U_{ua} = \sum_i w'_u X'_a + \varepsilon_{ua}
\]  

(3.5)

or

\[
U_{ua} = \sum_i w_u X_a + \varepsilon_{ua}
\]  

(3.6)

Hensher (1981) discusses the general advantages of these models with random attribute weights for the purpose of policy analysis. He points out that the estimation of these random-coefficients models can provide guidance on the validity of the usual assumption of deterministic attribute weights. Further on we will see that the major part of the literature devoted to probabilistic route choice modelling involves deterministic attribute weights in the utility function.
In the review to follow in the next section, we will identify a number of these different models that have appeared in the literature. Note that the existence of heterogeneous preferences implies that the preferences of the actual users of different alternatives will vary as well, in contrast to the assumption of constant or homogeneous preferences. Therefore, if the weights \( w \) in the utility function are specified as alternative-specific (in addition to being user-specific), implicitly, a certain variation in users' preferences is accounted for. Further on in this study, we will use this characteristic of the system to propose a general formulation of transport costs.

**ad 3 aggregation level**

Having mentioned that the availability of data may limit the models that can be applied in our case of European freight transport, we must also take into account the level of detail at which the transportation system has to be specified. A common distinction in transport modelling concerns the level of aggregation of the model's variables, resulting in modelling approaches of the *disaggregate* and the *aggregate* type. The former consider flows connected with individual firms, the latter concern flows between sectors of industry or larger geographical areas. In the first case, the population of users and flows that we try to model will usually be more homogeneous, i.e. the number of decision makers concerned and the variety of products, goods or vehicles in the system will be relatively small, as opposed to the aggregate case. In some of the aggregate modelling approaches, this heterogeneity within the system is represented by deriving the model from the individual decision makers choice process.

Although models of the disaggregate type are closer to the actual decision making unit and, therefore, more realistic in their description of decision making, an aggregation of firm-related flows is necessary to obtain insight in the pressure of freight flows on the infrastructure network for long term planning purposes. It should also be noted that the distinction between aggregate and disaggregate modelling approaches is for a large part application oriented\(^2\), due to the fact that models at the disaggregate level can also be applied at a higher level of aggregation, using data pertaining to a group of firms within a city or an industry. Therefore, in the classification, we will make a distinction between levels of aggregation in the theoretical sense and in terms of the applications reported in literature.

In the following sections, existing modelling approaches are described and classified according to the above criteria. The sections are ordered according to the level of analysis that is treated. Within these categories of models, the different modelling approaches will be further identified in terms of the treatment of stochasticity and the level of aggregation.

\(^2\) For a more detailed treatment of this issue, see Daganzo, 1979 and Winston, 1981
3. A review of existing modelling approaches

3.3 Partial models

3.3.1 Generation

The models of the generation stage find their application in policy issues that relate to measures regarding land use, production and logistics and also in background scenarios relating to regional development. Although a large number of models exist for the different decisions that constitute this stage (for the decision of location choice, see e.g. Eiselt et al.(1993), in this chapter we will concentrate on models that produce output relating to the flows resulting from production and consumption at given locations. We distinguish between two different approaches, namely

- the input/output approach in which intersectoral (but not interregional) exchanges are considered explicitly, and
- regional demand models, based on either the microeconomic theory of decision making that produces firms, or empirical functions on an aggregate level relating regional characteristics with goods demand and supply.

Input/output modelling

The input/output model, in essence a descriptive model of production and consumption, considers flows of commodities between different sectors of an economy. Its general idea is that each sector requires certain input from other sectors to produce a certain output, from which the demand for transportation (or the output of the transportation sector towards other sectors) within a region can be derived. Inputs and outputs are measured in monetary units; in order to transform these to physical quantities, functions relating values with weights or volumes must be constructed. The spatial dimension can be introduced by distributing the total activity of a sector within an area to different zones within this area; this procedure yields the production and attraction of goods by a region, also known as "trip-ends" (see e.g. Ortuzar & Willumsen, 1994, Kanafani, 1983).

Regional demand models

Derived demand models calculate the demand for a certain commodity, given the prices of the inputs to the production process and the production function, by minimizing the total production cost. The production function gives the functional relations between the firm’s inputs and outputs. In principle these models are mode generic (i.e. no distinction is made between modes, see e.g. Allen, 1977); however, they have been applied for estimating mode-specific transport demand as well. These approaches will be treated further in this paragraph under the section on integrative models.

In analogy with the passenger trip generation models, another class of aggregate production/consumption models assumes a simple (i.e. mostly linear) relationship between
transport demand or supply of a region and either a measure of industrial output, like floor area (Ortuza & Willumsen, 1994), gross regional product (see e.g. Bayliss, 1988), gross value added (NEA, 1995) or regional commodity prices (Harker, 1987, 1988).

Discussion

Although the theoretical basis for freight generation models at the disaggregate level seems to be available from microeconomics, data for the specification and calibration of these models cannot be obtained from the statistics offices. Among the aggregate approaches, the input/output model has been frequently applied, but has also been criticized for the assumptions that underlie its application. Because it assumes a linear dependence between inputs and output of a sector, some important elements of production are not taken into account, such as economies of scale and substitution between inputs (see e.g. de Wit & van Gent, 1986). In order to transform an I/O table to regional productions and attractions, additional assumptions are necessary with respect to the relationship between monetary flows and commodity flow volumes and the spatial distribution of production.

Given the aggregate and descriptive nature of I/O tables, their applicability for policy analysis is considered limited, unless formulated as a multiregional input/output model. Regarding data availability, however, a recent study (NEA, 1995) concludes that I/O tables for Europe are not available only at the national instead of the regional level.

Regional demand models using production and cost functions explain the demand for goods of a firm or region, using production costs as an explanatory variable. This makes derived demand models amenable to policy analysis on the firm or regional level. Linear regression models have also been applied on the regional level, with mixed results (Chisholm & O'Sullivan, 1973; NEA, 1995). Nevertheless, data concerning regional socio-economic aggregates are readily available for a number of regions in Europe.

3.3.2 Distribution

This class of models is used to calculate the magnitude of goods flows between geographical areas of economic activity. The approaches described here concern the simultaneous description of the flow pattern between all regions, i.e. the many-to-many distribution as described by an O-D table of flows. Naturally, variations on these model formulations and applications may concern the less general case of one-to-many or many-to-one distribution problems as well. Usually, these models are aggregate, as they consider the attributes of production and consumption regions. The data used in the application of this type of models are, therefore, aggregate as well. The models reviewed here apply to one type of commodity.

Depending on the underlying assumptions of spatial choice at the individual level we can distinguish two main types of spatial interaction models:
3. A review of existing modelling approaches

- linear programming models, assuming (implicitly) decision making based on deterministic utilities of alternative relations
- and the models of the gravity type, assuming decision making behaviour under random utility conditions.

**Linear Programming approach**

Firstly we consider the transportation problem, also denoted as the Linear Programming (LP) approach to the distribution of freight flows. In this model the region specific data are excess demand and supply quantities, or imports and exports, whereas the quality of the transportation services is given by the transportation costs per unit of commodity. The objective in the optimization approach is to find the flows \( t_{ij} \) between origins \( i \) and destinations \( j \) which minimize the overall transport costs at the system level while satisfying excess demands and supplies \( S_i \) and \( D_j \) for all regions. This results in the following linear programming problem:

\[
\begin{align*}
\min_{t_{ij}} & \quad \sum_{j} c_{ij} t_{ij} \\
\text{subject to} & \quad \sum_{j} t_{ij} \leq S_i \\
& \quad \sum_{i} t_{ij} \leq D_j \\
& \quad t_{ij} \geq 0 \quad \text{for all} \ i, j \\
\end{align*}
\]  

(3.7)

where

- \( t_{ij} \) = flow between \( i \) and \( j \)
- \( c_{ij} \) = transport costs between \( i \) and \( j \)
- \( S_i \) = excess regional supply in \( i \)
- \( D_j \) = excess regional demand in \( j \)

**Gravity type models**

The gravity model has received considerable attention in transport modelling literature, mainly due to its intuitiveness and simplicity. The gravity type models consider the flow between origins \( i \) and destinations \( j \) as a function of the attractiveness of locations and of the transport costs between them:

\[
t_{ij} = p_i \cdot q_j \cdot f( c_{ij} )
\]

(3.8)

where

36
Partial models

\[ t_{ij} = \text{flow between } i \text{ and } j \]
\[ p_i = \text{a measure of the attractiveness of origin } i \]
\[ q_j = \text{a measure of the attractiveness of destination } j \]
\[ c_{ij} = \text{the costs of transport between } i \text{ and } j \]
\[ f = \text{deterrence function} \]

Its background is the analogy with physics, hence the name gravity model; however, in the last two decades, a number of new derivations of the general gravity model formulation from physics, economics and information theory have been proposed (see Fotheringham & O'Kelly, 1989 or Erlander, 1991)\(^3\). In particular the observation that it can be derived from behavioural principles related to profit maximization (see e.g. Anas, 1988), allows a further interpretation of the variables of the choice model. Its application to the analysis of commodity flows, however, has been limited (see e.g. Bröcker, 1984; Chisholm & O'Sullivan; 1973; Black, 1972; Linneman, 1966).

Discussion

The LP-approach has an important disadvantage with respect to its applicability in our present context. The underlying choice process relating to quantities of goods, origins or destinations is assumed to be deterministic in nature. Evans (1973) shows that the implicit assumption, made within the LP formulation, is that flows are infinitely elastic to distance, therefore a trip will only be made if no competing trip can yield lower (system) costs. She also shows that relaxing this assumption yields the gravity model.

The structure of the LP approach thus suggests that a specific type of good must be shipped in a way that minimizes the total transportation costs in the whole system. As we aim at representing a large number of competitive shippers concerned with a heterogeneous set of goods, we cannot assume this mechanism inside the system. Its behavioural validity is, therefore, limited. What happens to this behavioural limitation turn out when compared to real world observations? The implicit assumption that the set of goods that have to be distributed is perfectly homogeneous eliminates cross-haul relationships (i.e. goods being moved both ways between two regions). Consequently, estimations with this type of model will, in contrast to the gravity model, result in a high number of zero entries in spatial interaction matrices\(^4\). Because cross-haul does exist in our study area, this rules out the application of this model in our context. Cross-haul relationships

---

\(^3\) hence the general heading of "gravity type models". Note that different derivations can result in different operational forms of the model. For example, the deterrence function by analogy with physics has a power form, whereas in the form derived from discrete choice modelling it has an exponential form.

\(^4\) The number of positive flows that minimize total transport costs is at most equal to the number of (independent) constraints in the LP-problem. The number of independent constraints is \(2n-1\), if \(n\) is the number of locations (see e.g. Wilson, 1975)
3. A review of existing modelling approaches

may be observed because of two reasons: first, the aggregation level of the analysis may be too high to observe differences between commodities. The problem has been recognized to exist even for specific commodities (see e.g. Harker, 1987 for the application of this type of distribution model to the transportation of coal in the United States). Secondly, cross-hauling may also occur in reality because of historical trading patterns, lack of information, or other institutional factors. We can avoid these mitigators by assuming a probabilistic choice framework.

3.3.3 Multimodal transportation

A large part of literature in freight transportation modelling is devoted to decisions related to transportation infrastructure and services. The intensity of the vehicle flows on the network is determined in this stage, given the origins and destinations between which goods move. The calculation of traffic from goods flows involves the following types of models:

- mode and route choice models, for the assignment of freight flows to sections of the infrastructure network,
- traffic and shipment conversion models, for the conversion of aggregate goods flows (e.g. yearly flows in weight or value units) into flows at the level of discrete shipments, load units and vehicle units.

Similarly as with models combining the different stages of analysis, approaches in which the above models are combined can be needed to model the impacts of e.g. restrictions on the availability of infrastructure for specific traffic on mode or route choice. The quality of the infrastructure network enters the transportation system models at this level so the primary consequences of network improvements on the transport system (e.g. travel time benefits) are studied with these models. The first category of models is necessary for studying system-wide consequences (such as the cumulative effects of freight flows on the network), while the second category is best to analyze changes that take place at the of individual products and shipments.

Mode and route choice models

For long term freight transportation planning, the choice of transport modes and routes have perhaps been studied the most. The routing of freight over the physical infrastructure has been treated much less extensively than mode choice. Routing models have been primarily developed for rail transport (see Friesz & Harker, 1985, for a detailed discussion of three predictive rail network models). The main distinction among mode choice models concerns the perception rule, i.e. the treatment of uncertainty in the attributes of alternatives. An early deterministic model of mode choice is the "abstract mode" type by Baumol & Vinod (1970). In the 1970's, a large

5 Traditionally, the shipment conversion models have been developed from the perspective of the inventory manager of a firm, hence these are generally treated under the heading of "inventory models".
number of mode choice models were developed that considered probabilistic mode choice (see e.g. Kullman, 1973; Boyer, 1977; Levin, 1978, Winston, 1978; and Chiang et al., 1980). These models all consider unimodal transport alternatives, i.e. intermodal transport is not taken into account.

In order to investigate the possibilities of transshipment between different modes of transport, mode choice models were integrated with route choice models by applying a multimodal network. In our view, these multimodal approaches give the most complete and elegant representation of the infrastructure network with its functional and physical characteristics, necessary to treat the question of infrastructure usage. Figure 3.1 illustrates such a multimodal network, which consists of the networks for three different modalities, or modes, tied together by transshipment links.

![Diagram of a multimodal network with railway, road, and waterway connections between origin and destination.]

**Figure 3.1 Example of a three-mode multimodal network**

The best way, perhaps, to characterize a multimodal network is by means of the possible routing options between origin and destination. These include direct transport, where goods are transported by one mode, without transshipment, as well as intermodal chains. The principle behind coding the multimodal network thus involves a specification of what is usually perceived as transshipment nodes by means of links in the network. The transshipment link thus becomes part of an alternative way for reaching a destination. Throughout this thesis, we will refer to these choice alternatives in the network as "routes"; these can, but do not necessarily, include multiple modes between an origin and a destination. The formulation of the network is thus general, in a sense which is stronger than the "abstract mode" concept introduced by Baumol and Vinod (1966), as the abstraction is extended towards transshipment as well. A further conceptual extension of this multimodal network model concerns the definition of arcs which, in addition to the physical infrastructure, pertain to activities other than transport or transshipment, such as waiting, access, and egress. This extended definition of the multimodal network concept was described as "hypernetworks" by Daganzo and Sheffi (1979). A "hyperpath", analogous to a physical path (or a series of arcs) through an infrastructure network is equivalent to a series of choices in a hypertextwork. This general formulation of a network also allows its use within an integrative choice context, for distribution, as well as generation problems.

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6 In later research, this network concept became also known as "virtual network".
3. A review of existing modelling approaches

The use of these network specifications in freight modelling, however, has been limited to deterministic models of combined mode/route choice. Examples of deterministic modelling approaches, reported in the literature, are those by Roberts (1966), Kresge & Roberts (1971), and Friesz et al. (1981). For recent examples of applications using deterministic choice models see the works of Guélat et al. (1990), Jourquin (1995) and Miller and Storm (1996) on the STAN, NODUS and STEM models, respectively. The formulation of a probabilistic model for combined mode/route choice is discussed by de Cea and Fernandez (1994) who propose a hierarchical logit model. The use of the logit model for network choices, however, is not without problems. Dial (1979) and Leurent (1993) describe a combined route-mode choice model which takes into account two choice criteria: transport times and costs. The model is formulated as a time/cost trade-off model with a random value-of-time (VOT) factor. All uncertainties with respect to the choice process are reflected by variations in the VOT factor between different individuals. Other sources of uncertainty are not accounted for. This assumption deviates from the assumption generally made in random utility models, i.e. that variations exist in the attributes of alternatives. The consequence of this simplified representation is that the outcome of the model is not stable with respect to changing network conditions. This poses problems for the estimation as well as the application of the model.

Models with a random cost specification that account for heterogeneous preferences may overcome these problems. Note that the assumption of independence of alternative choices is an obstacle to the application of the logit model for route choice in networks, as alternative routes may overlap. Models that assume the costs of alternatives to be independent, such as the non-hierarchical logit model (see e.g. Ben-Akiva, 1993, Wynter, 1995), are therefore not suitable for this purpose. Within the context of mode choice in passenger transport, Hausmann & Wise (1978) describe a probit model with random attribute weights. The model allows for interdependence between alternatives; the solution procedure proposed, however, requires that there be no more than about four or five alternatives. If we are treating the mode/route choice problem through route choice in a multimodal network, their solution approach cannot be used, however, as the number of alternatives potentially outruns this maximum.

Traffic and shipment conversion models

The shipment conversion models consider the conversion of goods flows into flows of discrete shipments. In order to control the availability of goods through time (note that the spatial dispersion of goods is dealt with in the distribution stage), storage of goods will be necessary. In order to establish the costs involved in storing goods, or not storing them (i.e. ordering them on an irregular basis), the characteristics of individual shipments (like size, frequency) must be determined. The output generated by inventory models is an optimum policy, which concerns

7 Apart from the assumption of independence between alternatives (which can be dealt with using hierarchical logit models), the assumption of identically distributed error terms also presents difficulties in applying these models. See Patriksson (1994) for a discussion of these issues.
attributes of shipments (size, frequency) and the inventory itself (size, costs of maintaining). Depending on the nature of the production process and the quality of transportation services, the required level of safety stock also contributes to the inventory costs (see e.g. Baumol and Vinod, 1970; Roberts et al., 1976). As transport time and reliability of transport play an important role in inventory models, the determination of inventory policy is strongly related to the second question, i.e. the choice of mode and route.\(^8\)

Inventory models in principle refer to individual items (goods, products, shipments); because of this level of detail, high demands are placed upon data. Therefore, such models have limited applicability for freight modelling in the present circumstances. As a result, we must assume certain characteristics of freight shipments throughout the system.

At the aggregate level, the calculation of the necessary number and type of load units and vehicles is traditionally solved in a straightforward manner by modelling the degree of loading or unitising the transport means. In some instances, different loading degrees are assumed for forehaul and backhaul trips. The aggregate models of this type will not be discussed in more detail here, as they are conceptually simple in their behaviouralistic description of events. For operational planning at individual firms, a large number of optimization models exist for solving this problem in an integrated manner with routing and scheduling problems. As these are outside the scope of this thesis we will not discuss them either.

Discussion

Particularly for the stage of multimodal transportation, detailed models have been developed for a number of choices regarding mode, shipment size, frequency of shipment, routes and so on. These models usually require observations of the characteristics of users and the transportation system, at the level of individual firms. As illustrated in the previous chapter, the available data that would allow the application of a freight transport model for Europe are mostly aggregate in nature, and relate only to the choice of mode of transport. On a limited scale, data on transport routes are available as well.

It is clear that in order to obtain traffic flows, ultimately an aggregate treatment of goods movements will be necessary. Moreover, we wish to design a model that is applicable to international freight flows as well, one for which the necessary data are available on a European level. For an accurate treatment of the behavioural aspects of choices in the assignment stage, the application of disaggregate models is preferred. The results needed and the data available will make it necessary to apply such a model using aggregate data. Especially from this perspective, the heterogeneity of the users should be taken into account. As we have seen, probabilistic models allow for this heterogeneity to be specified explicitly in the cost function. The model which is most

\(^8\) Few examples can be found of an integrated treatment of mode choice, route choice and inventory policy; however, Blumenfeld et al. (1985) extend the inventory model further towards mode/route choice.
3. A review of existing modelling approaches

complete in terms of ascribing the source of uncertainty is the random costs choice model with heterogeneous preferences. These have, however, not yet been reconciled with route choice in multimodal networks.

3.4 Integrative models

These approaches consider all three levels of analysis at the same time because in the modelling of combined stages, it is assumed that there is an equilibrium or "common optimum" that can be reached simultaneously for a number of different choices. Several approaches can be found in the international literature towards an integrated treatment of processes in the freight transportation system. They can be characterized according to the processes treated and the type of model used to describe these processes.

Direct demand models

A classical approach towards predicting demand by mode is to specify the costs of different transport alternatives in the total production cost function. In these derived demand models, production and mode choice can as such be calculated simultaneously. Two applications of this type of derived demand model (also called direct demand model) using aggregate data are by Oum (1979) and Friedlander & Spady (1981). Note that the decision concerning modes of transport is modelled as a continuous decision problem, as no explicit reference is made to a choice model involving discrete alternatives. A disaggregate approach combining discrete mode choice and a continuous production model is given by Daughey & Inaba (1978).

As these approaches do not consider, however, the effect of spatial distribution on the choice of mode, their use for spatial planning is limited. The line of research that has most extensively studied the integration of the different levels of analysis has taken the middle level, representing the spatial distribution of flows, as a starting point.

Multiregional input/output

Generation and distribution models have been treated in an integrated framework since the early 50's. Multiregional input/output models considered the introduction of the geographical dimension in input/output models, necessary to allow for their use in spatial planning. Different types of interregional flow models, based on the gravity model, have been introduced in I/O-modelling by Isard (1951), Moses (1955), Chenery (1967), Leontief (1970) and Polenske (1970). The generation part of these models, however, was in general independent of transport costs and thus remained essentially descriptive.
(Generalized) spatial price equilibrium

The spatial price equilibrium model (SPE) concerned a combination of regional demand functions and the linear programming model of distribution. In the SPE-model, the state of the freight transportation system when in equilibrium can be characterized by two basic rules:

i. A movement will occur between a pair of regions if the price at the destination is lower than the price at the origin, plus the costs of transportation between origin and destination.

ii. The price of the commodity at the origin will equal the price at the destination plus the transportation costs between these regions, if there is any flow present.

In a two-region system, the outcome of these rules in terms of transport flows was illustrated by Chang et al. (cit. Kanafani, 1983). Let $O_1$ be the supply of the first region and $D_2$ the demand of the second region. The supply $O_1$ will increase with the price of the good in this region, $P_1$. On the other hand, the demand of region 2, $D_2$, will decrease with increasing prices $P_2$. The demand for transport $t_{12}^*$ will be such that the cost of transport $c_{12}$ is equal to the price-difference of the good between the two locations (fig 3.2).

![Figure 3.2 Spatial price equilibrium in a two-region system](image)

The following equation describes the equality that must hold in case of the equilibrium:

$$t_{12}^* = t_{12}(c_{12}) = t_{12}(P_2 - P_1) = S_1(P_1^*) = D_2(P_2^*)$$  \hspace{1cm} (3.11)

Harker (1985) modifies the spatial price equilibrium model into a "generalized spatial price equilibrium" by introducing a model for the role of competitive carriers or transportation firms in the specification of the transportation costs. He thus simultaneously describes the three stages of production, distribution and routing. The latter stage, modelled simultaneously with mode choice,
3. A review of existing modelling approaches

remains deterministic in nature. Applications of the model have been limited (see Ashtakala and Murthy, 1993) owing to data needs and computational complexity. Analogously with problems presented for distribution models, the assumption of homogeneous goods in the LP approach implies that related modelling approaches, such as the spatial price equilibrium model and its generalized version, will also exhibit the drawbacks mentioned. Solutions for this problem have been formulated by means of a relaxation of condition (i) above (Bröcker, 1980; Erlander, 1977; Harker, 1988). By applying the concept put forward by Evans (1973) that the LP-formulation of the distribution problem is a special case of the gravity model, Bröcker (1980) shows that these formulations are equivalent to the application of a gravity model for the distribution stage of the SPE-model.

Interaction models

A model for the interaction between generation and distribution in passenger transport was introduced by Hamerslag (1972). These extensions towards the generation of flows and to multiple modes (Hamerslag, 1975) allowed for regional demand elasticities and mode-specific deterrence functions. In freight transport, a less general approach has been presented by Safwat & Magnanti (1988) in their STEM model. Firstly, the distribution model is cast as a one-to-many distribution problem, in contrast to the other approaches described here; secondly, the choice of mode is determined according to an all-or-nothing choice model (see also Miller & Storm, 1996). Nevertheless, the approach allows for crosshaul at the relational level, in contrast to the SPE and GSPE models.

Discussion

The existing simultaneous freight models that cover all three levels of analysis, introduced in the early 80's, still depart from a deterministic model of mode choice. In order to study problems that are import to the context of policy analysis, we consider an extension of flow models in the direction of the present passenger modelling approaches. In particular, the development of an interaction model for freight transport would allow a link between generation, distribution and mode choice within a unified framework, enabling study of changes in freight flows patterns from a multimodal perspective.

Despite the attractiveness of this integrative model for policy analysis due to its applicability for study of complex issues at different levels, these approaches have disadvantages. Firstly, there are few indications that individual firms have such integrative logistics policies. McKinnon (1989) notes that "managerial inertia, inadequate strategic planning, poor communication and a lack of data" can prove major factors in obstructing the integration of different logistics functions into one decision-making process. Despite the fact that decision makers strive to integrate several decisions to raise the firm's overall profit, in reality decisions are reviewed at different frequencies, under different circumstances and by different decision makers; therefore "joint optimality" cannot always be achieved. Secondly, simultaneous models can lead to more complex mathematical
formulations, and therefore are less easy to handle in the sense of the computational requirements. In a sequential model, the efficiency that is won by treating decisions independently can be traded off for a more complex, but more realistic model of the isolated decisions. Finally, one other drawback of this approach concerns the tractability of the model; models of joint decisions can lead to formulations where outcomes of intermediate decisions cannot be evaluated, making it unclear from which decision the eventual modelling errors originate.

3.5 Some freight flow modelling applications

Applications consist of (a set of) operational models together with the necessary databases, designed to be applied in specific problem areas, within a limited geographical area or to certain modes of transport. The Dutch applications for freight flow modelling concern all three levels of analysis. In this section, three applications are reviewed that describe domestic and international freight transport flows for domestic as well as international relations in Europe\(^9\). We will focus on the modelling aspects and will cover the databases only insofar as these are used to estimate the different models.

**Transport Economic Model II (TEM II)**

TEM II (see NEA, 1992) is a demand model that gives a forecast of domestic and international commodity flows, on a yearly basis, for three modalities (road, rail, inland waterways). TEM II covers freight flows within the Netherlands and between the Netherlands, Germany and Belgium. The base year of the data is 1986. The main stages of the calculations inside TEM are as follows:

- Generation: sectoral data (SBI-classification) of an input/output table on the domestic level are transformed to NSTR commodity groups. Based on the value/weight ratios of the sector/commodity combinations (one sector can produce more commodity types), the resulting input/output matrices are then translated from monetary units (Hfl.) to metric tonnes. Next, gross production, export and consumption are distributed over the Dutch regions (43 COROP\(^10\) regions). The regionalisation takes place using the corresponding shares of employment and population. The result is the economic production and attraction by commodity group and region in the Netherlands. In the calculations, regional differences in productivity growth and consumption patterns are not taken into account. The international

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\(^9\) For a more detailed review of applications in the Netherlands, see Tavasszy (1994).

\(^10\) COROP is a statistical, functional classification of regions in the Netherlands, designed around 1970 by the Coördinatiecommissie Regionaal Onderzoekprogramma (Commission of Coordination of the Regional Research Program).
3. A review of existing modelling approaches

flows at this point consist only of import and export figures; a spatial differentiation of these flows is made in the distribution stage.

- Distribution: The distribution of trade flows is determined by means of a gravity model, with as explanatory variables national production and consumption (for 15 European countries and one region for the rest of the world), distance between capital cities, and a dummy variable for different types of trade relation (e.g. EC or non-EC). Note that the model is indifferent to the mode of transport and that barriers to international relations are not taken into account.

- Transport operations: The share of international freight, which is (or will be) containerised is determined in the containerisation module through user-determined containerisation factors. The modal-split in TEM II are based on modal shares per commodity and origin-destination pair in the baseyear 1986. In the available forecasts, the resulting modal shift follows from 1) the base year modal shares, 2) the shares of containerisation changing for certain commodity groups and 3) difference between sectoral growth rates, resulting in change of the share of the various commodity groups in the total flows. Recently, a regression model for sensitivity analyses on modal shares, depending on transport times, costs and reliability measures has been introduced. No explicit network is specified, however. Route choice is calculated only in so far as it concerns the port of transshipment for in- or outbound international flows. The share of port on a specific relation depends on the accessibility of a port, and the total flows which are transferred through the port (the latter being defined as a proxy for service quality).

NEAC

NEAC (see NEA, 1992b) treats both the demand and supply systems for passenger and freight transport. The demand side of the freight transportation system is represented by a socio-economic database, linked to interregional OD-flows for 120 regions in Europe (EC, EFTA and Eastern-European countries). The supply system is represented by three separate networks for communautary (main) links for road, rail and inland waterways transport. Different levels of the freight transportation system are described as follows:

- Generation: Production and attraction of domestic transport are calculated using a function which links socio economic variables to flows that originate or are destined for a region. This function has been calibrated through time-series analysis. Recently, NEA has designed more detailed models of the link between transport flows and land use for different European regions (NEA, 1995).

- The distribution of domestic transport is calculated as a function of generation, attraction, and an aggregated cost measure. Production and attraction of international transport are calculated simultaneously with distribution by means of a gravity model, with added value per sector or branch and transport costs as independent variables. The distribution model is unimodal, however; the interaction between distribution patterns and modal choice is not modelled simultaneously. International flows are modelled without considering differences in international barriers to trade and transportation.
Conclusions

- Transport operations: in order to calculate modal shares, the O/D relations are grouped into "market segments", according to commodity group, distance category and the total volume of freight flows. The modal choice model is based on transport time and cost ratios of the modes in the respective segments. Combined transport is not considered. The number of trips (for road transport only) is calculated from commodity flows by means of a conversion function which has as independent variables average shipment weight (by vehicle category), share of vehicle category on a relation and the share of empty trips on a relation. Interregional flows by road are assigned to the network by means of an all-or-nothing.

SMILE

SMILE (Strategic Model for Integrated Logistics and Evaluation, see TNO-Inro/NEI, 1994) describes all levels of the transportation system. As this model was still under development at the time of the writing of this thesis, we do not describe its structure in detail. Some of the models' characteristics are worth noting at this stage, however. The model produces forecasts on a year-to-year basis, for domestic and international flows, for the modes road, rail, inland waterways, sea, pipelines and air transport. The demand side of the system has been operationalised by a segmentation of good types into "logistical families", which concern products with similar logistical requirements. In our conceptual model this could be translated as homogeneous groups for a choice problem, in terms of the preference of the users to certain attributes of the system. A further feature of the model concerns the representation of intermediate storage points within trade relations, as an intermediate step between the stages of distribution and (multimodal) transportation. As noted above, however, we keep the description of this particular model limited, as its design has not yet been finalized.

3.6 Conclusions

In this chapter, we have classified and reviewed a number of mathematical models, each describing the freight transportation system at a different level or from a different perspective. The categorization of these models along the three levels of analysis of generation, distribution and transport allows us to compare these models in terms of the issues identified in the previous chapter.

At the generation level, we find that there exist models with descriptive as well as causal (i.e. related to choice) elements. The regional demand models can be applied to assess the impact of new infrastructure on regional production and consumption (see e.g. Rietveld, 1989; Bruinsma & Rietveld, 1992). The descriptive models that concern the linkages between sectoral production and consumption, however, require data that are currently not available at the European level. Moreover, in order to apply these models to interregional commodity flows, an additional distribution model is necessary. Their application at a similar level as is performed within
3. A review of existing modelling approaches

Individual countries, however, will only be possible if new data become available (NEA, 1995). Regarding the data availability at this level of analysis, we will confine ourselves in this study to the models that relate to goods flows from the geographical, rather than the sectoral perspective, i.e. models of the distribution and the transportation of goods.

As we have seen, the models that describe the distribution of goods originate from the assumption of economic behaviour on the side of the shipper. As the linear programming model does not account for crosshaul, within the context of aggregate freight flows at the European level, we prefer the gravity-type distribution model. The behavioural details of this issue will be outlined in Chapter 5 in more detail. Policy issues that are prominent at this level concern the Single European Market and the perspective of multimodality in infrastructure planning. In order to study distribution problems from a framework which is 1) more realistic in the behavioural sense, 2) multimodal, and 3) international, an extension of the present approach towards modelling freight flows is necessary.

At the level of transport operations, we find that there is a wide variety of models that describe the choices of decision makers. Unfortunately, the problem of data availability again imposes restrictions on our ability to model the freight transportation system. As the systematic registration of freight flows is only carried out at the most aggregate level, we find that, in our context of European freight transport, the amount of detail is insufficient to allow the validation of models at the level of choices made by individual firms. Even if the choice models themselves are disaggregate in nature, their application will be restricted to aggregate data. These aggregate data concern mode and route choice only; at a limited geographical level, information on combined mode/route choice is available. Information related to the storage of goods at the European level is not available. Therefore, in this study, we will abstract from the flows at the level of individual firms or products. Where necessary, in our aggregate model of goods flows, we will account for the relation between inventory policy and goods flows in terms of parameters that express preferences of users towards the attributes of choice alternatives.

The following chapter introduces the modelling approach that was adopted in this study after considering the above findings. We introduce an information system which has been the basis for the development of these models, in terms of the data used for model development and for presentation purposes. We further propose a number of extensions to the existing freight modelling approaches, which will allow a more systematic study of the main policy issues identified.
4. Towards a freight flow model specification

4.1 Introduction

From the exploration of needs and possibilities for modelling European freight transport flows in the previous chapters, we conclude that needs for policy-related information do exist which are not fulfilled by present-day applications, particularly regarding two issues: the influence of barriers and European infrastructure networks. Unfortunately, the models that capture in detail the decision making context of individual agents rely on data that are presently not available for the majority of the European countries (and, if judged by the present research program, will not be available in the near future). The approach towards model design for European freight transport in this study can, therefore, be characterized as data-driven. As we have found, the data problem constrains the applicability of the described models to the aggregate level. Based on the data that are readily available, we will attempt to choose a modelling approach that complies to our conceptual model of the freight transportation system.

Further, the design of the models will be application oriented, in the sense that a new information system will act as a framework for the design of the freight transportation system models. The starting point for establishing the modelling approach in this study was the Informatiesysteem Goederenvervoer Europa, or Information System for Goods Flows in Europe (ISG, see Stada &
4. Towards a freight flow model specification

Hauwert, 1992). Conceptually, as we will see further in this chapter, the ISG is very well equipped for dealing with a number of the issues raised in earlier chapters. However, in order to make the ISG applicable for projecting transport flows in Europe under different scenarios, it is necessary to design new models that adequately describe the different processes in the freight transportation system.

The purpose of this chapter, therefore, is to conclude the problem analysis phase and, at the same time, to initiate the solution-oriented phase of the thesis, with the identification of the models to be designed, taking the ISG as a starting point. In the following section, a general outline of the ISG will be given. We will describe its network representation and the present modelling facilities in the ISG. In section 4.3 the additional modelling that is required for the application of the ISG is discussed extensively, by reflecting on the pros and cons of the modelling approach put forward in the ISG and the required extensions of this approach. The last section of this chapter concludes with an outline of the models that are the studied in the remainder of this thesis.

4.2 ISG: framework for model design

The ISG was designed for assessing the impacts of changes in the transportation system on freight flows within Europe. Its main design requirements concerned a number of interrelated issues.

Based on experiences with other models and applications, simplification of the daily use and maintenance of freight transportation system models seemed to be necessary. First, the ISG should function as a desktop application, i.e. as a program package on individual PC-systems with relatively low capacity. Second, it should have an interface and a database management system that allows easy modification and presentation of the transportation system model. Further, a number of transportation system models were needed to perform the necessary impact assessments. These models would have to comprise a

- structural description of the European freight transportation system in terms of networks and regions. The specification and implementation of the system as we will describe was done by Stada & Hauwert (1992) during the first years of research that led to this thesis.

- functional description of the choices made by different agents within the system. This required a further focus on the choice models applied at different levels of analysis in the system. This thesis focuses on the functional aspects of these models, complementary to the structural aspects.

To cover the requirements listed under the first issue, a Geographic Information System (GIS), TransCAD, has been chosen as the basis for implementing the ISG. With respect to the second issue, the networks and regions were defined in agreement with the present communautary standards. Publicly available data and the models provided by the GIS were used to describe changes in the use of infrastructure by goods flows within Europe. In the remainder of this section, these components of ISG are described in more detail.
4.2.1 A geographic information system

There is an extensive body of literature on GIS, and we will only touch the subject to the extent that is needed to introduce the ISG. We take the definition of a GIS, given by Ritsema van Eck (1993) as a starting point:

"A GIS is a computer system for input, storage, processing, analysis and presentation of data with a spatial component, that supports a geographic interpretation of these data."

The different GIS-facilities are provided by the TransCAD program. Figure 4.1 gives the general outline of these facilities. We will use this outline to schematically describe the ISG and its characteristics. Figure 4.1 identifies a number of facilities.

![Diagram of GIS facilities]

**Figure 4.1 Outline of a GIS (adapted from Ritsema van Eck, 1993)**

The first group of facilities concerns the exchange of data and commands between the user and the GIS. The *input* of data concerning geographically specified elements, or locational data, is usually performed either by digitizing existing maps or by directly copying an available database. In the case of the ISG, the first method was chosen. The output of data can be produced in different formats, textually (ASCII, binary or spreadsheet format) and graphically (charts, maps). For presentation purposes, the latter alternative provides an opportunity to draw thematic maps. The *user interface* determines the way in which the GIS can be controlled by the user. It allows
for the communication between the user and the data input, processing and output facilities. Here, again, commands can be given by means of both a graphical (e.g. mouse) and textual (e.g. keyboard) interface devices.

Secondly, the database within the ISG contains a description of different elements in the freight transportation system (such as the regions or transport infrastructure) and their attributes. The database management system encompasses the procedures for retrieval, adaptation and storage of data. Beside the topological attributes of each element (i.e. ist geographical coordinates and its relationship to other elements), any other attribute of interest can be assigned to each element. The ISG has four main types of elements: countries, regions, nodes and links. The first two concern the boundaries of administrative areas within Europe. The latter two form the infrastructure network. In the next section, the nature and attributes of these elements will be discussed in more detail.

Thirdly, there are facilities for data processing and spatial analysis. These can be divided into two groups, (non-spatial) attribute processing and spatial analysis routines. It is the latter category that is of primary interest to us in this study, among all the facilities that a GIS offers. These facilities allow us to observe the spatial characteristics of our problem and draw inferences from the data by combining and correlating different attributes. These concern three different types of functions:

- **spatial database functions**: these are the most basic functions, where the spatial attributes of elements are subject to query, editing and presentation. As these functions mostly concern the flow of raw data between different parts of the GIS database or between the user and the GIS (and not necessarily the processing of policy related information), this category of functions is not dealt with further.

- **graphical analysis functions**: these are typical GIS facilities as they relate to the combination of the spatial attributes of different elements to extract new information. Three types of graphical analysis functions can further be distinguished: those relating to locations (involving different and non-spatial attributes or elements with identical geographical attributes), those relating to regions (involving different elements within one area) and those relating to the environment of elements (involving the immediate area of the location of the element). These functions are relevant to the assessment of impacts of policies, as they involve different graphical mechanisms to correlate or transfer effects of transport between different locations. For example, in the first case we can think of the identification of areas with a high accident risk by combining data on expected consequences of accidents (e.g. related to the share of dangerous goods through an area and the population density) with the probability of occurrence of an accident (e.g. as a function of intensity or type of traffic). In the second case, consider the simple operation of adding the values of an attribute of all elements that lie within a region (e.g. total production of goods). The third type of process is useful in, for example, the calculation of the area around a link in the network in which emissions of pollutants are above a certain level.
• geographic modelling functions: these involve either a combination of different graphical analysis functions as treated above, or methods for a numerical analysis of relations between different elements and their attributes. The transportation system models that were reviewed in the previous chapter fall into this category. TransCAD provides a number of routines to perform calculations that concern the levels generation, distribution, and the use of infrastructure. However, as we will see, these fall short of considering some important issues in freight transportation at the European level.

4.2.2 Regions, networks and models

The specification of the regions in the EC and EFTA countries is based on the NUTS\(^1\) classification system of the European Community; in some cases, regions with low production and consumption were aggregated into larger ones, resulting in a total of 93 regions. The remaining part of the world has been modelled crudely at the level of countries (e.g. Central Europe) or whole continents (e.g. Latin America).

In order to study the repercussions of transport policy on European scale, a network was modelled for the main transport axes connecting the regions and countries. In contrast to most models of freight networks on a continental level, a multimodal network has been specified in the ISG. The network of the ISG consists of the multimodal network of links of four different modes of transport (road, rail, waterways and sea). Sea transport has been divided into three service classes, i.e. deep-sea, short-sea and ferries. Transshipment between modes has been allowed by connecting the links of separate modes of transport, wherever ports or terminals for transshipment are present.

Note that the distinction between modes disappears in this formulation of costs and times; in this sense we can speak of an "abstract mode" approach. The service attributes that have been assigned to the ISG network concerned freight rates and transport times for each mode\(^2\). Figures on freight tariffs were obtained by means of interviews among shippers and carriers. The out-of-pocket costs were assumed to be a linear and continuous function of distance and were specified by link (and thus by mode). They concern an average, marginal freight rate and additional costs due to e.g. transshipment.

\[
R_l = d_l \varphi_l + c_l
\]  \hspace{1cm} (4.1)

where

- \(R_l\) = freight rate on link \(l\)
- \(d_l\) = length of link \(l\)

\(^1\) Nomenclature for Statistical Territorial Units

\(^2\) For other detailed reviews of service and cost functions see e.g. Jourquin (1995)
4. Towards a freight flow model specification

\[ p_l = \text{freight rate on link } l \]
\[ c_l^a = \text{additional link specific transport costs} \]

The average rates for different modes, were specified in the ISG as follows:

<table>
<thead>
<tr>
<th>mode</th>
<th>rate [£/ton/km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>road</td>
<td>0.131</td>
</tr>
<tr>
<td>rail</td>
<td>0.087</td>
</tr>
<tr>
<td>inland waterways</td>
<td>0.020</td>
</tr>
<tr>
<td>short-sea</td>
<td>0.050</td>
</tr>
</tbody>
</table>

Table 4.1 Average transport rates per mode
(source: Stada & Hauwert, 1992)

Travel times on the network were determined by assuming average, link-specific travel speeds. Congestion on the road network has been taken into account by assuming higher travel times on frequently congested links. The railways system was modelled in a similar fashion as described for road transport. On the waterways network, delays at locks were added, varying by country. Additionally, delays experienced at border crossings were added for all modes. Transshipment between modes is represented by separate connections on the network; both time delays and transshipment costs can be defined for each individual transshipment link. The link cost function had the following form

\[ T_l = \frac{d_l}{s_l} + T_l^a \]  \hspace{1cm} (4.2)

where

\[ T = \text{transport time on link } l \]
\[ s_l = \text{mean speed on link } l \]
\[ T_l^a = \text{additional link specific transport times.} \]

The average speeds calculated for the three inland modes were the following:

<table>
<thead>
<tr>
<th>mode</th>
<th>speed [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>road</td>
<td>70</td>
</tr>
<tr>
<td>rail</td>
<td>30</td>
</tr>
<tr>
<td>inland waterways</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 4.2 Average transport speed per mode
(source: Stada & Hauwert, 1992)

3 Average rates were not calculated for the deep-sea and ferry
Figure 4.2 shows the geographical layout of regions and the transport network as specified within the ISG.

Modelling freight flows in the ISG

The TransCAD program provides a number of programs that are useful for freight flow calculations. The modelling of freight flows is performed by assigning an origin/destination (O-D) table of flows between regions to the multimodal network. The routines that are available for aggregate freight flow modelling concern spatial interaction and network assignment. A range of other options which are not directly related to calculating freight flow volumes on the infrastructure network, but are more in the line of policy applications, sensitivity studies or operational problems are offered as well. These concern e.g. critical link analysis, location models, vehicle routing and travelling salesman problems. Here we will focus on the routines developed for distribution and assignment problems.

The distribution of freight flows between regions is usually described by means of an interaction table, specifying the weight of the goods that were moved between regions, or origin/destination (O-D) table. The distribution of freight flows in TransCAD can be described by means of a gravity model. The distribution model specified here, however, does not allow for multiple modes to be taken into account simultaneously. Therefore, in chapter 5, we will extend the formulation of the gravity model to include multiple modes.

In addition, the routine for the estimation of the unknown model parameters requires a full O-D table. O-D tables for interregional freight transport in Europe can be constructed using data from European, national or regional statistics' offices. In general, however, data on international freight
4. Towards a freight flow model specification

Transport cannot be obtained at the regional level. This latter limitation applies to all sources that produce statistics on the level of individual origins and destinations for Europe. From some member states⁴, statistics are available that describe transport between the nations' regions with foreign countries.

These data are fragmented, however, and inadequate to build a complete O-D table at the European level. At present, the primary source of these data are the carrier surveys that are held yearly by the national statistics offices, together with the obligatory customs control documents⁵. A compilation of transport statistics is done each year by Eurostat, the statistical office of the European Community (see e.g. Eurostat, 1991). The Eurostat data that are readily available only pertain to tonnes transported between countries (all commodities taken together), tonnes transported between regions of the same country (all commodities taken together) and tons moved in and out of each region at the domestic level (broken down by commodity group)⁶.

By searching shortest routes in the multimodal network, the choice of mode(s) and routes made by a shipper or carrier are calculated simultaneously. The TransCAD package allows a series of route choice models to be applied. They include the all-or-nothing assignment routine, several equilibrium assignment possibilities and stochastic loading of flows onto the network. The routine which comes closest to our requirement of behavioural plausibility involves the stochastic assignment program. The route choice model used in the stochastic assignment program can be classified as a random-cost model, allowing for constant preferences and a random error term in the cost function.

4.2.3 The generalized costs of transport

From the international literature (see e.g. Bayliss (1988), Jeffs (1990), NEA (1990), Rotterdam Transport Centre (1991)) a long list of factors that play a part in the different choices in the freight transportation system can be identified. As indicated in chapter 2, they relate to the characteristics of the decision-makers (which include the products, goods or shipments in question) and the attributes of the choice alternatives. Apart from factors which directly concern the costs of transport, other factors (of e.g. a legal or temporal nature) have been found to be of relevance in choices in the freight transportation system (see e.g. McGinnis, 1989). For illustrative purposes, in table 4.3 we list a number of these factors which involve requirements and preferences from the side of the decision maker as well as some relevant attributes of the alternatives for transportation.

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⁴ These are the so-called "core countries": the Netherlands, Belgium, Germany and France (for a more detailed treatment see the review in NEA (1994))

⁵ Until 1993, this was the Single Administrative Document, later replaced by the Intrastat procedures (see e.g. Sherlock, 1994).

⁶ For some countries, statistics exist for domestic, interregional transport, broken down by mode of transport and main commodity group; as Eurostat maintains the format that can be filled in by the majority of the countries, this level of detail is not reached in the European statistics.
Table 4.3 Factors in the choice process

<table>
<thead>
<tr>
<th>Decision maker’s characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>nature and size of organisation</td>
</tr>
<tr>
<td>O-D relation</td>
</tr>
<tr>
<td>density of loading/unloading sites</td>
</tr>
<tr>
<td>shipment size</td>
</tr>
<tr>
<td>availability of own infrastructure</td>
</tr>
<tr>
<td>required lead time(^2) to customers</td>
</tr>
<tr>
<td>product characteristics</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alternatives' attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>rates for transportation and transshipment times</td>
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<tr>
<td>transport and transshipment times</td>
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<tr>
<td>reliability of transport and transshipment times</td>
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<tr>
<td>capacity of containers or vehicles</td>
</tr>
<tr>
<td>risk of damage and loss</td>
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<tr>
<td>legal constraints for transport</td>
</tr>
</tbody>
</table>

Unless detailed surveys are made, one's knowledge is usually limited to just a few of the above variables. Additionally, subjective factors on the side of the shippers or carriers play a role like e.g. the limited knowledge of alternatives or contractual bindings with transport suppliers. For modelling purposes, therefore, it is useful to obtain a general measure of transport resistance, which reflects the overall valuation of an alternative.

In analogy with the concept of "generalized travel times" in passenger transport (where variables measured in cost units were transformed into variables measured in time units), "generalized costs" or "total logistic costs" approaches have gradually been introduced in freight transport modelling\(^8\). These measures of the costs of transport usually involved a weighted sum of different service quality variables, including time, thus collapsing the measure of transport service quality into the costs dimension. The weights in these generalized costs formulas could be interpreted as monetary values attached to a marginal increase or decrease of the respective service variable, giving them economic (and thus behavioural) significance.

In the ISG, as a first approximation of these complex choices, the factors influencing mode and route choice have been defined using the following generalized cost function, expressed in terms of the available network attributes:

\(^7\) The elapsed time for the buyer of a product between ordering and receiving it

\(^8\) See e.g. Goss (1991) for a discussion of the application of the concept of generalized costs in passenger and freight transport.
4. Towards a freight flow model specification

\[ c_{1,g} = \alpha_{g} \left( \frac{d_{l}}{s_{l}} + T_{l}^{a} \right) + d_{l} \rho_{l} + c_{l}^{a} \]  

(4.3)

where

- \( c_{l,g} \) = generalized costs of transport
- \( s_{l} \) = mean speed on link 1
- \( d_{l} \) = length of link 1
- \( \alpha_{g} \) = value of transport time of good \( g \)
- \( \rho_{l} \) = marginal freight rate

The value of time of the goods was expressed as follows:

\[ \alpha_{g} = V_{g} \, \left( p_{g} + z_{g} + i \right) \]  

(4.4)

where:

- \( V_{g} \) = value of goods [$/ton]
- \( p_{g} \) = perishability factor [1/hour]
- \( z_{g} \) = risk factor [1/hour]
- \( i \) = interest rate [1/hour]

The perishability factor expresses the fraction of the transported value lost per unit of time due to deterioration or loss of a certain share of the goods transported. The risk factor can be seen as the insurance premium one would have to pay (also as a fraction of the transported value) to be covered against damage or loss. The term "insurance premium" should not be taken too literally, however. There is a certain relation between the tariffs charged and the risk of incurring losses during transport. The interest rate factor represents the loss on capital for the goods in transit. Based on these indicators, suggestions have been made for values of time to be applied in practice for different commodities.

One of the remaining research questions that has to be answered to allow for the descriptive application of the ISG is the theoretical and empirical underpinning of the value of time variable. The concept of the monetary value of transport time has been studied by transportation system researchers for assessing the efficiency of transportation services at the individual level (in order to study choice behaviour of agents in the system) as well as at the aggregate level (in order to determine the accumulated losses to users of a particular service). Clearly, we are concerned with the first topic here; nevertheless, we should point out that the importance of the concept of the value of time goes beyond interests at the individual level. Where transport times and rates can be determined reasonably well in practice, the value of time remains a variable which needs to be interpreted and quantified within a much wider, behavioural (and in our case logistical) context.
Transport time is one of among many attributes of a transportation service. Its importance for decision makers in the freight transportation system rests on the fundamental principle that time is a valuable resource in the logistic process. Depending on the goods’ attributes (e.g. their value) and the sending and receiving firms’ characteristics (e.g. their inventory policy), the time that goods spend in transit suggests additional costs to the transportation process, and thus also to higher level-processes within the freight transportation system.

The valuation of travel time will also depend on the decision maker and the choice problem at hand. As illustrated earlier, various agents involved in the freight transportation system each deciding upon dissimilar matters. For a carrier, for example, additional time spent on a detour for his trucks is directly reflected in the costs of equipment and drivers' wages. Beside possible rate changes by the carrier, introduced to pass his additional costs on to the sender of the good (which he may not be able to do in a competitive situation), the sender and receiver will be affected in a manner different than the carrier, e.g. through the depreciation of the goods. The monetary costs and benefits incurred by various processes in the freight transportation system may thus be different in nature.

An interesting (mathematical) interpretation of the value of time concerns this factor as a reflection of budget and time constraints for transport. Faller (1985) discusses the importance of transport time as a factor in the production process. A well known trend in production is the gradual acceleration of flows of materials and parts in the manufacturing process in order to 1) reduce capital costs and 2) allow lower lead times, facilitating a quick response to changes in market demand with respect to product characteristics. Lower transport times may thus directly result in lower production costs through a reduction of capital tied up in production. Indirectly, it is not only capital costs that are related to transport time, but also potential benefits that relate to marketing opportunities.

It may be clear that the quantification of this type of benefits of shorter lead times may be a difficult task to perform. Particularly within the context of the choice between different modes of transport, the importance of travel time to the costs of logistic processes has received attention in the literature. Goss (1991) points out that generally, the longer a movement takes, the greater the risk of market fluctuation will be for a product. Baumol & Vinod (1970) assume in their inventory-theoretical model, that the three attributes of transportation services that are likely to figure most prominently in the mode choice process are cost, speed and reliability; cost being an addition of freight rates, in-transit inventory costs and the cost of stocks held at the endpoints of the transport relation. In general, freight rates are inversely related to transit time, as opposed to

---

9 The value of time relative to costs of transport can be derived explicitly from known time and budget constraints by viewing the choice problem as an optimization problem; see e.g. Wynter (1995)

10 For references to background studies see McKinnon (1989)
in-transit inventory and stocks\textsuperscript{11}. From the users' perspective, the choice resulting from a trade-off between costs and times would depend on their individual values of time. With respect to inventory holding, McKinnon (1989) points out the importance of sales losses resulting from stock-outs, i.e. the unavailability of a good at the time that it is required by the costumer. The higher the expected stock-out costs or stock-out losses (in more general terms), the higher the safety stock. Stock-out costs are, however, hard to assess\textsuperscript{12}. In any case, the importance of lead time in this respect is obvious; in general, shorter lead times for replenishment of the inventory in case of stock-out will decrease the period in which actual stock-out losses occur and, consequentially, the risk of market fluctuations in that period. The goods that customers want immediately, will, therefore, tend to be transported fastest.

In our review of transport models in the previous chapter, we have paid attention to the issue of variations in preferences between individual decision makers with respect to the attributes of alternatives. Within the context of the value of time, we can operationalize this problem by considering possible sources of variation in the characteristics of goods and their logistical background. It will be clear that the present classification systems for goods types does not comply with a segmentation of goods along the logistical characteristics that were discussed above. Stada & Hauwert (1992) find that commodities within one group, according to the NST/R\textsuperscript{13} and Eurostat classification, can have a substantially different value density or perishability. Fowkes, Nash & Tweddle (1989) describe a similar experience in their study on the valuation of freight service attributes by fifty firms (manufacturers and hauliers) in the UK. They give examples of well-defined product types, such as tubes or cement, where the valuation of service attributes varied considerably, not only due to the value of the specific products, but also due to their handling requirements and the layout of the distribution channels (e.g. location and number of depots). We conclude that considerable variations in users' preferences do exist in the freight transportation system, and that these cannot be identified by segmentation of goods according to physical or sectoral characteristics, as is the case with the classification systems used at present in Europe.

In the following section, we will elaborate on ways to improve our insight into this variable contributing to the generalized costs of transport.

\textsuperscript{11} The lower the speed, the more time is spent in transit by the same shipment. Shipment sizes are on average higher for slow modes of transport, indicating higher stocks on the average in addition to even higher in-transit inventory costs.

\textsuperscript{12} "a formidable problem", op. cit., pp. 93; clearly, there are many long term issues that are hard to quantify, like lost marketing opportunities.

\textsuperscript{13} Nomenclature uniforme de marchandises pour les Statistiques de Transports, Révisée
4.3 Areas of model innovation

4.3.1 Multiple modes in the spatial interaction model

The application of the ISG presupposes the availability of an O-D table on the level of the European regions. In order to be able to calculate and analyse infrastructure related flows, full O-D tables have to be assigned to the network. Unfortunately, as we have indicated above, these tables are only available for the domestic transport flows of the individual countries. Therefore, they will have to be estimated. This estimation of "missing" O-D table values can only be done if we assume a model for the distribution of goods that explains observed freight flows. Such a model allows for deriving general freight flow patterns from the available statistics on domestic and international movements; by applying these general patterns to the whole study area (while accounting for the characteristics of domestic and international movements), an entire O-D table can be produced. In addition to satisfying the need for complete datasets on O-D movements, models also allow their use for forecasts and scenario studies. For purposes of freight transportation system analysis, model variables relating to the transportation system can be linked to policy measures (reflecting the "points of intervention") and to autonomous developments.

In the following chapter, we will adapt the general specification of the spatial interaction model as introduced in the review of modelling approaches to account for spatial interactions from a wider perspective. In particular we will focus on the issue of multimodality and on the representation of international barriers for trade and transportation.

4.3.2 Stochastic route choice in a multimodal network

In addition to some extensions of the spatial interaction model, a different area of modelling in which there seem to be a need for new research is stochastic route choice in multimodal networks. In the previous chapter we have seen that an area which has so far seen little investigation is that of the choice models with random attribute weights, or heterogeneous preferences. Recently, there has been increased interest for models accounting for this source of uncertainty within the context of route choice (see Dial, 1994, Leurent, 1994, Wynter, 1995). However, these models have not yet been formulated within a generalized context in terms of the multimodality of choice alternatives and the characteristics of the choice model. From a theoretical standpoint, it is appealing to combine the general multimodal network formulation with a general specification of the choice model, as discussed in the previous chapter. Firstly, we obtain insight in the effectiveness of treating combined mode and route choice in one choice framework. Secondly, we obtain insight in the validity of the usual assumption of constant preferences. From a practical perspective, we make a further step towards the applicability of the ISG, in terms of empirical estimations necessary to validate the route choice approach.
4. Towards a freight flow model specification

4.3.3 Assessing the value of transport time

From the transport modelling literature, two main approaches can be identified for assessing the valuation of transport times in freight transport by decision makers: the factor cost approach and the demand modelling approach.

The factor cost approach

The factor cost approach consists of adding the individual cost factors that relate the transportation of a good during a period of time. The costs calculated concern three categories 1) personnel and administrative costs (wages, premiums, overhead), 2) equipment costs (fuel, repairs) and 3) depreciation costs (interests, perishability). Examples of applications of the factor cost method can be found in HCG (1991), Stada and Hauwert (1992) and Jourquin (1995). The HCG study quantified the values of time of hauliers of different modes, concentrating on the quantifiable and transport related-costs only. Stada and Hauwert, within the framework of the design of the ISG, base their value-of-time calculations on capital costs and perishability costs of goods. The main drawback of the factor cost approach stems from the rigid formulation of costs. Firstly, the operational costs of a carrier do not necessarily represent the freight rates, and may thus not be a realistic approximation of the costs of transport incurred by the respective decision maker. Secondly, this approach does not account for the influence of time on the total logistic costs related to the production of goods. Beside failing to account for a number of quantifiable costs (e.g. inventory costs, stock-out costs) the approach also omits intangible aspects in the value of travel time.

Demand modelling

The demand modelling approach requires the explicit specification of the VOT as a choice factor within a transportation demand model. As part of the model design process, the approach involves the estimation of an optimal value for this variable, based on observed or hypothesized choice behaviour of agents in the system. Hence we can distinguish different modelling approaches, based on a classification of demand models as was presented earlier as well as on the type of experiment conducted for obtaining these data.

The estimations based on hypothesized behaviour (as a preference which is stated by the decision maker, within the context of an assumed situation) are classified as the stated preference (SP) approaches; estimations based on observed behaviour belong to the revealed preference (RP) approach. By definition, the data used in SP experiments are disaggregate (i.e. relating to the choices made by individuals), and hence, so are the models. In RP experiments neither the models nor the data need to be disaggregate. Mode choice within an RP context has been studied by Blauwens & Van De Voorde (1988), Ogwude (1993) and Wildert & Bradley (1992). Except for the study by Blauwens & Van De Voorde, the data used in these RP studies were all of disaggregate nature. The VOT of French truck drivers within a route choice context by means of an SP experiment has been studied by Wynter et al. (1994). The SP-study of HCG (1991) involved choices among "within-mode" alternatives, which may be interpreted as different routes.
Examples of SP experiments within a mode choice context can be found in HCG (1991) and in Fowkes, et al., (1989). An approach within a similar context combining RP and SP experiments was conducted by Vieira (1992).

Discussion

None of these approaches towards estimating the value of time in freight transport have made use of models describing simultaneous choices, like the combined choice of modes and routes that we are concerned with in the network as specified in the ISG, nor have these issues been studied in connection with the process of the spatial distribution of goods. From the logistical perspective, however, the VOT as an attribute of the user of freight transport services and spatial deterrence seem to be strongly related. In general, the VOT of the users will affect the generalized costs and thus the geographical coverage of their activities. The recent findings of Wynter (1994) indicate that there is indeed a relationship between the VOT of truck drivers and the distance that they cover. However, up to now, the relationship between the VOT in freight transport and spatial deterrence has not been explored from a multimodal perspective.

Summarizing the discussion of the concept of the value of time, we conclude the following:

- The value of time in general is of important to transport modelling: to obtain insight into choice behaviour, and to assess economic benefits at the system level. Seen from the behavioural perspective, transport time will gain more and increasing significance in logistics processes. In order to apply the ISG for impact assessment, however, it is necessary to have empirical estimates of the value of time of goods.

- The preferred method to determine these values of time for freight flows in Europe is through demand modelling. Experience with mode choice studies indicates that empirical estimates of the valuation of transport time exceed capital costs. Furthermore, the literature indicates that the importance of travel time to decision making goes further than what can be traced by means of a factor cost approach. In particular, the question of marketing opportunities is inherently qualitative; thus, its influence on transport choices preferably should be assessed by means of demand modelling.

4.4 Conclusion

In this chapter we have begun the solution oriented analysis of this thesis, aiming at the design of two specific models, each related to one level of analysis in the freight transportation system. The general framework for the design of the proposed models is an existing GIS application for assessing policy impacts at the European level. In the ISG a number of modelling issues are raised which require further research into the representation of complex choice problems when little data are available.

The proposed extensions of the existing models, therefore, are based on theoretical (i.e. the needs for developing new modelling theory that were identified in the previous chapter) as well as
practical considerations (i.e. the available data). They concern the design of 1) a spatial interaction model that accounts for multiple modes and can be estimated using the available data and 2) a stochastic route choice model in a multimodal network. The value of travel time, introduced as a factor influencing the generalized costs of transport, appears to be of considerable importance for indirectly treating logistical characteristics of the freight transportation system. In the following two chapters we will treat the distribution and route choice models in more detail.
5. The multimodal distribution of freight flows

5.1 Introduction

The objective of this chapter is to design a model that describes the spatial distribution of freight flows between regions\(^1\) in Europe. In Chapter 3 we have concluded that of the two main modelling approaches, the interregional flow equilibrium approach and the gravity type models, the latter is a more attractive alternative, as it allows for competition between shippers' decisions. This chapter describes the design of a multimodal distribution model for freight transport in Europe, starting from these findings. The design of the distribution model comprises the stages specification and estimation. In addition, we apply the model to a case study to assess the effect of decreasing border barriers.

The specification of the model is introduced in the following section. Here, we have to take into account possible imbalances between patterns of domestic and international transport flows as a result of international barriers to trade and transportation. In addition, our specification needs to allow for mode-dependent barrier effects. Therefore, we propose a multimodal distribution model.

\(^1\) Throughout this chapter, we will use "flows" or "OD-flows" to denote origin-destination flows between these regions.
5. The multimodal distribution of freight flows

The methods and techniques necessary to estimate the unknown parameters of this model are described in section 5.3. The estimation method takes into account the specific nature of the available data (i.e. that observations on international, interregional flows are not available). The specific case for which the estimations are made is described in section 5.4; here we describe the study area and its regional subdivision, as well as the data that will be used. The estimation results are presented and interpreted. In section 5.5, we describe a case study done with the distribution model. In order to gain insight into the sensitivity of freight flows with respect to international barriers, we make a projection of freight flows in Europe in the hypothetical case that these barriers do not exist. Section 5.6 presents the conclusions of this chapter.

5.2 Model specification

5.2.1 General form of the distribution model

The decision makers whose choices are modelled in the distribution model are the shippers; they may be characterized as traders in the system, or agents that observe producing (or buying) and selling opportunities in various regions and try to make profits by "bartering" between them. In order to capture the distribution of goods between regions in a mathematical model, we assume that shippers choose their locations of production and sale of their goods rationally, or, more specifically, in such a way that they maximize their profits. Starting from this assumption of profit maximization, the distribution model can be seen as a model of joint origin and destination choice.

The derivation of the distribution model from a choice model is presented in two stages. The first stage deals with the definition of the values that can be attached to each O/D relation, specified in the form of a profit function. We assume that the utility of an origin and a destination, or the profit of trade between two locations, is the profit resulting from producing a good in an origin, transporting it to a destination, and selling it there. The second stage deals with the specification of the choice of the shipper, given the specification of the profit of each O/D relation. Here we assume that the choice model is stochastic and of the logit type. These assumptions result in the gravity model, as has been demonstrated earlier for the case of passenger transport by Erlander (1990) and Anas (1983). We will not repeat the entire derivation, as its demonstration is not a new issue. However, a review of the assumptions necessary for the derivation of the model is useful, in the light of the new context of freight transport. We begin by examining the second assumption, as the general framework of the choice model is introduced at this stage.

Let $U_{ijm}$ be the perceived profit of a particular shipper, obtained from shipping a good from origin $i$ to destination $j$ by mode $m$. Let us further assume that

$$U_{ijm} = v_{ijm} + \varepsilon_{ijm}$$  \hspace{1cm} (5.1)

where $v_{ijm}$ denotes the deterministic or systematic part of the profit of shipping on O/D pair $(i,j)$ with mode $m$.
The error term $\varepsilon_{ijm}$ is a random variable representing variations in this profit as a result of:

- unobserved attributes of the transportation system
- measurement errors in the attributes of the transportation system
- errors due to the use of proxy or instrumental variables for the utility attributes

Under the assumption that shippers choose their relation $(i,j)$ and mode $m$ with probability $Pr(i,j,m)$ independently of other shippers, the multinomial logit model for the shippers' choice is obtained by assuming that the error terms of the different alternative relations are identically and independently distributed (i.i.d.) and that they have a double exponential extreme-value (Gumbel) probability distribution\(^2\), denoted as follows:

$$
\varepsilon_{ijm} \sim \text{Gumbel}(0, \pi^2/6\mu^2) \tag{5.2}
$$

where

$$
F_{\text{Gumbel}} = Pr[\varepsilon_{ijm} \leq x] = \exp(-\exp(-\mu x)); \mu > 0
$$

It can be shown that the probability of preferring one relation over all others becomes

$$
Pr(i,j,m) = Pr[U_{ijm} > U_{kln} : \forall (k,l,n) \neq (i,j,m)] = \frac{\exp(\mu \nu_{ijm})}{\sum_{ijm} \exp(\mu \nu_{ijm})} \tag{5.3}
$$

As $\mu$ and $\nu_{ijm}$ cannot be estimated separately, $\mu$ is set arbitrarily to 1. This yields the multinomial logit model.

The next stage in the derivation of the distribution model involves the specification of the deterministic part of the profit $U_{ijm}$. To specify the profit-variable further, we follow Hamerslag (1972), who bases his demand model for passenger transport on the general theory of microeconomics. It is assumed for our case that:

I. the profit of shipping a commodity between two locations is equivalent to the balance of costs and benefits of shipping on an O/D relation,

II. this measure of the profit of shipping on an O/D relation $(i,j)$ can be split into three parts, reflecting costs and benefits incurred by 1) production at the origin $i$, 2) marketing and sale at the destination $j$ and 3) transportation between these locations by mode $m$

\(^2\) From a behavioural as well as a mathematical perspective both the normal distribution and those of the extreme-value type may be appropriate. The assumption of Gumbel and i.i.d. error terms, however, allows the derivation of a convenient formulation of choice probabilities (see Ben-Akiva and Lerman, 1985).
5. The multimodal distribution of freight flows

The origin-specific part of the profit function can be interpreted as the supply price of goods in location $i$, the destination-specific part as the demand price of goods in $j$. The effect of transportation costs on $v_{ijm}$ will be negative.

Thus we define $v_{ijm}$ as follows

$$v_{ijm} = -a_i + b_j - c_{ijm}$$

(5.4)

where

$a_i$ = the cost of producing or buying a good in location $i$, with $a_i \geq 0$.

$b_j$ = the benefit obtained from selling the good in location $j$, with $b_j \geq 0$.

$c_{ijm}$ = the costs of transporting a good between $i$ and $j$ by mode $m$, with $c_{ijm} \geq 0$.

Comparing this distribution model to the spatial price equilibrium model, we make two observations:

- Firstly, the definition of the profitability of trade between two regions coincides with the definition of the costs of trade in the spatial price equilibrium model. This implies that the regional price of goods in the gravity model can be related to the demand and supply functions of each region, thus providing the intuitive relationship between the "mass" of a region (i.e. its total input or output) and its attractiveness.

- Secondly, in that model, flows are assumed to occur only in the situation that $v_{ijm}$ is positive. In the gravity model, this assumption is relaxed by adding the random error term $\varepsilon_{ijm}$ to the systematic part. For all values of $v_{ijm}$ there is a probability above zero that $U_{ijm}$ will be maximal and that, consequentially, transportation will take place.

By introducing this specification of the systematic part of the utility function in the multinomial logit choice model and by performing the following transformations

$$p_i = \exp(-a_i)$$

$$q_j = \exp(b_j)$$

(5.5)

$$f(c_{ijm}) = \frac{\exp(-c_{ijm})}{\sum_{ijm} \exp(v_{ijm})}$$

we obtain the following distribution model:

$$Pr(i, j, m) = p_i q_j f(c_{ijm})$$

(5.6)

If the total amount of goods moved in the study area is $t$, the expected volume $\hat{r}_{ijm}$, moved on each relation $(i,j)$ by mode $m$, is expressed by:

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\[ \hat{i}_{jm} = t_{Pr(i,j,m)} = t \cdot p_i q_j f(c_{ijm}) \] (5.7)

This model is similar to the gravity model, except for the general, multimodal formulation of the deterrence function and its formulation as a choice model, instead of a physical analogy to gravity in the form of tonnes moved. For the distribution of flows over O/D relations we obtain:

\[ \hat{i}_{ij} = \sum_m \hat{i}_{jm} = t \sum_m p_i q_j f(c_{ijm}) = t \cdot p_i q_j \sum_m f(c_{ijm}) \] (5.8)

The fraction of all users choosing a mode is given by the ratio of the values of the deterrence functions:

\[ \hat{i}_{ijm}/\sum_m \hat{i}_{jm} = f(c_{ijm})/\sum_m f(c_{ijm}) \] (5.9)

5.2.2 Specification of transport costs

Consider the transport costs between two locations, \( c_{ijm} \). These costs is specified in three additive parts as follows:

\[ c_{ijm} = c_{im}^A + c_{jm}^M + c_{jm}^E \] (5.10)

where

- \( c_{im}^A \) = the costs of access, i.e. reaching the main network connection of mode \( m \) from \( i \),
- \( c_{jm}^M \) = the costs of the trunk movement, i.e. the movement over the network between the network connections of the main mode of transport,
- \( c_{jm}^E \) = the costs of egress, or reaching \( j \) from the main network connection of mode \( m \),

In the remainder of this section we will treat these components of the transport costs in more detail.

5.2.2.1 Access and egress costs

These costs involve all location and mode specific costs that are necessary for transportation, like loading and unloading, packing and unpacking, sorting, as well as transportation and transshipment to and from the nearest interregional network connection. In general, different modes will have different requirements regarding e.g. unitisation and packaging. In general, the accessibility of industrial or retail sites within a region will also depend on the main mode of
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transport. Depending on the assumptions that we make regarding the access and egress costs, three different model specifications may result:

- the unimodal model
- the multimodal model with region generic access/egress costs
- the multimodal model with region specific access/egress costs

These three cases are described in more detail below.

The unimodal case

The first and most elaborate specification results if we assume that access and egress costs depend firstly on the mode of transport, secondly on the region of origin (access), and thirdly on the region of destination (egress). Here costs depend on the direction of transport, i.e. access and egress may involve different costs for the same region and mode. Thus we have as many variables as there are access and egress links. As this model has the same unknown parameters as three independent models for one single mode of transport, it is equivalent to the unimodal gravity model. In this unimodal case, all model parameters concern the fraction of goods moved by one mode. The unimodal specification, therefore, is not suited to study interactions between the distribution of goods over different O/D relations and the distribution over modes. However, for transportation system analysis, we would like to study the choice of mode as well. With some additional assumptions, we can specify a simultaneous model of distribution and mode choice (see Appendix A). The resulting specification is as follows:

\[
\hat{t}_{ijm} = t_{ijm} q_{ijm} f(c_{ijm})
\]  

The multimodal case with region generic access/egress costs

A different and more convenient model specification is obtained by assuming that access and egress costs only vary by mode, and are identical for all regions. Here, we have one access/egress cost variable per mode \(c_m^G\), throughout the whole area, i.e.

\[
c_m^A = c_m^A = c_m^E = c_m^E = c_m^G \quad \forall i,j,m
\]  

The resulting specification is:

\[\text{...}\]

3 Recently, Matton (1995) has estimated regional access/egress measures in a mode choice model for the Netherlands and found that these were related to the density of loading and unloading sites in each region.

4 \((n_m \times n_i + n_j)\) plus the parameters to be estimated for each deterrence function. The \(T\) variable is known, but does not influence the estimation, as the scaling of the variables \(p\) and \(q\) is arbitrary.
\[ t_{jm}^{m} = t_{p}q_{j}f \left( c_{jm}^{M} + 2c_{jm}^{G} \right) \]  

(5.13)

**The multimodal case with region specific access/egress costs**

In the third alternative we assume that access and egress costs are the same for one region, i.e.

\[ c_{jm}^{A} = c_{jm}^{E} = c_{jm}^{G} \quad \forall i, m \]

\[ c_{jm}^{E} = c_{jm}^{E} = c_{jm}^{G} \quad \forall j, m \]  

(5.14)

The specification of the related distribution model is:

\[ t_{jm}^{m} = t_{p}q_{j}f \left( c_{jm}^{M} + c_{jm}^{G} + c_{jm}^{G} \right) \]  

(5.15)

### 5.2.2.2 Trunk transport costs

In order to obtain a measure of transport costs, which is applicable to all modes of transport in a uniform manner, the principle of generalized costs has been taken as a starting point. Let us assume that the resistance of transportation for good \( g \), between two locations \( i \) and \( j \), by mode \( m \) is given by the generalized costs of transport:

\[ c_{jm}^{M} = \alpha \cdot T_{jm}^{M} + R_{jm}^{M} \]  

(5.16)

where:
- \( c_{jm}^{M} \) = generalized trunk transport costs between \( i \) and \( j \) by mode \( m \)
- \( \alpha \) = value of transport time
- \( T_{jm}^{M} \) = transport time on main link
- \( R_{jm}^{M} \) = freight rate on main link

We assume that these generalized costs relate to two attributes of freight transportation services, freight rates and transport time. In general, the value-of-time will vary among different goods, not only because of differences in physical characteristics, but also due to different logistical circumstances of the sending and receiving companies.
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5.2.2.3 Approximation of transport costs by distance

As the value-of-time of the goods is unknown we cannot enter the costs of transport in our model explicitly. For the purpose of model estimation, we have chosen to take distance as a proxy for transport costs. The resulting deterrence function is as follows:

\[ f(c_{jm}) = g_m(d_{jm}) \]  (5.17)

where the distance variable \( d_{jm} \) is specified in analogy with the cost variable \( c_{jm} \):

\[ d_{jm} = d_{jm}^A + d_{jm}^M + d_{jm}^E \]  (5.18)

where

\[ d_{jm}^A = \text{distance-equivalent of the costs of access} \]
\[ d_{jm}^M = \text{distance-equivalent of the costs of the trunk movement} \]
\[ d_{jm}^E = \text{distance-equivalent of the costs of egress} \]

This formulation implies the following:

1. one and the same relationship between distance and transport costs applies for all the choice alternatives within one mode of transport. As these relationships are different among modes, in the multimodal case, separate deterrence functions have to be estimated for each mode.

2. other parameters in the deterrence function as the costs of access/egress are estimated in terms of distance as well. Note that the quantification of the opportunity costs involved can be done along the same lines as with transport distance, once the unknown parameters in the cost function (5.17) have been estimated.

For the purpose of an application of the model it may be useful to link distance as a measure of transport resistance to the above service quality variables. The estimation of the value-of-time variable can be performed independently of the estimation of the parameters of the distribution model. This procedure is outlined below, and will be of use in interpreting the estimation results later on in this chapter.

Starting from the estimated deterrence functions, the cost function parameters to be estimated concern the value-of-time parameters \( \alpha_m \) and, in the case of a mode-specific and region-generic access/egress resistance, an additional variable \( K_m \) for two out of the three modes (e.g. by assuming no access/egress costs for road). The objective of the estimation of these variables is to minimize the differences between the deterrence functions of the different modes. This is equivalent to assuming that the sensitivity of transport to distance is equal for the goods carried by the three modes. However, as the scaling of the deterrence functions is arbitrary, one of the distance-related deterrence functions has to be taken as a yardstick. This implies immediately that
only relative values of the cost function variables can be determined. In figure 5.1 below a graphical illustration is given of the estimation of the value-of-time variable and the mode-specific constants.

\[
\begin{align*}
    f_m (c_{ijm}) & \quad f(c_{ijm}) \\
    m=1 & \quad m=2 \\
    c_{ijm} & = d_{ijm} \\
    c_{ijm} & = X_n \ast d_{ijm} + Y_n
\end{align*}
\]

Case I: costs approximated by distance
Case II: costs as a function of distance

*Figure 5.1 Estimation of cost function parameters*

The transformation of distance to generalized costs is done by first multiplying distances by the factor \(X_n\) and then, adding the mode-specific cost factors \(Y_n\); this is illustrated graphically as case one and case two in figure 5.1. Note that the cost factors are adapted in such a way that deterrence function two (indicated in the figure by \(m=2\)) assumes the shape of function one (\(m=1\)). The variables of function (1) may obtain arbitrary values; for any value of the variables of function (1), it will be possible to find a suitable transformation of the other deterrence functions. The transformation of these functions is treated in more detail in Appendix D.

### 5.2.3 International barriers to trade and transportation

In our effort to describe the distribution of goods among the European regions, we have to account for the phenomenon of international barriers for trade and transportation. Batten and Nijkamp (1990) formulate a barrier as a "particular type of obstacle which restricts or impedes the smooth transfer or free movement of a person or commodity from one place or another". The formulation of interregional resistances in the conventional distribution model (i.e. based only on distance) is insufficient, if there are additional impedances present that raise the costs of distribution and transport at the international level. Recall that these impedances or barriers can have a number of causes such as:

- bilateral agreements concerning the exchange of goods
- cultural differences between countries
- delays for cross-border transports due to veterinary and safety procedures
- administrative procedures due to national tax regulations
- technological differences between national transportation systems.
5. The multimodal distribution of freight flows

The relationship between international barriers and their visible effects (a relatively low intensity of international transportation, when compared to transportation over the same distance at the national level) concerns many interacting elements of a political and socio-economic nature that cannot in all cases be quantified directly. As early as in 1944, Lösch noted that the effect of political barriers on the intensity of trade compare to the effects of an increase in distance between two areas (figure 5.2).

![Diagram](image)

*Figure 5.2 Barriers and interaction (adapted from Batten and Nijkamp, 1990)*

Lösch's observation has been investigated by many researchers in the area of trade, transportation, and telecommunications. Studies on the magnitude and nature of barriers to trade and transportation have involved the application of models of the distribution of goods flows, modified in such a way that an additional deterrent effect of barriers could be taken into account. Peschel (1981) and Peschel et al. (1979) in their empirical work first introduced the spatial dimension in empirical research on the effects of economic integration. Bröcker (1980, 1988) analyses barriers to international trade for road transport by means of a gravity model. Applications of this theory have, however, remained limited to one single case, which was not reported independently in the international literature, but only referred to from within a wider context (Peschel, 1981). The investigations in question were performed using data on freight transport by road between six European countries in 1970. The results indicated an average barrier, comparable in magnitude to 375 km. of distance. To our knowledge, further details concerning the estimation method and the data used for this case have not been published in the international literature.

The latest application of a gravity model for the investigating of border barriers, at the time of this writing, comes from Bröcker and Rohwedder (1990) who determine trade barriers on a global level, on a country-by-country basis. This approach, however, is too coarse for our purposes. Beside this work on goods flows, some studies can be found that pertain to passenger and information flows. Rietveld and Rossera (1992) analyze the role of barriers in telecommunications demand. In their case study for EC and EFTA-member countries, they find that crossing a border leads to a reduction of the intensity of communication of around 30% to 40% of the volume one would expect without international borders. Blum and Leibbrand (1993) estimate border resistances for passenger transport within and in connection with Europe. Within Europe, they found that existing barriers (based on data for 1985) between Germany and its neighbour
countries reduce international transport by 10% to 15%. Other sources mention a reduction factor of 4 to 5 with respect to domestic transport flow patterns (ECMT, 1985⁵).

Based on the work done so far, we identified the following problems:

- Firstly, despite the importance of this issue from an international perspective, none of the above approaches considers border barriers within a multimodal framework. Batten and Törnqvist (1990) illustrate the need for incorporating the effects of differences between regions in the availability of transportation networks in estimations of the magnitude of international barriers. Their illustration is of a conceptual nature, and of a wider scope than just goods flows. It involves a modelling framework which is applicable to interactions between networks for different modes of transport. Although this framework is applicable for the exchange of information as well as goods, we will confine ourselves to goods flows in this study. Nevertheless, also in the case of goods flows within Europe, transportation and trade-related barriers will be intertwined, due to the existence of networks of different modes of transport. The variations in the voltage between electrical systems of different countries for rail transport is a well known example of a mode-specific barrier. It is conceivable that the alleviation of this type of barriers will evoke changes in the shares of different modes.

- Secondly, the unavailability of interregional trade data has apparently constrained applications of this theory to goods flows. The estimation of a gravity model requires an estimation method which is suitable for partially filled O/D tables. Although methods of this kind have been applied for passenger trip matrices (see e.g. Kirby, 1980), these have, to our knowledge, not been brought into connection with the estimation problem at hand.

In this study, we will specify a model that accounts for the possibility of modal re-distribution as a result of changes in border barriers. Furthermore, we will formulate and apply these partial matrix techniques to our specific estimation problem. Starting from the distribution model as defined earlier, we extend the formulation of the deterrence function with an additional variable of the same dimension as the costs of transport between two regions. An increase in the magnitude of a barrier between two countries will affect all interregional relations between these countries by increasing their resistance with the same value. This notion of international barriers assumes therefore that all regions of a country will be similarly affected in their willingness to exchange goods with foreign regions. Naturally, the more we will approach the border area, the smaller the cultural differences between regions on two sides of the border will be. We assume that other components of barriers, which equally apply to all regions of a country, outweigh this effect. Formula 5.19 now becomes:

\[
d_{ijm} = d^A_{ijm} + d^M_{ijm} + d^E_{ijm} + \delta'_{ijm} d^\theta_{ijm}
\]

\[
\begin{align*}
\delta'_{ij} &= \begin{cases} 
1 & \text{if } (i, j) \in (I, J) \\
0 & \text{if } (i, j) \notin (I, J)
\end{cases} \\
\delta'_{ij} &= \begin{cases} 
1 & \text{if } (i, j) \in (I, J) \\
0 & \text{if } (i, j) \notin (I, J)
\end{cases}
\]

(5.19)

⁵ No references were made to specific studies, however.
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Here $d_{im}^p$ represents the magnitude of a barrier, approximated by the amount by which the distance is raised for all movements by mode $m$ on O-D relations $(i,j)$ belonging to the international relation $(I,J)$. The variable $\delta$ indicates the membership of each individual O-D relation to international relations. Only one value is adopted for a relation between countries, even if on a particular journey more border crossings occur. At this point no assumption is made with respect to the marginal effect of an actual border crossing, relative to other types of barriers. The formulation further indicates that 1) each mode has different transport costs and 2) different border resistances. Note that the deterrence function is mode-specific; we assume that similar goods moved by different modes experience a similar deterrent influence of transport costs. However, the values of this function will be different for distinct modes, as the costs of transport will vary in general.

5.2.4 Towards a set of operational models

To summarize, we have specified a model of the interregional distribution of goods within Europe. The model was formulated from a multimodal perspective, i.e. different modes of transport have explicitly been taken into account in the problem of distributing a volume of $t$ tons in the entire study area over a number of O-D relations. Depending on the assumptions that are made concerning the access and egress costs, three different model versions result for the distribution of goods. As we have shown, one of these is in essence a unimodal model. The multimodal specification has a number of advantages over a unimodal model. Firstly, it allows applications in scenario studies involving modal choice. Secondly, mode-generic parameters can be linked to other real-world variables (e.g. socio-economic data) more easily than in the case of a mode-specific formulation. Thirdly, the available data on transport flows for different modes can be used simultaneously. In the specification of a measure for the costs of transportation, we have taken into account the influence of international border barriers. The three resulting model formulations are described below.

In the unimodal formulation, all model parameters to be estimated are mode-specific. The formulation of this model is:

$$\tilde{r}_{im} = t p_{im} q_{jm} g_m (d_{im}^m + \delta g d_{im}^p) \quad (5.20)$$

Depending on the assumption of region-specific or region-generic access/egress costs, two additional formulations of the multimodal model result. The second version of the distribution model concerns a multimodal formulation where access/egress costs are assumed to be the same for all regions, but differ only among modes of transport. The formulation is as follows:

$$\tilde{r}_{im} = t p_{im} q_j g_m (d_{im}^m + 2d_{im}^e + \delta g d_{im}^p) \quad (5.21)$$

In the third version we relax the assumption of region-generic access/egress costs, and assume that access/egress costs differ among modes and among regions. We assume, in addition, that access and egress costs are equal for one region, i.e. the costs to connect to the main network of a
mode are indifferent to the direction in which transport takes place. The model is specified as follows:

$$\hat{v}_{im} = t \ p \ g \ \gamma \ (d_{i}^{m} + d_{j}^{m} + d_{j}^{m} + \delta_{ij}^{m} d_{ij}^{m})$$  \hspace{1cm} (5.22)$$

In the following section, we propose a method for the estimation of the unknown variables of these models. These concern the regional parameters $p$, and $q$, the parameters that characterize the deterrence function and the access/egress and barrier related distance parameters that enter the deterrence function as an addition to the usual argument, trunk transport distance. An important requirement is that we have to be able to use the format of transport data that was described in the previous chapter, in addition to the usual data such as traffic counts and O/D level observations.

### 5.3 Estimation method

The application of the distribution model for scenario-building or forecasting requires the determination of the unknown parameters of the gravity model described above. Our purpose is to determine the values of the parameters of the gravity model that best describe the observed freight flows. This process is termed estimation. In the following section we describe the available data, as well as the methodology that we applied to perform the necessary estimations, given the limitations in data availability.

#### 5.3.1 Partially aggregate matrix estimation

As information on the magnitude of interregional flows between countries is not available from the existing statistics (see figure 3), we determine these flows after the estimation of distribution model parameters. Several methods are available to estimate the parameters of the distribution model (Hamerslag and Immers, 1988). The different approaches are not equally applicable, however, given our needs and data constraints. In particular, our data do not constitute a full O/D table. As we will see, however, we have sufficient data that cover the whole study area to estimate the parameters of the distribution model. In particular, we can exploit the structure of the observations within the O/D matrix to derive the estimation method.

Conventional estimation approaches either rely on completely observed O/D tables or on regional demand and supply data. In this case, this approach is not applicable, as the flow data are not available for international relations. Kirby (1979) describes a "partial matrix" estimation technique for the case where the available data have no particular structure, i.e. at some places data are missing in the O/D matrix. This case can be the result of surveys, where not all O/D pairs are covered. This case resembles ours, in the sense that no observations of individual cells are
5. The multimodal distribution of freight flows

available for international relations. However, we do have additional information on international O/D flows, at the level of country pairs.

We can use these additional data by adopting the maximum likelihood estimator originally developed to estimate O/D matrices based on aggregate observations such as traffic counts (Hamerslag, 1978). As traffic flows on a link are a weighted combination of origin-destination flows, the observations, or traffic counts, enter the estimation process as weighted sums of O/D volumes. In our specific case, the 'traffic counts' are the international flow totals (figure 3). As each international O/D relation has an equal contribution to the flow total, the "weights" are equal. We will use this second approach to estimate the O/D flows.

![Diagram](image)

**Figure 5.3** Availability of O-D data at the European level. Grey squares denote international flow totals as the sum of the respective interregional flows

The estimation method, formulated for the data available in our case, is described below. Note that this formulation is not restricted to the type of data pictured above; it is possible to use (additional) link counts as well. As we will see, the only requirement placed upon the data is that the individual O-D cells (that represent relations) contributing to an observed flow do not overlap in the matrix. Further on in the text, the estimation process for this specific case will be denoted as partially aggregate matrix (PAM) estimation.

The distribution of commodity flows, expressed in tonnage transported between a number of origins and destinations by a number of modes during a certain period, is represented in an O-D
matrix consisting of \( n_i \) rows (origins) and \( n_j \) columns (destinations). Assume that observations \( t_{ijm} \) are available only for a restricted number of cells in the matrix. Call these cells single cells. Further assume that in the remaining cells of the matrix \( n_b \) blocks or sets of cells can be distinguished. A block is a number of cells, not necessarily adjacent to each other, for which only the sum of the observations is known, not the values of the individual cells. In the problem at hand, these blocks represent the relations between groups of regions belonging to the respective countries. It is not required that the blocks cover all the remaining cells\(^6\).

The problem is now to estimate the parameters of the distribution model. We will derive a goodness-of-fit measure for the parameters, based on a likelihood function of the parameters of the gravity model and the observed flows. The objective of the estimation is to find the parameters that maximize the likelihood of the event that the flows calculated by the model are equal to those contained in our O-D table.

We assume that the observations in the O/D cells are independently and Poisson distributed, with expected value \( \hat{t}_{ijm} \) (see Appendix C for a more elaborate treatment of this assumption). The problem then is to estimate the \( \hat{t}_{ijm} \), such that the best possible agreement with the observations is obtained. For one particular cell with expected value \( \hat{t}_i \) the probability of observing \( t_{ijm} \) is:

\[
Pr(t_{ijm} | \hat{t}_{ijm}) = \frac{e^{\hat{t}_{ijm}} \cdot \hat{t}_{ijm}^{t_{ijm}}}{t_{ijm}!} \quad (5.23)
\]

If the observations for one O/D cell are Poisson distributed with expected value \( \hat{t}_{ijm} \) then the value for a sum of observations of O/D cells will also have a Poisson distribution. The expected value \( \hat{t}_{ijm} \) for a block will be equal to the sum of the expected values of the cells the block comprises. The probability of observing \( t_{im} \) for mode \( m \) is:

\[
Pr(t_{im} | \hat{t}_{im}) = \frac{e^{\hat{t}_{im}} \cdot \hat{t}_{im}^{t_{im}}}{t_{im}!} \quad (5.24)
\]

where\(^7\)

\[
\hat{t}_{im} = \sum_{i \in I, j \in J} \hat{t}_{ijm}
\]

\(^6\) The matrix has to be filled to a certain degree, however; see e.g. Day and Hawkins (1979), Kirby (1979) and Maher (1983)

\(^7\) Note that we can also specify the estimation problem in terms of blocks only, where the limiting cases would be the single cell as a block with one cell and the whole matrix as a block with the sum of all cells (clearly, this latter case is hypothetical). Instead of the more general formulation of the estimation method we give the case-specific derivation.
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Assuming independence between observed cells and blocks, the probability of observing the given O/D matrix may now be expressed as:

\[
L = \prod_{ijm} Pr(t_{ijm} | \hat{t}_{ijm}) \times \prod_{ilm} Pr(t_{ilm} | \hat{t}_{ilm})
\]

(5.25)

Note that the blocks and cells have to be independent, if they "overlap" each other in the matrix, the above formula for the likelihood does not apply. Substituting the observations in L an expression is obtained which, considered as a function of the $\hat{t}_{ijm}$ is called the likelihood function of the matrix for the given observations. The most likely values for the $\hat{t}_{ijm}$ are found by maximizing this function. Since the natural logarithm is a monotonic increasing function of its argument, maximizing the likelihood function is equivalent to maximizing the loglikelihood function:

\[
L^* = \ln(L)
\]

(5.26)

We now introduce the assumption that the values for $\hat{t}_{ijm}$ in the entire matrix can be expressed using the distribution model, as specified in formulas (5.20) to (5.22)

By classifying the distance values $d_{ijm}$ into an ordered range of $n_k$ intervals we can transform the deterrence function into a discrete function, see Kirby (1974). The values of $f(d_{ijm})$ are replaced by the deterrence factor $r_{km}$, when $d_{ijm}$ is in the $k$-th distance interval, and refers to mode $m$. Since both the variable $T$ pertains to the whole study area and the scaling of the model is arbitrary (i.e. the same flows can be obtained by multiplying the values of one of the variables by any number and dividing another again by the reciprocal value of this number), its value is not relevant to the estimation process. The gravity model then becomes:

\[
\hat{t}_{ijm} = p_i q_j r_{km}
\]

(5.27)

where

\[
r_{km} = g(d_{ijm}), d_{km}^{min} < d_{ijm} \leq d_{km}^{max}
\]

(5.28)

Substitution of (5.27) into the loglikelihood function (5.25) results in an expression for $L^*$, which is a function of $p_i$, $q_j$ and $r_{km}$. We find the maximum of the loglikelihood function by setting the first derivatives with respect to $p_i$, $q_j$ and $r_{km}$ to zero. This yields a set of $I + J + n_k n_m$ equations
that are solved for \( p_i, q_j \) and \( r_{km} \) using an iterative method. For the case of the multimodal versions of the distribution model for all \( i \), for all \( j \) and for all \( k \) the following equations are solved in turn\(^8\):

\[
\sum_{in \cdot col j} \frac{t_{ijm}}{p_i} - \sum_{j} \sum_{m} q_{j} \cdot r_{km} = \sum_{in \cdot row i} \sum_{m} \frac{t_{bm} \cdot \sum_{in \cdot col j} q_{j} \cdot r_{km}}{\sum_{in \cdot col j} p_{i} \cdot q_{j} \cdot r_{km}} - \sum_{in \cdot row i} q_{j} \cdot r_{km} = 0
\]

\[
\sum_{in \cdot col j} \frac{t_{ijm}}{q_j} - \sum_{i=1}^{n_i} \sum_{m=1}^{n_m} p_{i} \cdot r_{km} = \sum_{in \cdot col j} \sum_{i=1}^{n_i} \frac{t_{bm} \cdot \sum_{in \cdot col j} p_{i} \cdot r_{km}}{\sum_{in \cdot col j} p_{i} \cdot q_{j} \cdot r_{km}} - \sum_{in \cdot col j} p_{i} \cdot r_{km} = 0
\]

\[
\sum_{in \cdot row i} \frac{t_{ijm}}{r_{km}} - \sum_{j} \sum_{m} p_{i} \cdot q_{j} = \sum_{in \cdot row i} \sum_{j=1}^{n_j} \frac{t_{bm} \cdot \sum_{in \cdot row i} p_{i} \cdot q_{j}}{\sum_{in \cdot row i} p_{i} \cdot q_{j} \cdot r_{km}} - \sum_{in \cdot row i} p_{i} \cdot q_{j} = 0
\]

(5.29) (5.30) (5.31)

5.3.2 Implementation aspects

The values of \( p_i, q_j \) and \( r_k \) in formula (5.29-5.31) are determined using an iterative method. For each equation we first find values for \( p_i, q_j \) or \( r_k \), before continuing the iteration with the next equation. For solving the equations we used the van Wijngaarden-Dekker-Brent method (see e.g. Press et al., 1986) and an iterative fitting algorithm. The computer program has been tested extensively. In almost all cases the iteration process converged to a stable solution in up to 25 iteration steps.

In order to estimate the magnitude of the international barriers, instead of deriving the above formulas for the distribution model with barriers included, we followed a heuristic approach. Although more time-consuming in its execution, the method was relatively easy to implement. We repeated the computation several times, each time increasing the border resistances systematically, until convergence was reached of the likelihood function to the 1% level. Increasing the border resistance was done in steps of one distance class. The algorithm used is illustrated in figure 5.4 below.

\(^8\) The same equations result for the unimodal case, except that the locational variables \( p_i \) and \( q_j \) are modelspecific, i.e. written as \( p_{im} \) and \( q_{jm} \).
5. The multimodal distribution of freight flows

![Algorithm for estimating parameters of the gravity model]

Figure 5.4 Algorithm for estimating parameters of the gravity model

In figure 5.5, the curve showing the likelihood value during iteration of this algorithm. The 'jumps' in the curve indicate that additional border barriers are introduced. As shown above, the improvements in likelihood value become smaller with an increasing number of iterations.

![Likelihood function values during estimation]

Figure 5.5 Likelihood function values during estimation
5.4 Estimation of model parameters

5.4.1 Introduction

Having specified the model of the multimodal distribution of goods in Europe and having proposed an estimation method, we now turn towards the estimation of the model parameters. The estimation of the models has been performed in cooperation with Stada et al. (1991) for road transport and Veerman et al. (1995) for the simultaneous model with region specific access/egress costs. In the following we extend the work already published and give a more general treatment in terms of the multimodal characteristics of the European freight transportation system. We have described three alternative models, the form of which depends on the specification of costs of access and egress. We will treat them each in turn. First, the unimodal model is estimated for rail and inland waterways. Secondly, the performance of the multimodal distribution model is improved by introducing region specific access/egress costs. Thirdly, the estimated deterrence functions are given a new interpretation in terms of the generalized costs of transport.

5.4.2 Freight flows within the study area

We estimated interregional flows for the area of North-Western Europe, i.e. the Netherlands, Belgium, former West-Germany and France. The countries are subdivided into 52 regions, their size conforming to the NUTS-I classification (figure 5.6).

![Figure 5.6 Countries and regions within the study area](image-url)
5. The multimodal distribution of freight flows

The data concerned the movement of goods of all classes taken together, by the modes road, rail and inland waterways. Information on these freight movements is provided yearly to Eurostat by the national statistics offices. At the time the research was undertaken, the latest information available was for 1989. For the purpose of a general introduction, an outline is given below of the division of freight movements within the study area, as pictured in the Eurostat statistics. Table 5.1 shows the volume of flows within the study area for three types of relations, for three modes of transport. We distinguish intraregional flows (within the regions), interregional flows for national relations and international flows.

<table>
<thead>
<tr>
<th></th>
<th>intraregional</th>
<th>interregional domestic</th>
<th>international</th>
</tr>
</thead>
<tbody>
<tr>
<td>road</td>
<td>3698</td>
<td>975</td>
<td>166</td>
</tr>
<tr>
<td>railways</td>
<td>141</td>
<td>222</td>
<td>33</td>
</tr>
<tr>
<td>inland waterways</td>
<td>65</td>
<td>130</td>
<td>203</td>
</tr>
</tbody>
</table>

As we can see, road transport is strongly directed towards short distance relations. At the level of individual O-D relations, this pattern is even stronger. Intraregional flows by road are in general an order of two higher in magnitude than the interregional flows; this in contrast to rail and inland waterways. As, in addition to the unbalanced character of these specific flows, the analysis of within-region relations would require a specification of the system at a new level of detail (i.e. by viewing separate locations of individual forms and infrastructure of a lower order than the main transport networks) the intraregional flows were not retained in the estimation process. Also from an interregional perspective, however, the effect of distance on freight flows is clearly present. Figure 5.7 shows the relationship between the volumes moved by three modes and the distance of transport.

![Graph showing freight flows by distance](image)

Figure 5.7 Interregional, domestic flows for three modes by distance (source: Eurostat, 1991)

We can see that the total volume of freight moved decreases strongly with distance, while rail transport gains share in the higher distance segments. These modal shares are highlighted in figure
Estimation of model parameters

5.8 below. Note that these figures pertain to domestic transport only; adding the figures for international transport may change the modal split in favour of rail and inland waterways (observe in table 5.1 that inland waterways in particular is internationally oriented).

![Figure 5.8 Modal shares for interregional, domestic flows by distance (source: Eurostat, 1991)]

Figures 5.9 and 5.10 show the flows by mode at the domestic and the international level, respectively. At the domestic level, the role of rail and inland waterways is relatively modest. However, note the relatively high share of inland waterways and the minor role of rail transport in the Netherlands.

![Figure 5.9 Domestic interregional transport flows by mode (source: Eurostat, 1991)]

With respect to the production and attraction of different regions at the domestic level, we find that, looking at goods of all types at once, there is considerable symmetry between regional production and attraction, in particular for road transport flows. Figure 5.10 shows this relationship between in- and outbound flows of regions at the domestic level.
5. The multimodal distribution of freight flows

Figure 5.10 Symmetry in domestic production and attraction by mode (source: Eurostat, 1991)

Due to the specific nature of the available data, this relationship cannot be obtained from the international statistics. This notion of symmetry will assist us further in the interpretation of a number of results of the estimations. At the international level, the overall modal split is somewhat different, though the general patterns are analogous to the domestic level (figure 5.11). Rail and inland waterways are found to be particularly strong between countries where the internal shares of these modes are high as well.

Figure 5.11 International transport flows by mode (source: Eurostat, 1991)

Note that interregional origin/destination movements registered here do not necessarily match the trade relations, if a movement is connected to a transshipment or storage location, away from the location of purchase or sale\(^1\). As a consequence, (estimations with) transport data will not necessarily reveal pure trade patterns, but also other factors generating freight flows between areas, like warehousing and transshipment. It can be shown that under certain assumptions, the

\(^{1}\) Observations of trade relations are not available at this level of aggregation. Attempts to derive trade data from transshipment and transport statistics (see e.g. NEA, 1994, Zachcijal, 1992) have been limited to international and intercontinental flows, and without specifying new choice models from the perspective of transport chains. As our estimations have to be based on domestic flows, however, these studies are of limited interest in this case.
same gravity model applies to flows that depict trade and transport relations. As this is an issue connected to 1) data availability and 2) the generation of flows, we will not elaborate further on this matter\textsuperscript{2}.

As our aim is to estimate flows at individual O-D relations, it is necessary to check whether the variations in freight flows by different modes that are found at this high level of aggregation are comparable to the variations in flows at the level of individual O-D flows. Figures 5.12 shows the cumulative distribution of flow volumes by three modes at the level of individual O-D relations.

![Graph showing modal shares and flow volumes on domestic O-D relations](image)

\textbf{Figure 5.12 Distribution of modal shares and flow volumes on domestic O-D relations}

The graphs indicate that substantial variations can be found at the lowest level of aggregation as well. The volume of the flows as well as the shares vary widely for all modes of transport. Note that the number of O-D relations on which inland waterways transport is conducted is less than half of those for road and railways. This is not surprising, considering the low density of the network. From these charts we conclude that the three modes are represented adequately enough to include each of them in the estimation, and that the flows exhibit a fair amount of variation, in terms of their spatial characteristics and in terms of the modal split as well.

For all interregional relationships the distances between regions were approximated by the distances of the shortest routes between the regional capitals. The networks of the three modes of transport as specified in the ISG have been taken as the starting point for these distance calculations. The calculations were done using the standard all-or-nothing shortest path routine in the TransCAD package. For the estimations, the O-D relations were classified into distance bins

\textsuperscript{2} A discussion of the assumptions necessary to apply the gravity model to trade relations can be found in Appendix B.
5. The multimodal distribution of freight flows

of 75 km. width each. The tables specifying these distance classes and the O-D flows that were used for the estimations can be found in Appendix E.

5.4.3 Preliminary testing

The estimation method described in section 5.3 was tested by using the national transport data for the former West-Germany (see Stada and Tavasszy, 1991). The objective was to gain insight in the suitability of the estimation method and the distribution model for predicting the unknown cells in the partially aggregated matrix of interregional flows in Europe. Germany was chosen as a test-case as it covers 21 regions (almost half of the regions in the study area) and because of the large volumes moved within this country. The approach involved a simulation of the estimation problem of the 'incomplete' European matrix for the case of road transport within Germany and was carried out in the following way:

First, the flows $t_{ij}$ were estimated using the completely filled O-D matrix of freight flows in Germany. The distances between the regional capitals were classified into distance intervals of 75 km. wide. The estimation yielded a set of 21 row and 21 column parameters and 12 deterrence function parameters $p_i$, $q_j$ and $r_k$, respectively. Next, the estimations were repeated using a partially aggregated matrix. This partially aggregated matrix was built by subdividing Germany into a number of zones, each consisting of a number of regions (figure 5.13).

![Figure 5.13 Partially aggregated matrix for the test-case Germany. Grey squares denote interzonal flow totals as the sum of the respective interregional flows](image-url)
Estimation of model parameters

In this way we obtained a matrix, similar to the European one, where in addition to the interregional movements within zones (called 'single cell' flows in section 5.3) all movements between zones ('block' flows) were known. This aggregation procedure reduced the total number of observations within the matrix (cells and blocks) to almost one third of the original amount. Using this matrix with single cells and block cells, the flows $t_{ij}$ were estimated once again. The estimation yielded new values for the parameters listed above. In addition, estimates of the barriers between the artificial blocks were produced, together with values for the total flow volume in each of these blocks.

Below we compare the results of the two estimations. We will look at the estimated parameter values first and then examine the resulting flow volumes. Figure 14 shows a comparison of the parameters $p_i$, $q_j$ and $r_k$ for the two estimations. Recall that the scaling of the individual parameters is undetermined because of the multiplicative structure of the model. Therefore, we will only assess the similarity of the parameters up to an arbitrary constant. Despite the fact that the two sets of observations had only one third of the matrix in common, the values of the parameters $p_i$, $q_j$ and $r_k$ produced from the two separate estimations proved to be reasonably similar. Apparently the relation between distance and flow volume in terms of the variable $r_k$ is much less sensitive for changes in the O-D table than the region-specific parameters. The estimation results for row and column totals of the partially aggregate matrix were found to be comparable in quality to the results for the parameters $p_i$ and $q_j$.

![Figure 5.14 Comparison of parameters resulting from the partially aggregate matrix (PAM) and the full matrix estimation](image)

In figure 5.15 the observations for all cells in the matrix are compared with the results of the estimations based on the partially aggregated matrix as well as the full matrix.

On the whole, the patterns of the O/D matrix are reproduced well by the gravity model; however, a certain amount of variation at the relation level remains unexplained. Clearly, goods are heterogeneous in the sense of the logistical requirements and the physical characteristics of all the products. Further, as we assume production and consumption is centralized in a region, the classification of O-D relations with respect to distance is subject to errors with a magnitude related to the size of regions. As expected, the estimation results obtained by using the partially aggregated matrix show a slightly greater variation than those calculated by using the completely filled matrix.
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![Graph showing partial vs. full matrix estimations for Germany.](image)

*Figure 5.15 Partial vs. full matrix estimations for Germany*

In order to quantify this difference, we expressed the error between the observed O-D flows and the flows in the two estimated tables in terms of the root mean square error (RMSE) of the estimated cell values, where the RMSE was calculated as follows:

\[
RMSE = \sqrt{\frac{1}{n-1} \sum_{i} \sum_{j} (t_{ij} - \hat{t}_{ij})^2}
\]  

(5.29)

where

\( n \) = number of (interregional) O-D pairs in the matrix.
\( t_{ij} \) = observed flows in cells
\( \hat{t}_{ij} \) = calculated flows in cells

The RMSE of the estimated flows is in the same order of magnitude as the flows themselves. Further, we find that the RMSE of all cells in the matrix had grown by 60% after aggregation, whereas the RMSE of the O-D relations contained by the blocks in the matrix had doubled. As the single cells represented a relatively high share in the observations in the partially aggregate matrix estimation, the error of these single cells was somewhat lower than in the full matrix estimation.

**Table 5.2 Error measures for two test cases**

<table>
<thead>
<tr>
<th></th>
<th>RMSE (*1000 t.)</th>
<th>RMSE (*1000 t.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>full matrix estimation</td>
<td>PAM estimation</td>
</tr>
<tr>
<td>single cells</td>
<td>1257</td>
<td>979</td>
</tr>
<tr>
<td>block cells</td>
<td>1196</td>
<td>2344</td>
</tr>
<tr>
<td>total</td>
<td>1218</td>
<td>1963</td>
</tr>
</tbody>
</table>

90
Considering that this result was obtained after discarding almost two third of our observations, we regard the outcome as acceptable. Further evidence in favour of the applicability of the distribution model and the estimation method was obtained after comparing the estimated and "observed" zonal totals of our test case with the partially aggregated matrix. The total flow volumes between the different blocks in the matrix were reproduced almost exactly (figure 5.16).

Figure 5.16 Estimated vs. observed international block totals

As expected, no additional barriers between these blocks had to be introduced in order to equalise the calculated to the observed totals. Considering further the unresponsiveness of the model parameters for changes in the structure of the O-D matrix and the number of observations, we conclude that the estimation of a European O/D matrix based on a partly aggregated matrix of observations may produce results comparable to an estimation for a complete matrix.

5.4.4 Estimation for individual modes

In this subsection we present the results of the estimations of the model of the first type, the unimodal distribution model. The formulation of this model is reproduced here for convenience:

\[ \hat{t}_{jm} = \rho_m a_{jm} r_{km} \]

where

\[ r_{km} = g\left(d_{jm}\right), \quad d_{jm}^{\text{min}} < d_{jm} \leq d_{jm}^{\text{max}} \]

and

\[ d_{jm} = d_{jm}^M + \delta/d_{jm}^{B} \]

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5. The multimodal distribution of freight flows

The objective is to estimate the unknown parameters \( p_{im}, q_{jm}, x_{km}, d_{im}^\theta \) for different modes of transport using the respective O-D tables and network distance data. Together with a short description of the infrastructure networks, the estimation results are presented below for each of the different modes.

5.4.4.1 Road transport

Figure 5.17 shows the road network in the four core-countries. We can observe that the density of this main network is rather similar throughout all regions, with the highest density in the Benelux/Ruhr area, followed by the rest of former Western Germany and France.

![Figure 5.17 Road network](image)

Figure 5.18 shows a comparison of estimated and observed cell values for the European regions. A logarithmic scale has been chosen to accommodate both high and low tonnage values for all the domestic, interregional relations.

![Figure 5.18 Estimated and observed domestic flows by road \((R^2=0.81)\)](image)
It appears that the patterns of observed and calculated flows are well correlated. The variation that remains at the level of individual O/D relations, indicates that it is preferable to retain the observed O/D values in domestic transport for practical purposes. For international relations, the calculated O/D values present the best possible estimates for our case, that match the observed totals.

Figure 5.19 shows the estimated deterrence function. In order to facilitate its interpretation, the function was normalized to a value of 1 for the first distance class, and plotted on a logarithmic scale.

![Deterrence function for road transport](image)

*Figure 5.19 Deterrence function for road transport*

The estimated border barriers for road transport are shown in table 5.3 below.

<table>
<thead>
<tr>
<th>from</th>
<th>NL</th>
<th>F</th>
<th>D</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>NL</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>F</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>B</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 5.3 Border barriers for road (distance classes 75 km.)

where NL = the Netherlands, D = Germany, B = Belgium, F = France

It appears that the additional cost for international commodity flows between two countries is equivalent to 2 to 4 distance classes. Note that the values for the resistance are equal for both directions on a relation. This is not surprising if we consider that freight flows at the domestic as well as at the international level are, to a certain degree, symmetrical (see figure 5.10). Note also

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3 Although it might be argued that in some cases model outcomes may give a more truthful representation of events in the real world than the observations we used, due to different sources of uncertainty along the process of surveying, statistical analysis and data-processing.

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that the border barrier between the Netherlands and Belgium is smaller than the barriers between other countries. This might be explained on the one hand by the longstanding cooperation between these countries within the framework of the Benelux union, and on the other hand by the relatively small differences in language and culture.

5.4.4.2 Railways

The network that was used for calculating transport distances for the railways is shown in figure 5.20. The network is again polycentric, with density building up towards Paris, the south of Germany, and the Benelux countries. The majority of lines run north-south.

![Figure 5.20 Rail network](image)

Figure 5.20 Rail network

Figure 5.21 shows a comparison between observed and estimated cell values for rail transport.

![Figure 5.21 Estimated and observed flows by rail ($R^2=0.79$)](image)
The correlation is somewhat lower; the general patterns are represented, however, over the entire scale of four orders of magnitude. The deterrence function, as can be observed in figure 5.22, again has an exponential shape.

![Graph showing deterrence function value against distance (km)](image)

*Figure 5.22 Estimated deterrence function for railways*

For the border barriers, we find a pattern which is different from that in road transport; although values are higher in general (table 5.4).

<table>
<thead>
<tr>
<th></th>
<th>to</th>
<th>NL</th>
<th>F</th>
<th>D</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>from</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NL</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>8</td>
<td>5</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>8</td>
<td>5</td>
<td></td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 5.4 Border barriers rail (75 km.classes)*

This might be explained by the considerable magnitude of physical barriers between countries (e.g., differences in voltage of electrical systems). Note the symmetry in the table for the Belgium, France and Germany. Apparently it is more difficult to acquire goods for the railways when flows are directed towards the Netherlands. However, flows directed away from the Netherlands seem to fit nicely into the pattern of domestic flows throughout Europe; border barriers are relatively low here.

5.4.4.3 Inland waterways

The inland waterways network is the least dense of the three. There are large dissimilarities between the accessibility of individual regions, not only as a result of the density of the network, but also due to the limited capacity of individual links. In the ISG, the waterways that were
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modelled concerned the ECMT\textsuperscript{4}-waterways classes II to V, corresponding to a waterway capacity of at least 400 deadweight tonnes. Figure 5.23 shows this network of main waterways in the four countries under study\textsuperscript{5}.

![Waterways network](image)

\textit{Figure 5.23 Waterways network}

The estimated and observed domestic flows are compared in figure 5.24. Despite the relatively low accuracy that is obtained for small flows (in the order of magnitude of one thousand tonnes per year), the overall fit is better than in the case of road transport.

![Estimated and observed flows](image)

\textit{Figure 5.24 Estimated and observed flows by waterways ($R^2=0.86$)}

\textsuperscript{4} The European Conference of Ministers of Transport established an inland waterways network classification system in 1961. Since 1993, a modified version of this network is in use. For more details, see NEA, 1994b.

\textsuperscript{5} Where necessary, such as in the north of France, the network was adapted to contain waterway classes for small ships as well.
The estimated deterrence function (figure 5.25) shows that it is only after about 300 km that an increase in distance affects the intensity of flows. Apparently, a certain segment of the market involves movements on relatively short distances, and is relatively insensitive to the marginal transport costs.

![Figure 5.25 Estimated deterrence function - inland waterways](image)

The border barriers for waterways (table 5.5) seem to be absent on most relations.

<table>
<thead>
<tr>
<th></th>
<th>to</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>from</td>
<td>NL</td>
<td>F</td>
<td>D</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>NL</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

This is not surprising as in general inland waterways transport has depended on movement over relatively long distances; several agreements on free shipping of the 19th. century between these countries illustrate this dependence. Domestic markets are in general regulated through the "tour de rôle" (Netherlands, Belgium, France) or tariff systems (Germany). A "tour de rôle" system exists between France and the Benelux countries as well; however, this system applies only to outward movements from France (de Wit & van Gent, 1986); perhaps explaining the asymmetry found in the table on France’s external relations.

---

6 These are the Mannheim Act (1868) concerning traffic on the Rhine, the "Scheldestatuut" (1839) and the "Maasreglement" (1815) concerning traffic between the Netherlands, Belgium and France. As these agreements do not concern German-French relations, this might explain the additional resistance found between these countries.

7 The "tour de rôle" system involves the regulation of agreements between shippers and carriers, by assigning freight to be moved to available carriers turn by turn.
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5.4.5 Simultaneous estimation for road, rail and inland waterways

Although the results for the unimodal version of the model are promising, the production and attraction factors in this model are not mode-independent, limiting its use for policy scenarios involving changes in model split. The estimated regional coefficients relate to both region-specific attributes and the mode-specific access and egress costs. The multimodal distribution model enables separate quantification of these factors. Different versions of this model account for differences between regional access/egress costs, depending on related assumptions.

Depending on the assumption regarding differences between regional access/egress costs, Recall that in the first alternative we assumed that access and egress costs were similar for each region, but different for the network of each mode of transport. The formulation of this model was as follows:

\[ \hat{i}_{jm} = p_j q_j r_{km} \]

where

\[ r_{km} = g(d_{jm}), d_{km}^{min} < d_{km} \leq d_{km}^{max} \]

and

\[ d_{jm} = d_{jm}^{m} + 2a_{jm}^{c} + \delta_{jm}^{a} d_{jm}^{p} \]

The second alternative concerned mode-specific access and egress costs. However, in order to distinguish this alternative from the unimodal model, we assumed that for each mode/region combination, access and egress costs were the same (i.e. the resistance for connecting to the main network is indifferent to the direction of transport). Thus, we extended the specification of transport costs. The formulation of this model is:

\[ \hat{i}_{jm}^{**} = p_j q_j r_{km} \]

where

\[ r_{km} = g(d_{jm}), d_{km}^{min} < d_{km} \leq d_{km}^{max} \]

and

\[ d_{jm} = d_{jm}^{m} + d_{jm}^{c} + d_{jm}^{p} + \delta_{jm}^{a} d_{jm}^{p} \]

In the next two sections, we present the results for each model. In these estimations, the border barriers that were estimated in the unimodal modal were retained. We first discuss the estimation results that are obtained if one assumes constant access/egress costs across all regions.

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5.4.5.1 Region generic access/egress costs

Figures 5.26 shows the estimated versus the observed values for road transport flows on the domestic O-D relations.

![Figure 5.26 Estimated and observed domestic flows by road ($R^2=0.75$)](image)

The correlation between observed and estimated values is somewhat lower than in the unimodal case; however, the model reproduces the general patterns of the observed flows. For rail transport the observations are not reproduced sufficiently (figure 5.27).

![Figure 5.27 Estimated and observed domestic flows by rail ($R^2=0.30$)](image)
5. The multimodal distribution of freight flows

In the case of inland waterways (figure 5.28), we have the same systematic deviation between estimated and observed cell values.

![Figure 5.28 Estimated and observed domestic flows for inland waterways (R²=0.35)](image)

Note that this effect cannot be avoided using a non-linear cost function. The effect of a change of classes on the estimated volumes can be absorbed by a different deterrence function, similarly as in the case of the estimation of the cost function parameters. The figures tells us that transport flows are systematically overestimated in the lower volume range, while underestimated in the higher ranges. This effect is related to the assumption of region generic resistances. The effect of an average resistance for all regions is that regions with a relatively low accessibility will still have too strong interactions with other regions (and, of course, similarly for the opposite case).

In summary, this model has a limited capacity for describing freight transport flows. The large differences with the results of the unimodal models may not be surprising, if we consider that the number of variables has been reduced to one third. Firstly, the fit is not as good as in the case of sequential estimation (with coefficients of determination of of 0.75, 0.30 and 0.35 for road, rail and waterways, respectively). Secondly, we note that the volumes are reproduced best in the higher ranges; in the lower range, only road transport is estimated to a degree of accuracy which is similar to the unimodal case. We conclude that the model gives structural deviations of the type that can be avoided by using access and egress costs.

5.4.5.2 Region specific access/egress costs

The second alternative specification involves the same parameters to be estimated as the previous model, with an additional set of access/egress cost variables $d^G_{im}$ and $d^G_{jm}$ to be estimated. The goodness-of-fit of this model was somewhat higher than the previous model, but not as high as in
the unimodal case (this will be discussed in more detail later). Similarly as in the previous case, we took the same border barriers as estimated in the most complete model, i.e. with independent modes, instead of estimating them again. Figure 5.29 to 5.31 show the estimated flows for the different modes of transport.

**Figure 5.29** Observed and calculated domestic flows by road \((R^2=0.79)\)

**Figure 5.30** Observed and calculated domestic flows by rail \((R^2=0.63)\)

For waterways transport (figure 5.31), there is still an array of relations, especially in the lower intensity relations, which is either under- or overestimated. Apparently, the group of commodities moved by inland waterways is too heterogeneous to be characterized by one single access/egress variable. Beside the availability of infrastructural connections of firms within the region to the main network, the access and egress costs also necessitate arrangements for the preparation of
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shipments for transport which differ by mode, like packing and conditioning of goods. If the group of goods treated in the estimation is heterogeneous in terms of these characteristics, a single region-specific variable per mode will be inadequate.

Figure 5.31 Observed and calculated domestic flows by inland waterways ($R^2=0.82$)

Figure 5.32 compares the observed and estimated international flows. Despite using the border barriers that were estimated in the unimodal version of the model, the international totals are explained well, particularly in the higher ranges.

Figure 5.32 Observed and calculated volume of international transport
Estimation of model parameters

Summarizing the estimation results, we find that this model performs comparably with the unimodal model and considerably better than the multimodal model with region generic access/egress costs. Table 5.6 lists the correlation values between estimated and the observed O/D flows are listed for the three models.

<table>
<thead>
<tr>
<th>Table 5.6 Coefficients of determination ($R^2$) for O/D flows</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>road</td>
</tr>
<tr>
<td>rail</td>
</tr>
<tr>
<td>inland waterways</td>
</tr>
</tbody>
</table>

where  
UM = unimodal model;  
MM-1 = multimodal model, region generic costs,  
MM-2 = multimodal model, region specific costs

In all three models the representation of rail flows is the least accurate; this may be explained by the crude representation of network resistances (routing and pricing are based on line schedules which were not modelled as such). Although the multimodal model performs worse than its unimodal counterpart, the former operates within an explicit multimodal framework. Among the multimodal models, the model with region-specific access/egress costs

- gives a better description of the observed O/D flows,
- eliminates the systematic bias that is found using region generic costs, and
- provides insight into the access/egress costs of regions.

Among the three models, we thus prefer the multimodal distribution model for evaluating changes in balance between transport modes. If changes in modal split are not an issue, we prefer the unimodal model because it gives somewhat better predictions of the observed domestic O-D flows. The choice of which model to apply thus depends on the specific issues that are treated.

Deterrence functions and the value of transport time

Earlier in this chapter, we have shown that appropriately interpreting the shape of the estimated deterrence functions indicates how modes differ in their sensitivity for distance. Assuming that goods moved by different modes are equally sensitive to the generalized costs of transport, we derived a straightforward formulation for the relationship between values of time of goods carried by different modes (see appendix D). Below we give the resulting interpretation of the deterrence functions for our current case.
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The deterrence functions estimated with the multimodal model with region-specific access/egress costs are shown below in figure 5.33. The smooth shape of the function indicates that the use of a continuous deterrence function would be appropriate for this model\(^8\).

![Figure 5.33 Deterrence functions as estimated in the multimodal approach](image)

The deterrence functions of the different modes were approximated by an exponential function with two parameters. The transport rates and speeds for different modes were assumed to be similar to those specified in the ISG. We chose the deterrence function of road transport as a yardstick for the calculation of the value of time relationships, assuming the access and egress costs of road to equal zero. The relationships between the values-of-time of goods moved by road, rail and inland waterways were estimated as follows\(^9\):

<table>
<thead>
<tr>
<th>mode</th>
<th>value of time</th>
</tr>
</thead>
<tbody>
<tr>
<td>road</td>
<td>(\alpha_{rd})</td>
</tr>
<tr>
<td>rail</td>
<td>(0.30\alpha_{rd} + 0.04)</td>
</tr>
<tr>
<td>inland waterways</td>
<td>(0.04\alpha_{rd} + 0.12)</td>
</tr>
</tbody>
</table>

\(^8\) Two functional forms suggested frequently in the literature (see e.g Fotheringham and O’Kelly (1989), Hamerslag (1994) or Willumsen and Ortuzar (1994)) are the exponential function \(F(x) = a \exp(bx)\) and the power function \(F(x) = ax^b\), where \(a\) and \(b\) are the parameters in these functions to be estimated. A tentative test of these two functional forms indicates that the exponential form gives an excellent fit (\(R^2=0.97\)) as opposed to the power form (\(R^2=0.70\)).

\(^9\) Assuming an exponential shape of the deterrence function, and rates and transport speeds as specified in the ISG.
The table indicates that goods carried by road transport have the highest value-of-time, followed by rail and inland waterways. We expected this result was expected, as road transport is the costliest and fastest mode of the three; on the other end of the cost/time scale is the inland waterways mode, at low costs and low speed. Rail transport fits in between both in terms of rates as well as transport times.

These relationships are close to those found in earlier studies concerning the value of time of freight transport. Within a different modelling context, HCG (1992) gave indications of values of time for the Netherlands. The values of time resulting from our estimations were compared with these results as index values (choosing $\alpha_{vt} = 1$, see table 5.8). The results match remarkably well, considering that the context of the choices reviewed in these studies differs greatly.\(^{10}\)

**Table 5.8 Comparison of value of time indices (index of $\alpha_{vt} = 1$; absolute value Hfl. 4.74 /h/ton)**

<table>
<thead>
<tr>
<th>mode</th>
<th>Dutch VOT study</th>
<th>this study</th>
</tr>
</thead>
<tbody>
<tr>
<td>road</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>rail</td>
<td>0.26</td>
<td>0.30</td>
</tr>
<tr>
<td>inland waterways</td>
<td>0.06</td>
<td>0.06</td>
</tr>
</tbody>
</table>

See figure 5.34, below, for the deterrence functions for the three modes, after the above transformation. For illustrative purposes, we calculated the generalized costs of transport (along the horizontal axis) under the assumption that the value of time for road equals f. 5.-/h./ton.

![Deterrence functions of the three modes, $\alpha_{vt}=f. 5.-/h/ton$](image)

Note again that the deterrent effect of generalized costs on the intensity of interactions compares well for the three modes, almost along the whole domain of transport costs. This indicates a clear pattern in the spatial behaviour of decision makers, namely that the elasticity of the intensity of

\(^{10}\) the estimates of HCG (1992) based on a stated preference approach, within a unimodal context, and without considering the distribution of goods
spatial interactions with respect to costs is constant if transport costs are modeled using a straightforward measure for the generalized costs of transport.

**Regional access and egress costs**

Below we show the region-specific access and egress costs as they were approximated by distances for rail and inland waterways transport. Figure 5.35 shows the additional distance classes for rail transport, for the European regions. The darker the shade of the individual regions' colour, the higher these region-specific resistances are.

We can see that there are only a few regions that have a high resistance; these are situated mainly in the Netherlands. Note that the ports of Antwerpen, Rotterdam and Hamburg are the only regions within their surrounding area with relatively good rail connections.

![Regional access/egress resistances in connection with the rail network](image)

**Figure 5.35 Regional access/egress resistances in connection with the rail network**

Figure 5.36 depicts the regional access/egress resistances for the inland waterways network. Again, the darker the shade of the individual regions' colour, the lower these region-specific resistances. As expected, the regions with small interregional access/egress resistance can be found around the major waterways. For example, we can recognize the Rhine- and East-West corridors; the connections of the South-Eastern part of Germany with the other German regions had not yet been established (the Rain-Main Danube Canal) in the base year of the observations.
Moderate to good waterway connections are found along the North-South corridor (the Netherlands, Belgium, and France).

![Map of regional access/egress resistances in connection with the inland waterways network](image)

**Figure 5.36** Regional access/egress resistances in connection with the inland waterways network

### 5.4.6 Discussion

In this section we have shown that through a simultaneous estimation of the distribution model for multiple modes, the existing patterns in freight transport in Europe can be reproduced. In addition, the estimations provide new insight into international barriers for trade and transportation, the relationship between the distance sensitivity of different modes and, finally, in the region-specific accessibility of regions.

Despite the geographical extent of the area, and the heterogeneity of the commodities concerned, the model explains the observed flows with high values for the coefficients of determination. The unexplained variation remaining is high enough, however, to discourage the use of the estimated volumes at the level of individual relations. To apply the model we recommend using the observed values for domestic transport as a basis for the development of scenarios. One can then use the model for calculating growth factors for individual relations, to be applied to the matrix of real observations. As we have no knowledge of the cross-border interregional flows, the estimates given are the next-best alternative to observations.
5. The multimodal distribution of freight flows

With respect to the existing barriers, we find considerable differences between transport modes. In road transport, we find barriers that have an effect on distribution which is equivalent to 150 to 300 km. We can observe what is probably the result of five decades of the Benelux Union; between the Netherlands and Belgium, these barriers are relatively low. In rail transport, barriers can reach an equivalent distance of 600 km; the general symmetry that is found for road transport is found again, except for relations to and from the Netherlands. In inland waterways transport, international barriers are of minor importance with relations to and from France as the exception, with barriers up to 225 km.

The estimated barriers only provide a static, or cross-sectional picture of the state of European trade and transport in the late 1980's. Therefore, it is difficult to extend these results into the future in an attempt to forecast the development of these barriers. However, some of the findings regarding the Benelux Union may guide the specification of scenarios. Firstly, the magnitude of the barriers between the Netherlands and Belgium may provide us with a tentative indication of a "feasible" magnitude for barriers. Secondly, the fact that the Benelux agreement has been in place for already exists half a century may indicate the timeframe within which we may expect changes in the present border barriers as a result of the European Integration, along with any redistribution effects.

In the conventional version of the multimodal gravity model, it is assumed that access and egress costs are similar for all regions studied. With the proposed model incorporating region-specific access/egress costs, we can investigate the effects of an improvement of the regional accessibility on the distribution of goods flows. The findings show, as expected, that these resistances are in general higher for inland waterways than for rail transport. Further, the access/egress costs for rail have been found to be relatively low at the major ports in the study area. Interestingly, some Dutch regions have a resistance for connecting to the rail network that is considerably higher than for inland waterways, and, moreover, higher than the regional resistances for rail in all other regions that were studied.

The estimations show that the effect of distance on the intensity of goods flows, as given by the deterrence function, is strongly related to the mode of transport. The smooth shape of the functions, throughout all distance classes, shows that using a continuous deterrence function for the demand model would be appropriate. In addition, from the linear shape of each of the functions (as plotted on a logarithmic scale) we may draw the conclusion that the assumed exponential effect of costs (approximated by distance, here) on transport flows is supported by the calculations. We have shown that we can interpret the differences between deterrence functions as differences in the cost functions. We found that a simple linear relationship between the mean values of time of goods moved by different modes is adequate to relate the estimated deterrence functions. This indicates that the deterrent effect of transport costs on the distribution of goods can be modelled independently from the mode of transport.
5.5 A projection of freight flows without barriers

5.5.1 Introduction

The estimations of the distribution model showed that international transport is strongly overestimated relative to observed international flows, if no additional resistance is introduced. In order to obtain a satisfactory agreement between estimated and observed border flows, we introduced international barriers in the distribution model. Having established the magnitude of these barriers at present (i.e. in the base year of the observations, 1989), the following question becomes relevant: in what way will decreasing border resistances affect freight transport flows within Europe?

In general, it is expected that international transport will continue to grow at a higher rate than domestic transport (see e.g. CPB, 1989; ECMT, 1995). The data on flows within the area of our case study appear to support these expectations (figure 5.37).

![Index of freight flows](image)

**Figure 5.37 Index of international and domestic freight flows for the study area (source: Eurostat, 1991)**

Although international transport flow volumes are but a fraction of the total flows in the area (close to 4% in 1970 against 6% in 1989), the impacts of its growth will be felt in two ways:

- Changes in transport flow patterns: apart from the system level, the amount of freight moved is also subject to change on individual O/D relations. These changes in flow patterns are important for the long term planning of the infrastructure networks. By assigning the calculated flows to the infrastructure network, we can make an assessment of the areas where these changing patterns will accumulate in network flow changes. In addition to transportation
issues, changes in flow patterns might also be useful for regional development policy, e.g. to establish which regions will benefit most from a possible redistribution of goods exchanges.

- Changes in transport performance: as average transport distances will grow along with the share of international transport, the performance of freight transport (in terms of ton-kilometers) will increase more than proportionally. This measure is useful to establish the internal (production) and external effects (economical and environmental) of transportation. Not only can we establish the system-wide consequences of decreasing border barriers, we will also be able to relate the share of different trade relations to the increased performance of freight transport.

In this chapter we use the multimodal distribution model to investigate three scenarios for the reaction of freight transport demand on the complete abolition of border barriers. The main objective of this application is to provide an illustration of the sensitivity of the freight transportation system for the border barriers identified. More specifically, we intend to demonstrate that assumptions regarding the reactions of individual companies on decreasing border barriers are important to evaluate future freight flows. The investigations do not concern "forecasts" in the sense that we attempt to identify some future state of the system. Instead, this study comprises a projection of how the freight patterns would be at present had there been no border barriers.

Therefore, although the complete abolition of these barriers is somewhat unrealistic (having found that even between Belgium and the Netherlands, border barriers still exist), this assumption suffices to indicate the spatial characteristics of changes in freight flows. Our main concern will be to pinpoint the locations and directions of major changes in freight transport flows that may occur in the future. In addition, note that the scenarios we generate here will only partially account for possible developments in European freight flows. They do not take into consideration global economic developments other than those resulting from the realization of the Internal Market.

In order to forecast changes in freight flows as an effect of decreasing border resistances, we can distinguish between the different levels at which decision makers in the freight transportation system can react to increasing opportunities for foreign trade and transport. On the one hand we can be expect, in addition to the existing trade relations, new markets will open up, because companies will increase activity due to cost benefits. One would expect total freight transport in Europe to grow as an effect of an increasing international orientation of commerce and industry. In this case the alternative use for resources no longer tied up by international barriers is directed entirely at new production and consumption. On the other hand, as international trade becomes easier, existing trade relations on a national level will to a certain degree be replaced by foreign trade relations. This implies a re-distribution of flows over O-D relations, and possibly modes of transport. The benefits that the system attains from lowering its internal barriers is now reflected at the level of distribution of flows only, the newly released resources are absorbed by the regional prices of goods, to the extent that no new interactions are generated. Possible changes in the balance among transport modes, however, will also depend on the ability of different agents in the freight transportation system to reorganize their services, equipment, production processes and so
on. Finally, at the level of transport operations, the carriers of individual modes can react to changes in the costs, time and effort to realize an international movement; these changes will concern the assignment of loading units, vehicles and drivers to goods. As discussed, however, these latter decisions in essence consider the short term and fall outside the scope of this thesis. We will concentrate on the distribution level, with a tentative analysis of possible consequences for the generation of goods.

How companies will react to decreasing border barriers result in different contrasting scenarios for the future development of freight flows. The common assumption is that the increasing opportunities will cause existing distribution patterns at the international level to slowly approach the patterns which can now only be observed within the individual countries. In summary, we present the following scenarios for analysing changes in European freight flows:

- The first concerns an unconstrained growth of transport; we will call this the "generation" scenario. It assumes elastic regional production and attraction, and hence the generation of new freight flows.
- The second comprises spatial substitution of the present flows under the assumption that the modal split remains the same at the regional level. We call this case the "substitution" scenario.
- The third scenario also concerns a spatial redistribution; in addition, however, we allow for a shift between modes to take place at the origins and destinations. We call this scenario "multimodal substitution".

Having identified these mechanisms for analysing the effect of disappearing border barriers, we now will describe the way in which the model will be used.

**Generation**

In order to determine the international commodity flows in the generation scenario, we applied the model that was estimated in the previous sections, while ignoring the role of the estimated border barriers in the deterrence function. The effect of this straightforward calculation is that domestic flows remain as estimated, while the growth in the international flows is determined by the regional coefficients in the model and the physical network resistance between regions, as described by the networks of the different modes.

**Substitution**

The main idea behind the redistribution of freight flows can be translated relatively easily into the general methodology adopted here. If the total volume of goods transported does not change, and we assume that the needs of each region remain unaltered, the condition which has to be satisfied by the estimation method is that the freight volumes entering and leaving each region remain
5. The multimodal distribution of freight flows

constant and equal to the values presently observed. This condition adds two constraints to the gravity model, pertaining to the regional production and attraction of regions:

\[ \sum_j \hat{t}_{jm} = S_{im, \text{base year}} \]  \\
\[ \sum_i \hat{t}_{jm} = D_{jm, \text{base year}} \]  

(5.32)

Multimodal substitution

In the case of a multimodal redistribution of flows, the \( m \) suffix is dropped, implying that the modal markets are no longer separated.

\[ \sum_j \sum_m \hat{t}_{jm} = S_{i, \text{base year}} \]  

(5.32)

\[ \sum_i \sum_m \hat{t}_{jm} = D_{j, \text{base year}} \]

For both substitution scenarios we use a Furness algorithm to estimate the parameters of the gravity model. Kirby (1979) has shown that a Furness algorithm, an iterative scaling of the regional parameters, is consistent with the maximum-likelihood estimation method for the parameters of the gravity model as discussed in section 3. As the execution of this algorithm also requires observations of the trip-length distribution for the study area (which of course are not available for the future), we assume that the deterrence function, found in the estimation for the base year, would remain valid in the future.

The following sections describe the results for each of these scenarios. First we look at the changes occurring at the level of the whole area, i.e., without treating the spatial element in the analysis. Later, we will focus on international relations. For convenience, in the following, the names of the scenarios substitution, multimodal substitution and generation are abbreviated as S, MS and G, respectively.

5.5.2 Outline of the results

A first overview of results for the three scenarios shows that international flows may change considerably in each of the scenarios; in the case of an unconstrained development they grow to about three times their magnitude of the base year.
Figure 5.38 International transport flows in three scenarios

In the case of a spatial redistribution, international transport, by definition, grows at the cost of domestic transport. We can see that the share of road and rail transport increase further. In terms of total international flow within the study area, the two scenarios with constrained demand do not yield very different results; it is mainly road and rail that accommodate the growth in international flows.

Figure 39 shows the flows at the domestic level at present and in the three hypothetical cases. At the domestic level as expected the flows decrease 20-40%, relative to the baseyear flows. The decrease can be attributed almost entirely to road transport. Flows decrease overall in the substitution scenario and, by definition, remain unchanged in the generation scenario. Apparently, at this level, there is little difference between the two substitution scenarios. Rail increases its share slightly when modal substitution is allowed. In the case of a totally unconstrained development of transport, the changes are only determined by the deterrence factors for international relations, in contrast to the cases where substitution effects are assumed. As the change in border barriers only affects the deterrence factors pertaining to international relations, the domestic flows within the area remain the same.

Figure 5.39 Domestic transport flows in three scenarios
5. The multimodal distribution of freight flows

In the following sections, we examine the different scenarios in more detail. In particular, we will look for changes in the balance of international relations.

5.5.3 International freight flows

The results for international transport flows are given in figure 5.40 to 5.44. Figure 5.40 shows the international flows for all modes together.

![Figure 5.40 International transport flows, all modes](image)

The graph indicates a large growth potential for freight transport by road; in the generation scenario, total flows triple on some relations. Note that the extent of growth is not proportional to the present magnitude of the flows; as can be expected when barriers are taken away. The effect on total freight flows is still considerable in the substitution scenarios; a growth potential for international transport appears to exist up of about 250% at the cost of national transport. In the new configuration, however, some relations do not profit from spatial redistribution (the Netherlands and Belgium for example). There appears to be little difference between the S and MS scenario, in terms of spatial redistribution. Figure 5.41 shows the performance of freight transport, again for all modes, measured in tonkilometers.

![Figure 5.41 International transport performance, all modes](image)
A projection of freight flows without barriers

At first sight, the development of the performance of transport mirrors that of transport flows. A closer comparison of the flows with figure 4, however, reveals that average transport distances are also subject to change. For example, between France and Germany, average transport distance increases strongly. On the other hand, transport distances between France and Belgium appear to decrease. When we break down these results by mode, we can observe the relations where, from a spatial perspective, a high potential is present for changes in the modal balance of flows. We first show the results for each mode (figure 5.42 to 5.44) and then give a summary and interpretation of the main findings.

Note that the scales of the charts are different. Recall our earlier finding, that the question of modal substitution was only marginally relevant to the spatial distribution of total flows. Here we see that the modal substitution scenario results in an increased share for road and in particular rail transport. If we compare these charts with the scenarios without a modal shift on the regional level, we see that the main difference concerns the flows between Germany and the Netherlands and between Germany and France.

**Figure 5.42 International transport flows by road**

**Figure 5.43 International transport flows by rail**
5. The multimodal distribution of freight flows

Figure 5.44 International transport flows by inland waterways

In the following section, we assign the calculated O/D flows to their respective networks, to obtain more insight into the intensity on the transport network. Here we will specify a straightforward route choice model, that will allow us to relate the origin-destination flows to the individual link sections.

5.5.4 Network flows

As flows between regions are "rearranged" due to changes in border barriers, flows of freight on networks react. We indicate this reaction by means of an assignment of O-D flows, using a model of route choice. For the the three scenarios, the projected O-D flows were assigned to the network of main transport axes in the study area and compared with the assignment results of the base year O-D estimation. As our objective here was to provide a tentative illustration of possible consequences for network flows, the approach towards assigning the freight flows to the network has been rather straightforward. The shortest routes in the network were obtained using the stochasting loading procedure in the standard TransCAD toolkit (see Caliper, 1988). The choice among competing routes was based on travel time considerations, with a minor random variation in these travel times, according to the random costs model introduced in chapter 3. We made no attempt to calibrate the assignment model to any observation of traffic flows. A more accurate estimation of link loads would require the additional development of the necessary traffic conversion models.

Figure 5.45 and 5.46 show the road network in the study area with the flows in the base year and the additional flows that would result in the generation scenario. We added the link loads in both directions to obtain an aggregate measure of change. The intensity of flows is shown by a varying width of the respective link. The scaling of the flows was kept as low as possible to depict even relatively small changes in flows, making sure, however, that individual links could be still distinguished.
Changes concentrate around the point where the Netherlands, Belgium and Germany join borders. Growth rates for these link flows can exceed in some instances 180%. Note that this is less than the maximal growth rates found at the level of O-D relations. Apparently, the spatial layout of these relations and the topology of the network are such that these extreme changes level out.

Figure 5.45 Baseyear flows - road

Figure 5.46 Change in flows - road (G)
5. The multimodal distribution of freight flows

The flows in the scenarios concerning spatial and modal substitution are pictured below in figure 5.47 and 5.48. Traffic flows grow by as much as 80% of their present volume. Note that the geographical scope of the changes in the multimodal substitution scenario is somewhat narrower. As we will see further on, rail and inland waterways increase their share in these areas.

Figure 5.47 Change in flows - road (S)

Figure 5.48 Change in flows - road (MS)
The following two figures show the assignment results for rail transport. Figure 5.49 shows the absolute flow levels in the base year situation; figure 5.50 shows the growth-effect of the generation scenario. Note that flow volumes are low relative to road transport. In the generation scenario changes are in the same order of magnitude as the flows themselves, with growth up to 230%. Note that growth in the northern area is absent, in contrast to freight moved by road.

**Figure 5.49** Baseyear flows - rail

**Figure 5.50** Change in flows - rail (G)
5. The multimodal distribution of freight flows

In the substitution scenarios (figures 5.51, 5.52) the growth in link flows concentrate on the Belgium-Germany-France triangle. In peripheral areas we observe a minor decline of flows (not shown in these figures).

Figure 5.51 Change in flows - rail (S)

Figure 5.52 Change in flows - rail (MS)
The base year flows by inland waterways shown in figure 5.53 reveal that the usage of the network is limited to the just a few links. In the generation scenario (figure 5.54) we can observe relatively small changes on relationships which at present are connected through lower order links (ECMT class II). Despite the relatively low speed, we have assumed limitless capacity and thus these links have potential for growth.

Figure 5.53 Baseyear flows - waterways

Figure 5.54 Change in flows - waterways (Q)
5. The multimodal distribution of freight flows

In the scenario involving spatial or modal substitution of flows (figures 5.55, 5.56), waterways in the peripheral regions profit only from the decrease in barriers if an opportunity for modal substitution is given by the available infrastructure.

Figure 5.55 Changes in flows - intr. wways (S)

Figure 5.56 Change in flows - wways, (MS)
Note also that inland waterways in the Netherlands may loose some of their share to rail, and particularly road transport (see also section 5.5.3). As expected, the waterways connecting to France offer the main potential for growth when barriers disappear.

5.5.5 Regional generation

The generation scenario also shows the effect of decreasing border barriers on regional growth. Recall that the growth of regions was calculated by assuming that the benefits obtained from the disappearing barriers would be devoted entirely to the generation of new freight flows. The extent to which the different regions increase the intensity of their interactions with other regions thus depends on their attractiveness as expressed by the locational parameters \( p_i \) and \( q_j \) in the distribution model, and the attractiveness and proximity to other regions in the surrounding area. Figures 5.57 and 5.58 show the regional production and attraction in the different regions in the base year of the estimations and in the generation scenario, respectively. For convenience, we have abstracted from imbalances between in- and outward flows; therefore, production and attraction were added. The darker the shading of the regions, the larger the volume of freight flows generated there. In these pictures, the flows by the three modes are summed.

![Figure 5.57](image_url)

**Figure 5.57 Regional activity in the base year**

We can see that the main center of generation of flows is situated in and around the Ruhr area. The degree of centralisation appears to increase, as we see that the outer regions of Germany become lighter, and the core becomes darker.
5. The multimodal distribution of freight flows

This perception is supported by the relative growth rate for each region (figure 5.59), which expresses growth in activity, weighted by the present flows in and out the region.
A projection of freight flows without barriers

We can see that the growth rate of these regions follows the existing pattern to a reasonable extent, with the result that the present core is fortified. Some regions near this core have almost doubled their activity in the generation scenario. The strongest growth takes place in the southern region of Belgium and the northern region of France.

5.5.6 Discussion

This application has shown that changes in border barriers not only can have a substantial effect on the relative importance of international freight flows, but also on the spatial and modal distribution patterns throughout Europe. An important question concerns the extent to which these scenarios can be considered as a realistic rendition of the future developments. Firstly, it should be emphasized that the investigation reported in this section has been a structured analysis of the sensitivity of the model, and not an attempt to picture a future state. If the question is whether the border effect may be relevant to the future network loads from international movements, the answer is affirmative. On the other hand, we have made no projections about environmental variables, such as the rate of change of the barriers and the absolute level of economic growth, which is generally assumed in trend-based scenario analysis. Implicitly, however, we made assumptions on a number of these issues.

In order to gain insight into the sensitivity of the distribution to the identified international barriers, we have assumed that all barriers will vanish completely. As for specific forecasts one would want to carefully consider the validity of such an assumption for the horizon year; more detailed investigations are necessary to determine a reasonable rate of change for these barriers. In the case of road transport for example, the barriers between Belgium and the Netherlands can be considered as the result of fifty years of gradual economic integration.

The growth in the total intensity of interactions the system is a similar case. In the substitution scenarios, we assume no growth at all to take place in the system, which causes domestic flows to decrease at the cost of international flows. In the generation scenario, the extent of regional growth is unrestrained, that is, fully determined by the present regional characteristics. In both cases, economic growth in the system is predetermined, either directly or indirectly. A more flexible, but simplified representation of economic growth of the whole system can be given by relating the growth of regional demand to the growth of the total flow in the system. In this approach, the interregional flows can be calculated by applying a growth factor to the base year O-D table, followed by calculating substitution or generation effects.

Obviously, the reaction of producers and consumers will entail both a substitution of domestic for foreign products and, also, an increasing demand for new foreign goods as a result of changes in the allocation of resources (e.g. substitution with non-physical goods). However, a representation of the mechanisms behind regional growth would require an extension of the distribution model with a generation model, which specifies the regional demand as a function of the prices of goods. This lies outside the scope of this thesis.
5. The multimodal distribution of freight flows

5.6 Conclusions

In this chapter, we have designed and applied a model for the interregional and multimodal distribution of goods in Europe. The main stages in this design concerned the specification and estimation of the model. We assumed that shippers attempt to combine regional supply and demand to maximize profit. Within the European context, we had to account for economical barriers to these interactions at the international level. By specifically including the costs of access and egress in the model specification, a multimodal specification is obtained, accounting for regional differences in accessibility to the main transport axes in Europe. The model expressed the costs of transport in such a way as to incorporate the valuation of transport time, in order to reflect the problem that transport costs depend not only on supply, but also on demand characteristics.

To account for the model’s unknown variables, the estimation method had to be designed with the availability of observations on transport flows in mind. As these data are aggregated for international relations to the level of country pairs, a method was developed that allows their use, in addition to other sources. The method makes use of the experiences with another estimation problem to which it bears some similarity, i.e. O-D matrix estimation based on traffic counts. The estimation of the model was performed for the case concerning northwestern Europe. Based on the readily available transport data, we estimated the O-D tables for three modes of transport were estimated. The correlation between observed and estimated flows proved to be acceptably high.

In the estimations, barriers to trade and transportation were quantified. We find that there are substantial impediments to international trade, which, to some extent and in a qualitative sense, can be explained if we observe present day regulatory measures in international transport. A further result of the estimation concerned the regional access/egress costs in connection to the main transport axes in Europe. As expected, substantial differences between regions were found. In the Netherlands, the railways network exhibits relatively high access/egress costs, in contrast to the inland waterways network. The estimation concludes with an interpretation of the estimated deterrence functions. We find that the deterrence functions that apply to transport by different modes show a suprisingly similar relation between interaction and transport costs, if we account for changes in the time sensitivity of goods. The estimated relations in time sensitivity of goods moved by different modes prove to match closely the results obtained in other studies related to the value of time.

The application of the model concerns an exploratory analysis of freight flows in the case were the international barriers to trade and transport would not be present. For a structured analysis of possible reactions of firms to increasing opportunities for cross-border interactions, we distinguish different scenarios. The first and second concern the assumption that at a regional level, no growth takes place at all, and consequently, changes in the system only concern a redistribution of flows over existing alternatives. In the first scenario, only a spatial redistribution of flows can take place. The total demand and supply, as well as the balance between modes are maintained at the
Conclusions

regional level. The second scenario relaxes the restriction of no modal interaction, thus allowing regions to better exploit multimodal network connections at the international level. The third scenario allows for generation of flows as well, where the underlying hypothesis is that the savings that result from the vanished border barriers are completely transformed into new demand for goods. Each of the scenarios indicates that a considerable growth of international transport may result when barriers disappear. The scenarios show substantial differences in terms of spatial and modal redistribution effects. A tentative assignment of the calculated O-D tables allowed us to identify sections of the network where new freight flows may accumulate. The analysis indicates that the growth rates of flows at the network level are less than those at the level of O-D relations.

We conclude with the design and application of a multimodal distribution model for freight transport in Europe. One aspect of the freight transportation system which we have not treated explicitly up to this point is intermodal transportation as an alternative for moving goods. An intermodal alternative entails the use of multiple modes on a door-to-door transport with one or multiple transshipments underway at a terminal or a port. Although we have formulated the distribution model from a multimodal perspective, some issues that concern the level of transport operations (see Chapter 2), necessitate the explicit treatment of the different segments of an intermodal transport chain. As we have seen in Chapter 3 and 4, these issues can be treated with route choice in a multimodal network. In particular the stochastic assignment models appeared suitable for this type of analysis. The next chapter adds an integrated treatment of the multimodal routing of freight flows to our modelling approach.
5. The multimodal distribution of freight flows
6. The multimodal routing of freight flows

6.1 Introduction

In the previous chapter we have treated the distribution and modal choice for goods flows, with simplifying assumptions regarding the process of route choice. This way, we took transport chains of more than one mode into account to a limited extent only, i.e. up to the treatment of access and egress towards the main network. The mode and locations of access or egress were not identified. Other limitations of the approach towards modelling presented in the previous chapter concern firstly the assumptions on the variations in the profit of goods movements. Secondly we assumed that the users' value-of-time was mode specific. The first assumption permitted the derivation of the distribution model and thus the tractable iterative solution procedure. The second assumption allowed us to define one single deterrence function and thus provided a more general specification; however, it also restricted the applicability of the model to the analysis of modal shift scenarios.

Although these assumptions were necessary to formulate the distribution model, a different approach is necessary to address policy issues related to the network assignment stage. Issues which concern the choice of modes and routes require a more detailed model in terms of 1) the
6. The multimodal routing of freight flows

definition of the network of different modes and possible interchanges and 2) the variations in transport costs within and between the modal networks.

The purpose of this chapter is to introduce a model that describes the choice between alternative, multimodal routing options for goods on a door-to-door transport, while taking into account the heterogeneity of goods. The basis of the choice model lies in its formulation as a route choice problem in a multimodal network and the assumption that the routing of a good is decided simultaneously for all modes, ports of transshipment etc. Thus, an individual decision maker values different segments of an intermodal transport chain in exactly the same way. Even though in many cases there are transport chains (e.g. in intercontinental container movements) it is not always clear whether the routing decision has been made on a door-to-door basis. Therefore, the more the real-world decision making process integrates the whole transport chain the more accurate our model will be in reproducing real world transport decisions, for example by through-billing (i.e. one single rate for the entire journey). Hayuth (1987) gives an extensive discussion of the concept of intermodality. He argues that intermodality is a "transport system concept" with an integrative organizational structure of services, that goes beyond, say, containerization as a primarily technological unitization concept. In contrast to the intermodality concept, the latter does not necessarily imply that decisions concerning ports, modes and routes are made in a fully coordinated fashion.

In the following section we propose a new and more general form of the multimodal route choice model, based on a review of existing modelling approaches. The methods and techniques available for evaluating and estimating the model are discussed in section 6.3 and 6.4. Section 6.5 deals with a specific example that serves to demonstrate the applicability of this model to a complex choice situation. We end this chapter with a discussion of the results of this case.

6.2 Model specification

In order to formulate a modelling approach we will review a number of modelling attempts that are directly relevant to our problem of combined route and mode choice. Both on the demand as well as on the supply side of the freight transportation system, the characteristics of the modelling problem limit the set of possible modelling approaches. We discussed different modelling approaches in the review of Chapter 3, and concluded that there were certain requirements for modelling transportation systems that are of particular interest for the case of goods flows in the European context. These requirements concerned:

1. the interaction between users,

2. the independence of route attributes and

3. the treatment of sources of uncertainty in transport costs.

Below we briefly summarize the requirements for modelling, the available options and the model that was chosen to describe the multimodal routing of freight flows.
Model specification

**ad 1 interaction between users**

As infrastructure capacity is not limitless, interactions between users on the network will influence transport times. However, the incorporation of congestion phenomena in the present modelling context presents some conceptual difficulties:

- As generally freight and passenger traffic will use the same road space (or rail track, or waterway), the interaction between route choice and traffic intensity cannot be studied in isolation from passenger transport.

- In addition, the major use of infrastructure will concern short-distance transport (as the exponential shape of the deterrence function has pointed out). Consequently, intraregional transport will have an important share in the total network load.

As the model that has been developed so far does not account for either passenger or intraregional freight flows, we have chosen to refrain from modelling congestion effects on route choice explicitly. The importance of this subject to modelling on a European scale remains, of course; we will, however, regard this as a possible extension of the problem under study.

**ad 2 network attributes**

The representation of the mode choice problem in terms of route choice within a network makes a high number of alternatives for the routing of goods possible. Additionally, in some cases, these alternatives cannot be considered to be independent from one another, due to physical overlaps between alternative routes. Beside the dependence that exists within sets of alternative unimodal routes or multimodal chains, there may also be an overlap between unimodal and intermodal alternatives. We can illustrate this interdependence in figure 6.1. Consider here the alternative routings from O to D; there are two intermodal overlapping alternatives crossing the nodes 1 and 2. Unimodal alternatives all pass through 3 and 4. Here we have many overlapping alternatives. All intermodal and unimodal alternatives overlap on the links OA and BD.

![Multimodal network with overlapping routings](image)

*Figure 6.1 A multimodal network with overlapping routings*
6. The multimodal routing of freight flows

ad 3 sources of uncertainty

The incorporation of mode choice into a route choice framework complicates the representation of user characteristics. More so than in the case of unimodal route choice, transport alternatives are heterogeneous in terms of their physical and logistical characteristics. Consequently, if we describe goods by the same attributes, but within the wider context of modal choice, we must realize that goods will be more heterogeneous with respect to these attributes.

From the perspective of variations in transport requirements within groups of users we favour stochastic modelling approaches. Surprisingly, the majority of modelling attempts in multimodal route choice for freight transport has concentrated on deterministic choice models. Within the category of stochastic models, we have reviewed a number of approaches in Chapter 3. We have found that there are three basic approaches towards representing uncertainty in these choice models. Below we briefly repeat in short the results of the discussion of the resulting model types and their characteristic features.

Random utility route choice models were operationalized within a network context for passenger transport by Daganzo & Sheffi (1977). Their model takes into account only one choice factor, transport time. The main drawback of these models from a policy point of view, is that they do not account explicitly for the heterogeneity of the population in terms of attribute preferences. Rather, they implicitly account for a range of sources of uncertainty, including these preferences. The second type of choice model concerns the taste variations approach. Here, we assume that variations in choice behaviour originate from differences between individual users in terms of their valuation of the attributes of alternatives. The main drawback of this model is its instability with respect to changes in network characteristics. Consider a choice situation where a group of users of the transportation system have to choose between three alternatives (e.g. routes or modes). Each of the alternatives is characterized by two service-related attributes (e.g. transport time and the rate charged for transport). In the taste variations model, the costs of the alternatives is expressed as follows:

\[ c_{ui} = X_{a}^{(1)} + w_{a} \cdot X_{a}^{(2)} \]  \hspace{1cm} (6.1)

where  
\begin{align*}
\mathcal{c}_{ui} & = \text{generalized costs of alternative } a \\
X_{a}^{(1)} & = \text{value of attribute } t \text{ of alternative } a \\
w_{a} & = \text{weight attached to attribute } t \text{ by user } u
\end{align*}

An individual user will be indifferent for the choice between the two alternatives if \( c_{1} = c_{2} \) i.e. \( w_{1} = w_{2} \), where

\[ w_{1} = \frac{X_{1}^{(1)} - X_{1}^{(1)}}{X_{1}^{(2)} - X_{2}^{(2)}} \]  \hspace{1cm} (6.2)
In the case that $w_0 > w_0^*$, alternative 1 will be preferred, and vice versa. Now imagine a fourth alternative, with higher scores for both attributes. According to the taste-variations model, this alternative will not be chosen, regardless of the preference of the user. This alternative is called "inefficient". The only cause for variation in choices is the variation in user preferences. Graphically, this can be illustrated as follows:

![Diagram](image)

*Figure 6.2 Efficiency of alternatives in the bicriteria trade-off model*

Clearly, if the attributes of any one of the alternatives would be slightly different (i.e. higher for alternatives 1 and 2, or lower for alternative 4), alternative 4 would be chosen by users with a specific preference. Thus, by not taking into account small variations in the attributes of the alternatives, alternative 3 is totally excluded from the choice set. This problem is similar to the instability of the all-or-nothing assignment technique, where the only alternative chosen is that which has the highest "objective", or deterministic costs. In other words, small changes in the alternatives' attribute values may have a large effect on the result of the choice process. Note that this applies to the level of the individual user, i.e. with one fixed preference value. If we look at the consequences for a whole group of users, we have to presume a distribution of users over different preference values. If the proportion of users with a preference value near $w_u^*$ is high, the instability of the model at the individual level will have considerable impacts at the aggregate level as well.

**Discussion**

The model type that we wish to study in more detail involves cost functions where user preferences are represented explicitly and that do not exhibit the problem of instability towards network attributes. We distinguish between two approaches that treat the problem from a different angle.

- The first approach concerns the attributes of alternatives as random variables. This is particularly useful if there is information on the amount of variability in the attributes. As such, the reliability of network attributes enter the choice model explicitly, without considering it as a separate choice factor. This type of model is used for the case of cross-Atlantic freight transport services by Tavasszy (1995). Using the above figure 6.2, we can illustrate that this model is a straightforward extension of the 'taste variations' model (figure 6.3).
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The same transport alternatives can now be pictured as areas within which the attributes of each alternative lie, greatly reducing the sensitivity of the outcomes for changes in either of the attributes. The area that characterizes an alternative in this graph depicts the probability distribution of the attributes. In this example, the attributes are uniformly distributed. In the case of European freight transport services, however, the data necessary to use this type of model are not available. Moreover, as this approach is behaviourally closely related to the following approach (see Mirchandini and Sorouch, 1987), we will not be treating it further.

- The second approach accounts for an additional error term in the taste variations model. Ben-Akiva et al (1993) specify a logit choice model with random preferences. This model, however, assumes independence between alternatives, which is not realistic in a network context¹. Hausmann & Wise (1978) estimate a probit model with random preferences, that does allow for interdependence between alternatives. Their solution technique, however, requires that there be no more than about four or five alternatives. Unfortunately, as we are approaching the mode/route choice problem through route choice in a multimodal network, the number of alternatives potentially outruns this maximum.

The characteristics of the different model types are summarized below.

Table 6.1 Comparison of different choice model types

<table>
<thead>
<tr>
<th>random preferences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>error</strong></td>
</tr>
<tr>
<td><strong>term</strong></td>
</tr>
</tbody>
</table>

At one end of the scale we see the all-or-nothing, or fully deterministic approach. Here, only one alternative is chosen with probability of 1. Models 1 and 3 are the only ones stable under changing network conditions. Of these, the third type accounts for random preferences. In the remainder of

¹ See e.g. the discussion of logit and probit models for network assignment in Daganzo and Sheffi (1979).
this chapter, we will proceed with the combined mode/route choice model based on the cost formulation of the third type, and choose an approach towards its solution and estimation that allows a large number of interrelated alternatives. Further on we apply the model for the case of the combined choice of mode of transport and port of transshipment between the United Kingdom and Germany.

6.3 Calculation of route flows

6.3.1 Route choice probabilities

By using a choice model for routes, which is based on the formulation of transport costs given above, route choice probabilities are calculated. The distribution of flows over the alternative routes are determined using these route choice probabilities. The relation between route choice probabilities and route flows is given by the following multinomial distribution:

\[ Pr\{ t_{1,r} \} = t! \prod_{r=1}^{R} \frac{p_{r}^{t_{r}}}{t_{r}!} \]

(6.3)

where

- \( Pr\{ t_{1,r} \} \) = joint probability of flow distribution among routes 1 to R
- \( t_{r} \) = flow on route \( r \)
- \( p_{r} \) = choice probability of route \( r \)
- \( t \) = \( \sum_{r} t_{r} \)
- \( r \) = index for routes

Our objective is to calculate the expectation of the route flows, \( E[t_{r}] \) for each route \( r \). This expectation is given by:

\[ \hat{t}_{r} = E[t_{r}] = p_{r} \cdot t \]

(6.4)

The probability that a route is chosen equals the probability that this route has the lowest generalized costs, and is given by the function

\[ p_{r}(X, w) = Pr\{ \zeta_{r}(X, w) < \min_{\zeta_{r}} \{ \zeta_{r}(X, w) \} | X, w \} \]

(6.5)

where

- \( X \) = the vector of attributes of route \( r \)
- \( w \) = the vector of preferences of user \( u \)
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In the probit model, the error term is assumed to be normally distributed for each alternative; consequently, the joint distribution of the vector of utilities \( \epsilon_r \), \( r \) is multivariate normal, with the vector of means \( \mathbf{V} \) and the matrix of covariances \( \Sigma \) specified by \( \mathbf{X} \) and \( \mathbf{W} \).

The probability that the costs of alternative \( r \) are minimal can be written as:

\[
p_r(\mathbf{V}, \Sigma) = Pr(\epsilon_r \leq \min_{s \neq r} \epsilon_s) \mid E(\epsilon) = \mathbf{V}, \text{cov}(\epsilon) = \Sigma)
\]

where

\[
p_r(\mathbf{V}, \Sigma) = \int_{c_{\epsilon_r} \in \mathcal{C}^r} \phi(\epsilon | \mathbf{V}, \Sigma) \, d\epsilon
\]

and

- \( \mathbf{V} \) = vector of systematic utility components
- \( \Sigma \) = matrix of variances and covariances of utilities
- \( \phi(\mathbf{V}, \Sigma) \) = multivariate probability density function of generalized costs with mean \( \mathbf{V} \) and covariance matrix \( \Sigma \)
- \( \mathcal{C} \) = the set of values of \( \epsilon \) for which \( \epsilon_r \leq \min_{s \neq r} \epsilon_s \)

### 6.3.2 Operational form of the cost function

In this section we introduce the general specification of transport costs. We assume that every individual decision maker chooses a routeing which maximizes his profit, and that this is equivalent to seeking an alternative which minimizes his generalized transport costs.

The costs for transport of a good \( u \) over route \( r \) for a particular decisionmaker are expressed as follows:

\[
\epsilon_{r,u} = R_r + \alpha_u \cdot T_r + \epsilon_r
\]

where

- \( \epsilon_{r,u} \) = generalized costs of transport of good \( u \) over route \( r \)
- \( R_r \) = transport rates over route \( r \)
- \( T_r \) = transport time over route \( r \)
- \( \alpha_u \) = value-of-time (VOT) of good \( u \)
- \( \epsilon_r \) = contribution to the generalized costs of other non-observable factors

Note that the random variables in this cost function are underlined. We assume the VOT to be normally distributed, with expectation \( \alpha_u \) and variance \( \kappa_u \):
\[ \alpha_s \sim N(\bar{\alpha}_s, \kappa_s) \]  

(6.9)

The term \( \varepsilon \) expresses non-observable factors other than the VOT which also vary within the population of decision makers, e.g.:

- contributions to the utility of non-included network attributes
- measurement errors in the systematic utility variables
- purely random behaviour on the part of decision makers

As we are approaching the choice model by means of route choice, a condition which has to be met in the formulation of transport costs is the consistency between specifications at the link- and the route-level. As route choice is in our case an additive operation\(^2\), the main requirement for the cost formula is the additive quality of costs at the link level. This places demands on the cost functions in terms of:

- the type of probability distribution function: the family to which the cost distribution function belongs should be stable under addition, i.e. the link cost distributions should be of the same type at both the route and link level. The normal and gamma distribution functions are two examples of families that have these properties.
- the specification of the error term: the added variance at the link level should equal the variance at route level. This condition can only be met if the variance of the error term \( \varepsilon \) is either a constant or proportional to some network attribute. In the latter case, this network attribute must also be additive.

We assume, therefore, that the term \( \varepsilon \) is normally distributed around its mean zero and that its variance increases proportionally to the geographical length of a link. The route-specific disturbances are defined as:

\[ \varepsilon_i \sim N(0, \theta d_i) \]  

(6.10)

where

\[ \theta = \text{ dispersion parameter} \]
\[ d_i = \text{ link length} \]

We may interpret \( \theta \) as the variance of the perceived transport costs over a network segment of unit length. Assuming that non-overlapping segments are perceived independently, the variance of transport costs for a longer segment of length \( d_l \) equals \( \theta d_l \).

Here, the cost specification at the link level is analogous to the specification at the level of the alternatives. The distribution of the route costs at the route level are obtained from the specification of

\(^2\) i.e. shortest routes are determined by adding the costs of links in the network. Other model types are also possible (e.g. multiplicative cost formulations); in any case, consistency requirements remain.
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costs at the link level, and the link-route incidence relationships. The transport costs at the route level, for one decision maker, are thus specified as follows:

\[ E[c_{ru}] = \sum_{l \in r} c_{lu} \delta_{lr} \]  
\[ Var[c_{ru}] = \sum_{l \in r} \theta d_l \delta_{lr} \]  
\[ Cov[c_{ru}, c_{s \bar{u}}] = \sum_{l \in r} \theta d_l \delta_{lr} \delta_{ls} \]  

where

\[ c_{ru} = \text{costs of transport on route } r \text{ for user } u \]  
\[ \delta_{lr} = \begin{cases} 1, & \text{if link } l \text{ belongs to route } r \\ 0, & \text{if link } l \text{ does not belong to route } r \end{cases} \]  
\[ c_{lu} = \text{costs of transport on link } l \text{ for user } u \]

6.3.3 Solution techniques

Approaches towards the estimation of random utility models models for unimodal networks are discussed in Bovy (1990), Daganzo & Sheffi (1977) and Daganzo (1979). We will evaluate these approaches below, and choose among them to evaluate our model. The calculation of route choice probabilities can be performed by three different types of techniques, each with its own advantages and limitations. These are:

- numerical integration
- numerical approximation
- simulation

The first approach comprises the numerical integration of the above function. The computational effort of the integration of this function increases exponentially with the dimensionality of the integral. As a consequence, the number of alternatives that can be handled, within reasonable time limits, is limited to around five alternatives (see Daganzo, 1979).

Numerical approximation is the second approach, which, in its most common version, relies on the assumption that the greatest of two random variables can be approximated by a variable which is, again, normally distributed (see Clark, 1961). The calculation of the above integral is thus simplified by the recursive application of the technique of approximating the mean and variance of the greatest of a set of two random variables. The approach allows relatively large sets of alternatives; however, in general it will be unsuited for the number of alternatives encountered in network analysis (see Sheffi, 1985). Moreover, it suffers from a decrease in accuracy with an increasing number of alternatives (see Bovy, Daganzo). Other approximation approaches have been developed by Langdon (1984) and
Kamakura (1989); however, to our knowledge, no applications have been reported in the literature of these latter two.

The flows over the alternative routes can also be calculated for a given set of parameters by repeated assignments, using Monte Carlo simulation. In each assignment, the link resistances are determined by drawing from the distribution of $g_i$ and the distribution of the VOT. As each individual assignment yields one shortest route, we can calculate the route choice probabilities of different routes by recording, after a large number of assignment runs, say, $N_{\text{tot}}$, the relative frequency of each of the shortest routes found, $N_r$. The relative frequency of a route occurring as the shortest is an approximation of the choice probability of each individual route:

$$p_r = \frac{N_r}{N} \quad (6.14)$$

Multiplying each route's choice probability with the total flow of goods on the respective OD-pair, gives the route-specific flows. Figure 6.4 illustrates this process.

![Figure 6.4 Simulative calculation of route choice probabilities](image)

The computational effort that is necessary to calculate route choice probabilities, based on link costs, can be reduced by enumerating "reasonable" alternative routes, in order to avoid the necessity of repeatedly searching shortest routes. The enumeration of routes yields a link-route
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incidence matrix. The further implementation of this solution technique is discussed in the following subsection.

6.3.4 Enumerating intermodal choice alternatives

Using the simulation approach towards evaluating route choice probabilities, we can now find the solution of the model along the lines of the procedure described in the previous section. By enumerating the alternative intermodal routings (assuming, again, that for each port-mode combination the routing possibilities are equivalent in terms of generalized costs), searching shortest routes in each experiment is avoided. The calculation of transport costs at the route level in each experiment in figure 6.4 is now performed by adding up link travel costs to the route level, using the link-route incidence relationships. In each experiment one value for \( \alpha \) is drawn which is valid for all links in the network, and one value for \( e \) for each link. This way we conform to the idea of all links being valued in the same manner, as illustrated in the introductory section. If the influence of the random value of time on transport costs would be specified at the link level, this would not be the case; in addition, the additivity requirement (see section 6.3.2) would not be satisfied. This point is illustrated in Appendix F. Note further that as we do not need to use a shortest route algorithm in the simulation, drawing negative values for the random parameters is not a problem; negative route costs are evaluated along with the positive ones. The operation for the calculation of route costs in one experiment can be denoted as follows:\footnote{Note: the operator \( \ast \) concerns the element-by-element multiplication of two vectors or two matrices, the operator \( \ast \) concerns a matrix multiplication}

\[
C = (\alpha \cdot T + c + e \ast A) \ast \Delta
\]

(6.15)

where

\[
\begin{align*}
C & = \text{ the vector of route costs} \\
T & = \text{ the vector of link times} \\
\alpha & = \text{ a realization from the VOT-distribution} \\
c & = \text{ the vector of average link costs} \\
e & = \text{ the vector of link error term variances } e_i = \sqrt{\theta_i}, \forall \\
A & = \text{ a vector of realizations from the standardized normal distribution} \\
\Delta & = \text{ the link-route incidence matrix, size } (L \times R)
\end{align*}
\]

6.4 Estimation method

6.4.1 Goodness-of-fit measures

Here, our objective is to estimate the parameter values which yield the best fit between observed and estimated transport flows. In addition to information regarding transport rates and times, for
the calibration we need observations of traffic flows on the route or the link level. For the
calculation of the goodness-of-fit between calculated and the observed traffic flows on the link
level, Daganzo (1977) derives a likelihood function, for calibrating the probit model on link data.
This function yields a measure of the probability that the observed flows result from the calculated
flows. The higher this probability, the better the postulated model will fit the observed traffic
flows. Approximating the distribution of route flows on an O/D pair, given in formula (6.4), by
means of a multivariate normal distribution, the loglikelihood function $\ln L(\theta)$ on the link level is
as follows:

$$
\ln L(\alpha, \kappa, \theta) = \frac{1}{2} \ln |\Sigma_{\hat{f}}(\alpha, \kappa, \theta)|
- \frac{1}{2} (t - E(\hat{t} | \alpha, \kappa, \theta))^T \Sigma_{\hat{f}}^{-1}(\alpha, \kappa, \theta) (t - E(\hat{t} | \alpha, \kappa, \theta))
$$

(6.16)

where

- $\Sigma =$ variance-covariance matrix of the calculated link flows
- $\hat{t} =$ calculated flow
- $t =$ observed flow
- $T =$ transposition operator for matrices

As Daganzo (1977) and Bovy (1990) have indicated, under certain conditions, a good approximation
of this measure of goodness-of-fit that is relatively easy to implement and requires less computational
effort (which can be a decisive factor for applications in larger networks, for example) is the root mean
square error (RMSE):

$$
RMSE = \sqrt{\frac{1}{n-1} \sum_{o=1}^{n} (t_o - \hat{t}_o)^2}
$$

(6.17)

where

- $o =$ observation
- $n =$ number of observations

6.4.2 Implementation aspects

The values of the cost function parameters that minimize the RMSE can be found by an
exhaustive search of all possible combinations. As this approach is impractical, we can perform an
extensive exploration of the function, or adopt an optimization heuristic using steepest ascent,
area elimination, random search or "guided" random search (e.g. simulated annealing or genetic
algorithms) techniques. In the case to follow, we have estimated the three parameters of the

---

4 i.e. 1) that route flows are not directly dependent (in our case the alternatives used by 10% of the flows
are not taken into account) and 2) approximating the multinomial distribution of route flows by a
multivariate normal distribution.
goodness-of-fit function by using a grid search algorithm due to Mischke. The grid search algorithm, an optimization technique for multiple dimensions of the "area elimination" type, is described in more detail in Shoup (1979). The algorithm was tested extensively, and has shown to be sufficiently robust for computing an optimum in our test case.

In order to reduce the estimation time, the number of necessary simulations for evaluation of the error-function can be reduced by applying variance reduction techniques; in our case we used the same series of random numbers for the evaluations during the calibration (see Bovy, 1990 and 1994, for a more detailed description of these techniques). For the calibration of the model, it was found that 1000 experiments per evaluation gave satisfactory results in terms of the "smoothness" of the RMSE-function.

6.5 The case of transport chains

6.5.1 Introduction

The objective of this section is to test whether the behavioural assumptions in the proposed model for combined mode and route choice are supported by real-world observations. The calibration of the model was done for a test case concerning the transportation of chemical products\(^5\) between the region "West-Midlands" in the United Kingdom and the "Köl"n" region in Germany (see figure 6.5). The part of the network near to the shortest route between these regions measured in distance, has been given a darker shading\(^6\).

\[\text{Figure 6.5 Regions and multimodal network in the case study}\]

\(^5\) Commodity group 8, according to the NSTR classification system

\(^6\) These routings appear to be the most plausible ones according to a recent study of port choice for road transport (see e.g. Spencer, Anderson and Whitcombe, 1991).
The transportation network considered included four modes of transport, i.e. road, rail, inland waterways and sea; four ports in the United Kingdom, and twelve ports on the mainland of Europe. As not all inland modes are available at each port, somewhat less than 144 alternative routings were considered altogether. The data on transport and transshipment times and costs were obtained from the ISG (Stada and Hauwert, 1992). The freight flow data used for the calibration involve tons of goods moved between these two regions, specifying the main port of transshipment (Rotterdam or Antwerp) and the mode of transport on the European mainland (road, rail or inland waterways). Despite the fact that the number of known routings is rather limited relative to the number of alternatives, they account for more than 90 percent of the tonnage moved, which is a large sample of the overall traffic between these regions. The data are part of an origin-destination table for freight transport in 1990, containing a breakdown of interregional flows by continental ports of transshipment and mode of transport. The O-D table is the result of a recent study on the identification of transport chains (see NEA Transport Research & Training, 1994). By combining statistics on different segments of door-to-door transport chains between UK and the European continent, the routing of these chains was identified in a series of steps:

- the first step involved the combination of international trade data with results from transshipment surveys in the major seaports of Germany, the Netherlands, Belgium and France. As the transshipment data are mode-specific, a first breakdown onto the modal level is provided by this step.
- the second step involved the disaggregation of country-to-country data to the regional level, resulting in transport flows, specified by regions of origin, destination and transshipment, and the mode(s) used.

Figure 6.6 shows the shares of the different routing alternatives between these two regions.

Figure 6.6 Shares of routing alternatives in example (source: NEA)
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6.5.2 Estimation results

Our objective here was to estimate the parameter values which yield the best fit between observed and estimated transport flows; we denote these as the set \((\hat{\alpha}, \hat{\kappa}, \hat{\theta})\). After minimization of the RMSE function, its minimal value was found to be \(9.5 \times 10^3\) tons. This conforms to about 5% of the goods moved. The values of the estimated parameters were as follows:

\[
\begin{align*}
\hat{\alpha} & = 2.86 \text{ f/h/ton} \\
\hat{\kappa} & = 2.71 \text{ f}^2 / \text{h}^2 / \text{ton}^2 \\
\hat{\theta} & = 1.26 \text{ f}^2 / \text{km}^2 / \text{ton}^2 /
\end{align*}
\]

Note that the estimated VOT variance implies a standard deviation of the value of time of 1.65. Although these results are difficult to compare with earlier results, as no previous estimations are available for continuous distributions of the value of time within a similar choice context, we recall the values found by HCG (1992) for different modes, as a result of a series of stated preference-experiments conducted in the Netherlands (table 6.3):

\[
\begin{array}{ll}
\text{mode} & \text{VOT [f. /h/ton]} \\
road & 4.74 \\
rail & 1.25 \\
waterways & 0.30 \\
\end{array}
\]

Despite the fact that the estimates have different experimental backgrounds, the above data give an indication of the values that would be representative for a population of goods, depending on the respective shares of the different modes. We find that our mean value of time lies within the range of these values. Note, finally, that these values were also found to match our estimation results in Chapter 5. Figure 6.7 gives a comparison of the observed and calculated route-flows.

![Figure 6.7 Observed vs. calculated flows (tons)](image)
The case of transport chains

As we can see, the major flows are reproduced quite accurately. Transport by inland waterways through Rotterdam and transport by rail through Antwerp are both underestimated, whereas rail transport through Rotterdam is overstated by the model. Beside the roughness of the estimates of transport and transshipment costs as a possible cause of these deviations, they might indicate that the service quality of these modes is not fully accounted for by transport time and transport costs alone. Given the strong orientation of transport and transshipment services in Rotterdam towards waterways, it is likely that transport costs and times into the Hinterland of Rotterdam have less influence on transport related decisions than in the case of other ports.

The relationship between the error measure and the model parameters can be pictured in response curves or surfaces. An observation of the relationship between the goodness-of-fit and different values of the parameters can give additional assistance in evaluating the plausibility of the model. More specifically, we are concerned with:

- whether the data support the hypothesis that transport choices are determined both by attributes of the transportation system and its users, as well as by other general unobservable characteristics of the system represented in the dispersion parameter, and
- whether the data support our hypothesis of minimization of generalized costs as the common objective of decision processes.

This evaluation is not only useful for determining whether the model is applicable in the specific case, but, as we will show in the next section, also for a comparison between different types of choice models. Figure 6.8 shows the contours of the RMSE function around the optimal point. Because of the extensive range over which the parameters were varied, the axes have a logarithmical scale.

![Figure 6.8 Contour plot of the error function around the estimated parameter values](image)

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We can observe firstly that the parameters found concern a minimum of the model error function and secondly, that the model is sensitive to a variation of each of the three parameters, including the variance of the value of time.

In the following section, we give a more detailed discussion of the RMSE function in order to assess the further behavioural implications of our modelling results. We use a projection of the RMSE function in the dimension of the error term variance factor $\theta$, which indicates the degree of uncertainty of the generalized costs due to other reasons than variations in the value of time of goods. In terms of shipper behaviour, we will start from the presumption that the error term variance factor $\theta$ is an indicator of the degree to which these shippers tend to select routing options with minimal generalized transport costs.

6.5.3 Discussion

Bovy (1990) gives an interpretation of the response curve for a link-based simulative route choice model for bicycle traffic, in which travel time is the explanatory variable. In practice, an evaluation of the model error for different values of the variance of the dispersion parameter $\epsilon$ can yield different types of response curves (see figure 6.9). Each curve type results from a different situation with respect to the actual choices made by users of the transportation system.

![Diagram](image)

*Figure 6.9 Possible response curves*
The case of transport chains

A. If users invariably choose the routes that are "objectively" the shortest (i.e. given the modelled criteria and the characteristics of the transportation system), the results will be best if the variance of the dispersion parameter equals zero (case A). Any other value will result in a higher error.

B. In the opposite case (case B) all routes, independent of their costs, have the same intensity of usage. The modelling error will approach zero for infinitely large variance of ε.

Note that our first hypothesis can be evaluated by making the distinction between these and other cases. In case A, a purely deterministic model would suffice, in contrast to case B, where the observed choices can be modelled by a pure random process. Therefore, these are two extreme cases where the actual choices made do not appear to be as complex as pictured in the random utility model. Between cases A and B we have the general case in which both the decision criteria that are explicitly modelled and other disturbing factors play a role. We can distinguish cases in which longer routes are more frequently used than shorter ones (case C), and vice versa (case D).

C. In the first of these cases users are not equally distributed over all routes and, as a consequence, the model error will not become zero even if the variance of ε becomes infinitely large (although it will tend to diminish for an increasing variance).

D. This case resembles case A, in the sense that only a minority of users will choose routes that are "objectively" not the shortest. This last case implies that users aim at cost-minimization, in contrast to case B and C. In order to account for the fraction of users not choosing the "objective" shortest route, we introduce a small disturbance in the utility function. Note that two subcases can be distinguished. If we observe the model errors at the origin (i.e. the deterministic model) and at an infinitely high variance, we can compare the explanatory value of two models: a deterministic model based on the assumed choice criteria and a stochastic model based on the assumption of random behaviour ("know-nothing" or "equal probability model"). Intuitively one can say that the more favourable case is the one where the error at the origin is lower than the error in the "know nothing" model (case D2), as opposed to the other case, D1, where the "know-nothing" model gives the better explanation. Nevertheless, both cases support the general assumption of cost-minimization.

Figure 6.10 shows the influence of the error term variance parameter θ on the performance of the model. This figure is a projection of the contour plots in figure 6.8 onto the θ -axis. Given our estimates of the VOT mean and its variance (which are estimates of the users' attributes), the behaviour of the RMSE-function, or calibration curve, with respect to the error term variance constant addresses the plausibility of the cost minimizing model we adopted in this study.
6. The multimodal routing of freight flows

![Graph showing relationship between \( \theta \) and RMSE; for \( \bar{\alpha}g = f. 2.86 \text{/h/ton} \) and \( \kappa g = f. 2.71 \text{/h/ton}^2 \)]

From this calibration curve we can conclude the following (see also Bovy, 1990 for a more detailed treatment of the interpretation of the shape of the RMSE-function):

- the horizontal line at RMSE=8.1*10^3 tons shows the asymptotic value of the calibration curve for very large values of theta. As theta becomes infinitely large, the distribution of flows over routes will be determined entirely by the error term, and will approach an even distribution over these routes. This case we denote as the 'equal probability' or 'know nothing' case. The fact that we find a higher RMSE for very large values of \( \theta \) than at the point where \( \theta \) is zero (at RMSE = 7.5*10^3), supports our assumption of cost minimization in the combined mode/port choice problem. If the costs of transport would not be relevant at all in the decision process, the 'equal-probability' or 'know-nothing' distribution over the alternative routes (which is represented by an infinitely large value for \( \theta \)) would give a better representation of the flows observed.

- the difference between the case where \( \theta \) is zero and the 'equal probability' case (about 7% relative to the latter) leads us to a second point. If the behaviour of users of the transport system would be determined only by the VOT (which is the 'zero-\( \theta \) case'), and not by other factors as represented by the error-term, the goodness-of-fit of the model would be 7% better than in the 'equal probability case'. Depending of how we value this difference\(^7\), we can think of cost-minimization as defined purely (i.e. in a deterministic manner) by the time/cost trade-off, as a 'good' or 'bad' approximation of the behaviour of users of the transport system.

- the fact that the RMSE-function decreases steeply in the lower range of \( \theta \) values implies that the density of the network is high, in the sense that more competing routes are used which approximate each other in terms of transport costs. If this were not the case, a small difference in spread over different routes (i.e. similar values of \( \theta \) in the lower range) would not yield such a dramatic improvement in the goodness-of-fit of the model. Having seen that the main

\(^7\) Consider, for example, that the optimal case predicts 88% better than the 'equal probability' case.
routing alternatives concern the port of Rotterdam and Antwerp, which are both not far from a straight line between the two regions, we can conclude that the model behaves as expected.

6.6 Conclusions

In Chapter 4 of this thesis we found that at the level of the routing of freight flows, an important issue concerning the mode of transport is intermodality. We have established that existing freight modelling approaches must be be extended in order to treat heterogeneity of the goods' characteristics and thus variations between agents who decide on the routing of goods. In this chapter, we have formulated and operationalized this new approach.

Approaching the routing problem as a route choice problem in a multimodal network, we assume that within the process of the choice of the optimal routing, all segments of unimodal and multimodal alternatives are valued in the same way. However, as there may exist substantial variations between decision makers in terms of their valuation of service attributes, we specify a random costs choice model with heterogeneous preferences. The main advantage of this approach is that one can account for heterogeneity in preferences without considering alternative-specific attribute weights. In order to retain the consistency between the cost formulations at the link and the route level, we adapt the simulative solution method for calculating route flows.

An estimation has been performed for the case of the transportation of chemical goods between UK and the European mainland. The simulative solution method for calculating route flows was shown to yield smooth response surfaces for the different model parameter, if the number of simulations is sufficiently high, thus allowing a search method to be used for the estimation of the optimal parameters. The estimation method thus behaved according to our expectations. The tests indicate that the accuracy of the route choice model is higher if we abandon the usual assumption of deterministic preferences. The estimated parameter values appear to be plausible as they lie within the range of values found for different modes in an earlier study for freight transport in the Netherlands. Ultimately, the estimation results appear to support our assumption of cost minimization in the choice of modes and port of transshipment. Although these results are encouraging, further testing remains necessary.
6. The multimodal routing of freight flows
7. Conclusions

Throughout the thesis, we have described the design and application of a model for freight transport in Europe. In this chapter we finalize the conclusions from the research, we establish the implications of the results and give recommendations for further research.

7.1 Research results

In the introductory chapter, we have identified three main research needs in freight transportation modelling for Europe. We repeat them briefly for convenience:

1. the framing of medium and long term problems in European freight transportation policy, in such terms that policy issues can be related to models of the freight transportation system;
2. the evaluation of existing modelling approaches given the nature of the available data at present.
3. the design of new models that fill the main gaps in the existing models for freight transportation.

The conclusions from our work with respect to these subjects are given below.
7. Conclusions

ad 1 - On issues in European freight transport

The need to enhance the interconnection and interoperability of transport networks appears to be a guiding principle in European freight transport policy. This principle focuses on two dimensions: one which is administrative (national versus international networks) and one which is functional in nature (the networks of different modes of transport). The issues that need studying at the European in general are therefore related to the effects of ongoing integration of national economies on freight flows and ways to accommodate these growing international flows with the existing or new infrastructure.

Due to the fact that the presently available data are primarily at the regional level and oriented towards domestic relations, the possibilities for extending existing modelling approaches are limited. In this research we have investigated some of the as yet unexplored opportunities for modelling. The importance of the behavioural aspect of modelling is evident; the validation of models that describe individual behaviour should ideally be performed using data at that level as well. The fact that we are dealing with Europe, however, poses difficulties. The availability of data at the level of individual decision-makers in freight transport is limited to certain countries and to certain choice problems, therefore data at this level are of limited use to our modelling efforts. This implies that we have to confine ourselves to modelling at an aggregate level.

ad 2 - On existing modelling approaches

We can conclude that the problem-oriented part of the research as well as the design-oriented part have shown us that there are needs for innovation in modelling, when it concerns policy analysis of freight transport at the international level. Seen from the perspective of policy issues, problems which typically relate to international transport flows, like the economic integration and policy measures concerning modal balance, have received relatively little attention in freight transportation modelling.

Existing approaches that consider multimodality in freight transportation have been based on a distribution model which assumes no variation in transport costs. Existing modelling approaches for combined mode and route choice are in general deterministic in nature. Different approaches towards specifying probabilistic models are available, however, if we look at experiences with passenger transport models. We explicitly consider one specific cause of uncertainty: heterogeneity in the preferences of decision makers with respect to the attributes of the transport alternatives. Choice models accounting for this type of uncertainty have not been studied yet in the field of freight transportation modelling, yet they are thought to be of importance for explaining the usage of different modes of transport in the system. Within this context, the value of transport time seems to be an important explanatory variable, accounting for a complex of logistical circumstances and connected to the choice of transport mode.
Particularly at the aggregate level, modelling choice problems within a deterministic framework is not always realistic, partly due to the heterogeneity of existing goods classification systems, partly as a result of variations in the preferences of decision makers, and partly due to the fact that they simply do not strive for a common optimum in terms of transport costs. Approaches in freight transport modelling that do take into account these variations in transport costs are the gravity-type models; however, these have not yet been extended towards multiple modes within the context of freight transport.

**ad 3 - On the proposed models**

By formulating the distribution model with barriers to international trade and transportation from a multimodal perspective, we found the following:

- The barriers for international trade and transport go far beyond the actual delays experienced at border crossings.
- There are considerable differences between modes and interational relations in terms of the magnitude of these barriers.
- Regional differences in access and egress play an important role in the spatial and modal distribution of goods.
- If we account for the value of time, we find that the deterrent effect of distance on the intensity in freight flows is indifferent to the mode of transport used.
- The potential impact of decreasing border barriers on freight flows is considerable, but depends on the assumptions regarding the mechanisms behind the reaction of the system.

In order to provide an instrument that accounts for intermodal movements as well, a probabilistic, multimodal route choice model was proposed.

- In the formulation of the source of uncertainty, we pay explicit attention to the heterogeneity of users' preferences
- The solution of the model is obtained by adapting an existing link-based simulation procedure.
- The results of an estimation of the model, for the case of combined choice of modes and ports of transshipment between the UK and Germany, support our assumption of cost minimization in the choice process.

In summary, the investigations have shown us that existing patterns in freight transport can be reproduced reasonably well, despite the high aggregation level and the persisting sparsity of the available data. In particular, there appear to be patterns in freight transport, which cannot be observed simply by looking at transport data, nor by applying the existing freight transport models. In terms of the spatial distribution of freight flows, the issue of economic integration should be considered explicitly in the design process of future infrastructure and service networks.
7. Conclusions

for international freight transport. When taking into account the possibility of changes in the use of infrastructure and services through choice processes at the level of transport routes, our findings support the relevance to these real world-processes of "what-if" explorations based on generalized transport costs.

With these conclusions in mind, the proposed models should provide useful instruments to policy analysts, for obtaining insight in the long-term development of European freight transport within a short period of time.

7.2 Recommendations for further research

Further work on modelling freight transport flows can be developed along two (interrelated) lines of research:

- The first line would follow the present direction of research, working to achieve results with available data, focusing on the spatial aspects of policy issues, but with less emphasis on product-level modelling. This research would focus on strengthening the scope of the analysis, in geographical as well as functional terms, i.e. the processes involved and their interrelations. This research is necessary to provide general scenarios for the future in a relatively short period of time.

- The second line would concentrate on a level of detail which can only be achieved through small-scale and detailed observations of the freight transportation system, not aiming to capture all flows within a study area. This would typically entail analyses at the level of individual shipments. This line of research is necessary to improve our insight in issues related to the behavioural mechanisms behind freight transport, for issues where a European view upon the freight transportation system seems less relevant.

Let us now review some specific questions that have been raised during the research and that can be taken up for investigation. We note that for some topics mentioned below, both lines of research are open. In these cases, the choice of the direction (as through a methodological compromise it determines modelling methodology, data needs and policy relevance) should be considered carefully.

Generalizing the multimodal distribution model

In the distribution model, we have simultaneously formulated different modes of transport. The results indicate that spatial deterrence can be modelled in a uniform manner for different modes, if the costs of transport are specified properly. Using this result as an assumption in a new model specification would imply that the mode-specific transport cost functions could, perhaps under additional assumptions, be estimated simultaneously with a general deterrence function. This
Recommendations for further research

abstraction from the choice of modes would allow more general conclusions for the spatial
deterrence of freight flows.

Barriers to trade and international transport

Although we have established the magnitude of the barriers that exist at present, a causal analysis
of these barriers is an entirely new issue, which would require different models and data but, in
our view, is necessary to allow more detailed scenarios to be made of the effects of the European
integration on the international exchange of goods. Such an analysis could involve time-series as
well, to trace the effect of recent policy measures directed at taking away such barriers.

The value of service in freight transport

A topic which was touched upon conceptually and, in part, quantitatively, is the value of time in
freight transport. Recent studies have provided estimates of the value of service quality in freight
transport within the context of other levels of analysis. This leads us to two research issues:
firstly, other service attributes than time could be considered in the distribution model. Secondly,
similar studies could concentrate on other choice problems, in particular related to time as a
resource for production and inventory.

Accounting for international transport chains

At present, it is assumed that the goods originating from or destined to locations of storage or
transshipment follow the same distributional principles as those flowing regions were production
and consumption are located. It was shown that under certain conditions, this distinction is
irrelevant. However, if these conditions are not fulfilled, and if the same distributional principles
do not apply for flows of different nature, it is useful to extend the formulation of the distribution
model in such a way that these chains can be treated separately from the flows between the sellers'
and buyers' locations.

Design of "user-friendly" applications

The ultimate purpose of the instruments discussed here is to provide support to people who do or
do not make decisions. As important as model output or figures can be, it may be necessary to
investigate a whole range of scenarios in a short period of time, not according to a pre-specified
plan, but in the course of a discussion, a meeting or a debate. This use of a desktop-application is
only possible if the suitable interfaces are available. Geographic Information Systems provide
some basic tools for such "user-friendly applications". Further research is necessary to specify the
requirements of these information systems for their use in an operational policy support
environment.
7. Conclusions
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Appendices
A Access/egress costs and the unimodal distribution model

The problem is to derive a distribution model with access and egress costs accounted for separately, by mode and region. In this appendix we show that the model resulting from the assumption of asymmetric access/egress costs is equivalent to the interaction model applied to goods moved by a single mode.

Consider the deterministic part of the profit of an interaction between location $i$ and $j$, given that transportation takes place by mode $m$:

$$v_{ijm} = -a_i + b_j - c_{ijm}$$  \hspace{1cm} (1)

Assume that the costs of transport $c_{ijm}$ are specified as follows:

$$c_{ijm} = c_{im}^A + c_{jm}^E$$  \hspace{1cm} (2)

where

- $c_{im}^A$ = the costs of access, i.e. reaching the main network connection $i_m$ of mode $m$ from location $i$,
- $c_{jm}^M$ = the costs of the trunk movement, i.e. the movement over the network between the network connections of the main mode of transport,
- $c_{jm}^E$ = the costs of egress, or reaching location $j$ from the main network connection $j_m$ of mode $m$.

Assume further that the probability of choosing an O/D relation is given by the logit choice model

$$Pr(i,j,m) = Pr(U_{ijm} > U_{kln}; \forall (k,l,n) \neq (i,j,m)) = \frac{\exp(\mu_v_{ijm})}{\sum_{ijm} \exp(\mu_v_{ijm})}$$  \hspace{1cm} (3)

Equation (1) can be rewritten as:

$$v_{ijm} = -\hat{a}_{im} + b_{jm} - c_{ijm}^M$$

where

- $\hat{a}_{im} = a_i + c_{im}^A$
- $b_{jm} = b_j + c_{jm}^E$

$$\hspace{1cm} (4)$$

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From (3) and (4) we can derive the distribution model:

$$Pr(i, j, m) = p_i \cdot q_j \cdot f(c_{ijm})$$

(5)

where

$$p_i = \exp(-a_{im})$$

$$q_j = \exp(b_{jm})$$

$$f(c_{ijm}) = \frac{\exp(-c_{ijm})}{\sum_{ym} \exp(v_{ym})}$$

Except for the constant in the denominator of the deterrence function, this model is equal to the distribution model for a single mode, applied independently from other modes. As in the estimation of the model this constant cannot be identified separately from other factors, in our context the model is equivalent to the unimodal interaction model.
B. **Validity of the distribution model for aggregate origins and destinations**

In the application of a model of flows between certain origins and destinations, we must assess the consequences of simplifications made in our model with respect to the real origins and destinations of movements. A well-known simplification concerns the aggregation of origins and destinations to access and egress nodes.

The usual situation in which this simplification is made is the determination of regions in the study area. Observations of goods movements may not be available for all origins and destinations. All individual origins and destinations within this region are then concentrated into one virtual node, a "feeder node". Another situation concerns flows connected to regions outside the study area. The external nodes to which the nodes in the study area are related are then pictured as a "feeder node" near the border of the study area. This situation arises, for example, in the case of large seaports on the European continent.

This section introduces some assumptions under which a gravity model remains valid in such a simplified network scheme, using only access and egress nodes\(^1\).

Assume the following:

1. the demand for transport \(T_{rs}\), between every pair \((r, s)\) of origin nodes \(r\) and destination nodes \(s\) is described by a gravity model

   \[
   T_{rs} = p_r \cdot q_s \cdot f(c_{rs})
   \]  \hspace{1cm} (1)

2. the deterrence function in the gravity model is a negative exponential function of the costs of transport

   \[
   f(c_{rs}) = \exp(-\beta c_{rs})
   \]  \hspace{1cm} (2)

3. the costs of transport are additive, i.e. if node B is on the path from node A to node C, then \(c_{AC} = c_{AB} + c_{BC}\)

4. Between nodes \(r\) and \(s\) there is a network consisting of an access/egress network for each node and a main network (fig. 1). The two networks meet in access and egress nodes. Each of the nodes \(r\) and \(s\) uses only one node of access to and one node of egress from the main network.

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\(^1\) see also van der Zijpp, 1996
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\[ \tau_{ri} = 1 \text{ if node } i \text{ is the access node to the main network from origin node } r \]
\[ \tau_{ri} = 0 \text{ otherwise, and} \]
\[ \tau_{sj} = 1 \text{ if node } i \text{ is the egress node from the main network of destination node } s \]
\[ \tau_{sj} = 0 \text{ otherwise} \]

![Diagram of network layout](image)

**Figure B-1** Layout of the network

We define an assignment map of values \( \tau_{rsj} \), denoting the contribution of flows between \( r \) and \( s \), \( T_{rs} \), to the flow on O/D pair \((i,j)\), \( T_{ij} \)

\[ \tau_{rsj} = 1 \text{ if the flow on O/D pair } (r,s) \text{ contributes to } T_{ij} \]
\[ \tau_{rsj} = 0 \text{ otherwise} \]

The flow between \( i \) and \( j \) can now be described by adding flows between all pairs \((r,s)\) that contribute to it

\[ T_{ij} = \sum_r \sum_s p_r q_s \exp(-\beta c_{rs}) \tau_{rsi} \quad (4) \]

The one-to-one relationship between origin/destination pairs and access/egress node pairs (assumption 4) implies that the assignment map of values \( \tau_{rsi} \) can be written as follows

\[ \tau_{rsi} = \tau_{ri} \tau_{sj} \quad (5) \]

Assumption 3 implies that \( c_{rs} = c_{ri} + c_{ij} + c_{js} \) \quad (6)

substituting (5) and (6) in (4), we obtain the following relationship:
B. Validity of the distribution model for aggregate origins and destinations

\[ T_y = \sum_r p_r \tau_{n_r} \exp(-\beta c_{n_r}) \sum_s q_s \tau_{y_s} \exp(-\beta c_{y_s}) \exp(-\beta c_{y_s}) \]  \hspace{1cm} (7)

Expression (7) can be simplified by introducing

\[ p^* = \sum_r p_r \tau_{n_r} \exp(-\beta c_{n_r}) \] and

\[ q^* = \sum_s q_s \tau_{y_s} \exp(-\beta c_{y_s}) \]

thus we obtain

\[ T_y = p^* q^* \exp(-\beta c_y) \]  \hspace{1cm} (8)

which again is a gravity model, analogous to model (1).

The above implies that a gravity model will apply to the relations between nodes of the main network as well. The deterrence function will be the same as in model (1); however, the production/attraction parameters \( p_i \) and \( q_{ij} \) will not be transferrable from one situation to another.
C. On the assumption of independent and Poisson distributed O/D flows

In the literature two separate likelihood functions can be found (see Willumsen and Ortuzar, 1992), which are presented as two distinct alternatives for the estimation of an O/D table. The first involves the use of a multinomial distribution as the simultaneous probability density of O/D flows. The second involves the assumption of independent Poisson distributed O/D flows. Below, we will show that these second assumption is a generalization of the first, involving an additional assumption regarding the distribution of the total flow within the system area.

From the model specification in the previous paragraph it follows that the simultaneous probability density of the O/D flows, i.e. the probability that a specific distribution of goods will occur within the study area, given the choice probability of each O/D relation, is described by the following multinomial distribution:

\[
\Pr(t_{11} \cdots t_{n_m}) | x = x! \prod_{i=1}^{n_i} \prod_{j=1}^{n_j} \frac{\Pr(i,j)^{t_{ij}}}{t_{ij}!}
\]  

(1)

where

\[
\Pr(i,j) = \text{choice probability of relation } (i,j) \text{ according to the gravity model}
\]

\[
t_{ij} = \text{observed flow between region i and region j}
\]

\[
x = \text{total flow within study area}
\]

\[
n_i = \text{number of origins}
\]

\[
n_j = \text{number of destinations}
\]

This probability will serve as a measure of goodness-of-fit for the O/D table. The likelihood of a particular distribution of flows in the O/D table is then given by the multinomial distribution function. This is one of the approaches referred to which is suggested for maximum likelihood estimation in standard textbooks. However, the multinomial probability density for the single cell values will not hold in the case that the flows \( t_{ij} \) are not only observed for individual cells, but for blocks as well. In our estimation problem this presents a difficulty for applying a likelihood function based on the multinomial distribution. In general, this will prohibit applications of this estimation procedure based on sums of cell values, e.g. the case of traffic counts.

The second approach states that each individual O/D flow that is calculated equals the mean of a Poisson distribution, and, in addition, that the Poisson-distributions of these O/D relations are independent. Although seemingly different from the approach described above, this approach can be interpreted as a combined result of the assumed multinomial distribution of O/D flows and the additional assumption, that the total flow \( x \) is Poisson distributed with mean \( T \), or the observed total flow. The motivation behind this assumption relies on the observation that the Poisson
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distribution is applicable in situations where certain "events" occur at certain points of time (see e.g. Ross, 1984). In our context, events constitute the trade of one unit of goods within the area. We define the total flow $x$ as follows:

$$Pr(x) = \frac{e^{-T^*}T^*}{x!}$$

(2)

By combining equations (1) and (2), it can be shown that the simultaneous probability of flows in the entire O/D table can be expressed as a product of Poisson variates, each giving the flow on a single O/D relation. As such, the flows on individual O/D relations are also independently distributed, with parameters (and, in the case of a Poisson distribution, with expectation) $T^*Pr(i,j)$. 
D. Simultaneously estimated deterrence functions and value of time relationships

From the calibration of the multimodal distribution model we obtain deterrence functions for multiple modes. In the case that the transport costs of different modes are not known, we have to use a suitable proxy, like distance, as the argument of the deterrence function. The question that is treated in this appendix is: given these functions for each mode, estimated on distance, can we derive cost function parameters for several modes?

Assume that one general deterrence function $F$ applies for all modes, where deterrence is a function of generalized costs

$$F(c_m) = f(Ac_m + B)$$  \hspace{1cm} (1)

Consider the estimated deterrence function of each mode, where the deterrence is a function of distance and characterized by two parameters $\beta_m$ and $\gamma_m$:

$$F_m(d_m) = f(\beta_md_m + \gamma_m)$$  \hspace{1cm} (2)

We assume that the generalized costs of transport are a linear function of distance, as follows:

$$c_m(d_m) = d_m\left(\frac{\alpha_m}{s_m} + \rho_m\right) + Y_m$$  \hspace{1cm} (3)

where

- $c_m$ = generalized costs of transport by mode $m$
- $d_m$ = distance of transport by mode $m$
- $\alpha_m$ = value of transport time
- $s_m$ = speed of transport
- $\rho_m$ = marginal rate charged for transport
- $Y_m$ = access/egress resistance for transport by mode $m$

In practice, it will be possible to observe the variables $s_m$ and $\rho_m$; however, the value of time variable has to be estimated. As indicated in section 5.2, one of the estimated deterrence functions will have to act as a reference, to which we can normalize the functions of the other modes. Let

---

1 In the case of a discrete deterrence function, these parameters can be estimated from the deterrence function's values that were estimated for the different distance classes.
us denote this reference mode as mode $I$, and denote all modes other than this reference mode as $m^*$. 

We can derive the following relationship between the unknown service variables of the different modes:

$$\alpha_{m^*} = \frac{\beta_{m^*} s_{m^*}}{\beta_1 s_1} \alpha_1 + s_{m^*} \left( \frac{\beta_{m^*}}{\beta_1} \rho_1 - \rho_{m^*} \right)$$  \hspace{1cm} (4)$$

$$Y_{m^*} = X_1 \left( \frac{\gamma_{m^*} - \gamma_1}{\beta_1} \right) - Y_1$$  \hspace{1cm} (5)$$

where

$$\alpha_1 = \text{value of time of reference mode}$$

$$Y_1 = \text{access/egress costs of reference mode}$$

A measure of access/egress resistance $Y_{m^*}$ which is indifferent to the scaling of the distance sensitivity parameter $X_m$ can be obtained by expressing this resistance $Y_{m^*}$ in terms of distance. As such $Y_{m^*}$ can be interpreted as the shift of a deterrence function along the distance axis necessary to fit the function $F_{m^*}$ to the reference function. Formula (1) becomes

$$c_m(d_m) = X_m(d_m + Y_m)$$  \hspace{1cm} (6)$$

where

$c_m = \text{generalized costs of transport by mode } m \ [\text{cost unit}]$  

$X_m = \text{distance sensitivity parameter of goods moved by mode } m \ [\text{cost / distance}]$  

$d_m = \text{distance of transport by mode } m$  

$Y_m = \text{access/egress resistance for transport by mode } m \ [\text{distance unit}]$  

we obtain

$$Y_{m^*} = \left( \frac{\gamma_{m^*} - \gamma_1}{\beta_1} \right) - Y_1$$  \hspace{1cm} (7)$$

We conclude that if an assumption is made concerning the value of time of one mode, the others' value of time can be derived using the parameters of the deterrence functions from a distance-based estimation. In the case of this linear generalized cost function, the relationship between the value of time variables of different modes is also linear.
E. European interregional distances and O-D flows by mode
<table>
<thead>
<tr>
<th>Region</th>
<th>1990</th>
<th>1991</th>
<th>1992</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>99</td>
<td>98</td>
<td>97</td>
</tr>
<tr>
<td>Germany</td>
<td>101</td>
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</tr>
<tr>
<td>France</td>
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<td>98</td>
<td>97</td>
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<tr>
<td>Italy</td>
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<tr>
<td>Netherlands</td>
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<td>97</td>
</tr>
<tr>
<td>Spain</td>
<td>99</td>
<td>98</td>
<td>97</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>99</td>
<td>98</td>
<td>97</td>
</tr>
</tbody>
</table>

Note: The table represents the trend in O-D flows (1000 L) for all goods, 1990 (Eurostat), by region capital.
F. Random taste variations in cost functions at the route and link level

In order to allow the use of standard route choice algorithms and to avoid estimation errors due to network modification, the formulation of generalized costs in the route choice model has to be chosen in such a way that the probability distributions of the transport costs at the route level and the link level are consistent. Here we illustrate the problem of specifying the influence of random taste variation on the generalized costs of transport at the link level, resulting in inconsistency with costs at the route level.

Consider the generalized costs of transport at the route level

$$\zeta_r = \sum_r w_u^k X_r^k + \varepsilon_r,$$

where

- $c_{ur}$ = generalized costs to user $u$ of choosing alternative $r$
- $w_u^k$ = weight or preference of user $u$ attached to the $k$-th attribute
- $X_r^k$ = $k$-th attribute of alternative $i$
- $u$ = index for user
- $ri =$ index for alternative route
- $k$ = index for attribute
- $\varepsilon$ = error term or unobserved variation in generalized costs

At the route level, the variance of the generalized costs of transport is as follows:

$$Var(\zeta_r) = \sum k \sigma^2(w_u^k) X_r^k + Var(\varepsilon_r)$$

$$Cov(\zeta_r, \varepsilon_j) = \sum k \sigma^2(w_u^k) X_r^k X_j^k + Cov(\varepsilon_r, \varepsilon_j)$$

(2)

The specification of uncertainty in costs at the link level is similar to (2), after replacing the indices $r$ and $s$ by indices for links. If the (co)variance is a function of the route attributes, consistency between variations at the route and the link level is only obtained if this relation is constant, or linear. It can be easily seen that if the random taste variation enters the cost function at the link level, the added (co)variance of costs at the link level (results out of the sum of the squares of the attributes) is not equal to the (co)variance of the costs of the added links (results from the square of the sum of the attributes).
### G. List of symbols and abbreviations

<table>
<thead>
<tr>
<th>Variables and parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha$</td>
<td>value of time</td>
</tr>
<tr>
<td>$a$</td>
<td>costs of producing or buying a good</td>
</tr>
<tr>
<td>$b$</td>
<td>benefit of consuming or selling a good</td>
</tr>
<tr>
<td>$\beta$</td>
<td>deterrence function parameter</td>
</tr>
<tr>
<td>$c$</td>
<td>transport costs</td>
</tr>
<tr>
<td>$d$</td>
<td>distance</td>
</tr>
<tr>
<td>$D$</td>
<td>sum of flows towards a region</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>error term</td>
</tr>
<tr>
<td>$\delta$</td>
<td>entry in region/country and link/node incidence matrix</td>
</tr>
<tr>
<td>$f$</td>
<td>function</td>
</tr>
<tr>
<td>$g$</td>
<td>function</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Euler's constant</td>
</tr>
<tr>
<td>$K$</td>
<td>access and egress costs</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>variance of value of time</td>
</tr>
<tr>
<td>$L$</td>
<td>likelihood</td>
</tr>
<tr>
<td>$n$</td>
<td>number of alternatives</td>
</tr>
<tr>
<td>$N$</td>
<td>normal distribution</td>
</tr>
<tr>
<td>$S$</td>
<td>sum of flows from a region</td>
</tr>
<tr>
<td>$P$</td>
<td>price</td>
</tr>
<tr>
<td>$p$</td>
<td>attractiveness of origin</td>
</tr>
<tr>
<td>$p$</td>
<td>marginal freight rate</td>
</tr>
<tr>
<td>$\phi$</td>
<td>normal probability density function</td>
</tr>
<tr>
<td>$q$</td>
<td>attractiveness of destination</td>
</tr>
<tr>
<td>$r$</td>
<td>deterrence function value</td>
</tr>
<tr>
<td>$V$</td>
<td>value of good</td>
</tr>
<tr>
<td>$R$</td>
<td>transport rate</td>
</tr>
<tr>
<td>$s$</td>
<td>speed of transport</td>
</tr>
<tr>
<td>$\tau$</td>
<td>entry in incidence matrix</td>
</tr>
<tr>
<td>$t$</td>
<td>yearly flow of goods</td>
</tr>
<tr>
<td>$T$</td>
<td>transport time</td>
</tr>
<tr>
<td>$\theta$</td>
<td>disturbance parameter</td>
</tr>
<tr>
<td>$v$</td>
<td>systematic utility component</td>
</tr>
<tr>
<td>$V$</td>
<td>value of good</td>
</tr>
<tr>
<td>$w$</td>
<td>preference of decision maker</td>
</tr>
<tr>
<td>$X$</td>
<td>attribute of alternative</td>
</tr>
<tr>
<td>$U$</td>
<td>utility</td>
</tr>
</tbody>
</table>
### Appendices

#### Indices

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
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<tr>
<td>A</td>
<td>access</td>
</tr>
<tr>
<td>a</td>
<td>alternative</td>
</tr>
<tr>
<td>B</td>
<td>barrier</td>
</tr>
<tr>
<td>e</td>
<td>additional</td>
</tr>
<tr>
<td>E</td>
<td>egress</td>
</tr>
<tr>
<td>g</td>
<td>good</td>
</tr>
<tr>
<td>G</td>
<td>general (access or egress)</td>
</tr>
<tr>
<td>i</td>
<td>region of origin</td>
</tr>
<tr>
<td>I</td>
<td>country of origin</td>
</tr>
<tr>
<td>j</td>
<td>region of destination</td>
</tr>
<tr>
<td>J</td>
<td>country of destination</td>
</tr>
<tr>
<td>k</td>
<td>cost class</td>
</tr>
<tr>
<td>l</td>
<td>link</td>
</tr>
<tr>
<td>m</td>
<td>mode</td>
</tr>
<tr>
<td>M</td>
<td>trunk transport</td>
</tr>
<tr>
<td>r,s</td>
<td>route</td>
</tr>
<tr>
<td>t</td>
<td>attribute</td>
</tr>
<tr>
<td>u</td>
<td>user</td>
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#### Matrices

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ</td>
<td>route/link incidence matrix</td>
</tr>
<tr>
<td>Σ</td>
<td>route variance/covariance matrix</td>
</tr>
<tr>
<td>A</td>
<td>realizations from standardized normal distribution</td>
</tr>
<tr>
<td>C</td>
<td>generalized route costs</td>
</tr>
<tr>
<td>c</td>
<td>average link costs</td>
</tr>
<tr>
<td>e</td>
<td>error term variances</td>
</tr>
<tr>
<td>T</td>
<td>average link times</td>
</tr>
<tr>
<td>V</td>
<td>systematic utility components</td>
</tr>
<tr>
<td>w</td>
<td>user preferences</td>
</tr>
<tr>
<td>X</td>
<td>route attributes</td>
</tr>
</tbody>
</table>

#### Abbreviations and acronyms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>COROP</td>
<td>COordinatiecommissie Regionaal OnderzoeksProgramma</td>
</tr>
<tr>
<td>ECMT</td>
<td>European Conference of Ministers of Transport</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>EFTA</td>
<td>European Free Trade Agreement</td>
</tr>
<tr>
<td>f</td>
<td>Dutch guilders</td>
</tr>
<tr>
<td>G</td>
<td>Generation scenario</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information System</td>
</tr>
</tbody>
</table>
## G. List of symbols and abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(G)SP EM</td>
<td>(Generalized) Spatial Price Equilibrium Model</td>
</tr>
<tr>
<td>I/O</td>
<td>Input/Output</td>
</tr>
<tr>
<td>ISG</td>
<td>InformatieSysteem Goederenstromen Europa</td>
</tr>
<tr>
<td>LP</td>
<td>Linear Programming</td>
</tr>
<tr>
<td>MS</td>
<td>Multimodal Substitution scenario</td>
</tr>
<tr>
<td>NSTR</td>
<td>Nomenclature uniforme des marchandises pour les</td>
</tr>
<tr>
<td></td>
<td>Statistiques de Transport, Revisée</td>
</tr>
<tr>
<td>O-D</td>
<td>Origin-Destination</td>
</tr>
<tr>
<td>PAM</td>
<td>Partially Aggregate Matrix</td>
</tr>
<tr>
<td>RMSE</td>
<td>Root Mean Square Error</td>
</tr>
<tr>
<td>RP</td>
<td>Revealed Preference</td>
</tr>
<tr>
<td>S</td>
<td>Substitution scenario</td>
</tr>
<tr>
<td>SBI</td>
<td>Standaard BedrijfsIndeling</td>
</tr>
<tr>
<td>SEM</td>
<td>Single European Market</td>
</tr>
<tr>
<td>SP</td>
<td>Stated Preference</td>
</tr>
<tr>
<td>TEM</td>
<td>Transport Economisch Model</td>
</tr>
<tr>
<td>TP</td>
<td>Transportation Problem</td>
</tr>
<tr>
<td>VAT</td>
<td>Value Added Tax</td>
</tr>
<tr>
<td>VOT</td>
<td>Value Of Time</td>
</tr>
</tbody>
</table>
Summary

Cross-border freight flows in Europe have, throughout the decades, grown at a substantially higher rate than domestic transport. This growth pattern is expected to persist during the gradual implementation of the Single European Market. Research on the prospects of a unified Europe has, however, hardly touched upon the effects of this unification on the spatial development of freight flow patterns and the resulting changes in usage of the infrastructure networks of different modes of transport. Existing studies on problems in freight transportation policy at the European level, directed at a quantitative analysis, have been restricted in their scope, mainly due to the limited availability of suitable instruments and data. The need for a new and practicable approach towards freight transport modelling for the investigation of these issues seems high, given the rate at which strategic decisions are made in this area.

The main objective of the study is to design and demonstrate a model of freight transportation in Europe. The intended group of users of this model consists of policy analysts and transportation planners, who advise government on long term transportation policy. In order to identify their modelling needs, we address the following research questions:

- what are the main issues in European freight transportation policy? Given these issues,
- to what extent are existing data and modelling approaches sufficient for studying the effects of policy on European freight transport flows?
Summary

In Chapter 2, the first of these questions is treated by introducing a conceptual model of the freight transportation system. With this conceptual model, the framework is given for the identification of policy issues, data and modelling approaches. The analysis of the freight transportation system is done at three levels: the locational level, involving the processes of production and consumption, the relational level, involving the process of distribution of goods, and thirdly, the level of transport operations, involving the transportation of goods. Each one of these processes can be studied at different levels of spatial detail, by means of models of the decision making processes of the agents involved. The identification of policy issues is done by expressing these issues as information concerning a set of objectives, policy measures and background developments. These components are discussed by using the recent policy-oriented literature. The focus is limited to issues that on the one hand are of specific interest on the European level and on the other hand have a direct relation to freight flows. Seen from this European perspective, the need to enhance the interconnection and interoperability of transport networks focuses on two dimensions: one which is geographical (national versus international networks) and one which is functional in nature (the networks of different modes of transport). These two aspects, multimodality and the international barriers for trade and transportation, will play an important role throughout the thesis. The inventory of available data focuses on two dimensions, one concerning the three levels of analysis, the second concerning the levels of aggregation at which the system is represented. The data that are necessary to model processes in the system at the level of individual firms are limited, while their sampling would require enormous financial and organisational efforts. Therefore, the modelling will have to take place using aggregate data.

In Chapter 3 the existing modelling approaches are reviewed with respect to the policy issues identified and their data needs. The modelling approaches concern the mathematical models of the freight transportation system at different levels, as well as applications of such models that focus on European freight flows. In the review we find that the research in freight transport modelling has paid relatively little attention to the issue of multimodality, even though these models have been applied in the area of passenger transport for quite some time. Further we note that the spatial price equilibrium approach, and its generalised version are closely related to the interaction models in passenger transport modelling. We show that in analogy with the interaction model these equilibrium models simultaneously treat processes at the three levels, neglecting, however, variations in the preferences of decision makers. At the level of transport operations, we find that probabilistic models of route choice have not yet been applied in the area of freight transport. Deterministic approaches, however, will not be able to deal with heterogeneity in the attributes of goods. This is an important issue, particularly within a multimodal context.

Chapter 4 gives a short synthesis of the needs and possibilities for modelling freight transport flows at the European level. As a framework for model design, we introduce the Information System for Goods transport (ISG). This application is implemented as a Geographic Information System and comprises a description of the European freight transportation system. This description emphasises the structural aspects of the system, in particular the regional and the network characteristics. As such the ISG provides the framework for the further design of the functional aspects of the system, in terms of a number of choice models to describe the formation
of freight transport demand. Based on the existing features of the ISG and the modelling needs and possibilities identified in the previous chapter, three areas are identified in which model innovation can take place. These concern: firstly, a multimodal distribution model, taking into account international barriers for trade and transport; secondly, a probabilistic route choice model for a multimodal network, and thirdly, the explicit treatment of heterogeneity in users' preferences concerning transport time.

In Chapter 5, a new distribution model is introduced for freight transport, which is derived as a model of joint choice of origin, destination and transport mode. In addition to the usual distribution models, this model is sensitive to changes in the regional accessibility variables, in the value of time of goods moved by different modes and in the magnitude of international barriers to the distribution of goods. It is shown that if the multimodal distribution model is formulated with separate access and egress costs whose magnitude depend on the region in question, the regional access and egress costs cannot be identified separately by estimation from observed origin-destination flows. Two other versions of this distribution model are proposed which consider either region-generic or region specific access/egress costs. A method is developed to estimate the unknown variables using the available format of origin-destination data at the European level. These data concern a partially aggregate matrix, where international flows are only known at the country by country level.

The unimodal and the two multimodal versions of the model are then estimated using data concerning the countries Belgium, the Netherlands, France and Germany and the three mode road, rail and inland waterways. The results of the estimations indicate that existing flows can be reproduced to an acceptable degree. The magnitude of barriers to international distribution is determined for all modes. They appear to be of considerable magnitude, equivalent to 150 to 300 km. of transport distance in road freight transport up to 1200 km. of distance in rail transport. In inland waterways, these barriers are relatively low. Both in terms of regional accessibility and international barriers, the Netherlands stands out among the countries studied. Regional access/egress costs are relatively high towards the rail network and relatively low towards the inland waterways network. Interestingly, barriers appear to be highly asymmetric for rail transport in connection with the Netherlands.

In order to illustrate the applicability of this model, we make a projection of freight flows for the case that the identified barriers vanish completely. Two scenarios are distinguished for the reaction of decision makers in the freight transportation system, depending on whether the generation of new interactions in the system is permitted. In the second case, we further distinguish two possibilities as regards the possibility for changes in the balance between modes on O-D relations. All the cases studied indicate that there is a considerable potential for generation as well as redistribution of freight flows, involving a growth on certain interregional relations of several times the present volumes. In particular the German-French relation and the rail mode appear to profit from disappearing barriers. The effects at the network level appear to be less severe, however, due to the additive effect of the assignment of different origin-destination pairs.
Summary

In Chapter 6, the issue of multimodality is treated at the level of transport operations, focusing on intermodal transport chains as an alternative for unimodal transportation. Intermodal transport chains concern the use of multiple modes on a door-to-door transport with transshipment underway between the respective modes. The general approach for the analysis of the efficiency of these intermodal transport alternatives concerns the treatment of the transport choice problem as a route choice problem within a multimodal network. This allows a flexible formulation of the different components of an intermodal transport chain, including access, transshipment, waiting, egress and so on. As observed in Chapter 3, until now, this approach has been restricted to deterministic models of route choice only. We highlight the theoretical and practical problems of methods to deal with uncertainty in the choice process. Working within the context of route choice in a network, the additional requirement must be satisfied so that the dependence between transport alternatives due, for example, overlapping routes is allowed for in the choice model. The probit choice model allows for this interdependence to be taken into account; however, the conventional probit model with homogeneous preferences does not account for the heterogeneity of goods in terms of their physical and logistical requirements. Therefore, we choose to specify a probit route choice model with random values of time.

From the existing methods for estimating route choice probabilities, the simulative method based on network costs at the link level turns out to be a feasible approach. The method is operationalized by enumerating alternative transport chains. During the simulation it is assumed that within each intermodal alternative, all segments of the chain are valued in exactly the same manner. For an illustration of the working of the model, the parameters of the model are estimated for the case of the simultaneous choice of port of transshipment and mode of transport on the relation between a region in the United Kingdom and one in Germany. The estimation results appear to sustain the assumption of minimisation of generalised costs in the routing of freight flows. Thus we conclude the specification and estimation of a probabilistic multimodal route choice model.

The main conclusions and recommendations of this study are:

- Seen from an international perspective, the effect of international barriers to the distribution of goods and the issue of multimodality in freight transportation has received relatively little attention in the modelling literature. Existing modelling approaches must be expanded to accommodate for these issues.

- Uncertainty in the system has only been represented to a limited extent. In the choice among different approaches towards modelling freight transport at the European level, the requirement of a plausible behavioural basis for a choice model favours the approach usually taken in passenger transportation system models, i.e. a probabilistic framework for modelling choice.

- By formulating a multimodal distribution model with international barriers to distribution, we have found that there are considerable differences between modes in terms of their role in the accessibility of regions and the magnitude of the existing barriers. When studying optional
policy measures for changing the balance among transport modes, the effects of changes in these barriers should be taken into account. The effect of generalised transport costs on the intensity of freight flows appears to give similar patterns for different modes, once we allow for variations in the goods' value of time.

- A multimodal route choice model was formulated for complex choice situations involving combinations of different modes into intermodal transport chains. An approach towards the solution and estimation of a stochastic choice model with random values of time was proposed. A tentative test of the mode supports the assumption of minimisation of generalised costs within this context.

- Topics recommended for future research in freight transportation modelling concern 1) the generalisation of the multimodal distribution model in terms of the value of time variable, 2) a causal analysis of international barriers to trade and transport, 3) the valuation of other service variables at the levels of distribution and generation, 4) the integrative use of the proposed models for route choice and distribution for the modelling of international transport chains and 5) the design of user-friendly applications such as the ISG.
Summary
Samenvatting (Summary in Dutch)

Het modelleren van Europese goederenvervoersstromen

Het onderzoek naar goederenvervoer in Europa heeft lange tijd in de schaduw gestaan van enerzijds onderzoek naar het vervoer van personen, anderzijds vervoer binnen landsgrenzen. Het grensoverschrijdende perspectief krijgt echter steeds meer aandacht nu de economische integratie van Europese landen ook formeel uitwerking krijgt. De informatiebehoeften ter ondersteuning van het goederenvervoerbeleid in internationaal perspectief heeft hierbij betrekking op enerzijds veranderingen in het volume en de ruimtelijke patronen van de vervoersvraag, anderzijds op de manieren waarop deze vervoersvraag afgewikkeld kan worden. Gezien het belang van een adequaat instrumentarium voor de kwantitatieve ondersteuning van het goederenvervoerbeleid op Europees niveau is een herijking van de huidige modellen aan de actuele beleidsvragen noodzakelijk. Deze mathematische modellen voor de beschrijving en analyse van het goederenvervoerssysteem zijn het onderwerp van dit onderzoek.

De doelstelling van het onderzoek is het ontwerp en de toepassing van een mathematisch model ter beschrijving van goederenvervoersstromen in Europa. De beoogde groep van gebruikers van een dergelijk model bestaat uit beleidsanalisten, verkeersplanologen en anderen die overheden van advies voorzien omtrent het te voeren beleid ten aanzien van het goederenvervoer vanuit het
Samenvatting

Europese perspectief. Voor het vaststellen van de behoefte aan nieuwe modellen in deze context worden eerst de volgende vragen behandeld:

- wat zijn de huidige beleidsvragen die op Europees niveau spelen ten aanzien van het goederenvervoer?
- in hoeverre kunnen de huidige modellen en gegevensverzamelingen toegepast worden voor het beantwoorden van deze vragen?

Deze vragen worden behandeld in hoofdstukken 2 en 3 van de dissertatie, en dienen als uitgangspunt voor het modelontwerp. In hoofdstuk 4 wordt een synthese gegeven van de vastgestelde problematiek, en wordt een oplossing, dat in eerste instantie breder van functie is dan het beoogde model, als ontwerpkader aangedragen. Hierbij wordt de keuze gemaakt uit te gaan van momenteel vrij beschikbare gegevens omtrent het Europese goederenvervoer. Het ontwerpgericht gedeelte van de studie, in hoofdstuk 5 en 6, werkt een tweetal onderdelen van de aangedragen oplossing in detail uit.

In hoofdstuk twee wordt, ter behandeling van de eerste vraag, een conceptueel model geïntroduceerd van het goederenvervoersysteem, om het raamwerk vast te leggen waarbinnen de inventarisatie van beleidsvragen, gegevensverzamelingen en modellen zal plaatsvinden. Hierbij wordt gesteld dat een analyse van het vervoersysteem zich op drie detailniveaus kan afspelen: het niveau van locaties van vertrek en aankomst, dat van relaties voor handel en distributie en dat van de vervoeroperaties. Deze processen kunnen vervolgens op verschillende ruimtelijke schaalniveaus, aan de hand van modellen van het keuzegezag van individuele ondernemers beschreven worden. Beleidsvragen, modellen en gegevensverzamelingen zullen zo steeds betrekking op een of meerdere aspecten van dit systeem. Het begrip beleidsvraag wordt ontleend als een informatiebehoeftes die betrekking heeft op een samenstelling van doelstellingen, toekomstbeelden, externe ontwikkelingen en beleidsmaatregelen. Aan de hand van recente beleidsnota's worden deze componenten één voor één nader uitgewerkt. Hierbij blijft de analyse beperkt tot zaken die zich enerzijds met name op het Europese niveau manifesteren en anderzijds direct van invloed zijn op de huidige of te verwachten goederenvervoersstromen.

De onderzoeksvragen, die recentelijk in de Europese context naar voren zijn gebracht, leggen met name de nadruk op samenhang tussen netwerken van verschillende landen en van verschillende transportmodaliteiten. Twee aspecten die dus sterk naar voren komen als zijnde specifiek voor het Europese vervoerbeleid zijn het slechten van de internationale barrières voor handel en transport en de verdeling van goederenstromen over verschillende vervoerwijzen. Ten slotte wordt een kort overzicht gegeven van de beschikbaarheid van verschillende soorten gegevens op Europees niveau. De gegevens die nodig zijn om op het niveau van individuele zendingen bepaalde keuzeprocessen te modelleren zijn niet aanwezig; het verzamelen hiervan vereist een enorme financiële en organisatorische inspanning. Dit legt een belangrijke randvoorwaarde op aan het modelleren van het goederenvervoer.

In het derde hoofdstuk worden de huidige modellenaderingen beschreven en geëvalueerd ten aanzien van de mate waarin aan de beschreven beleidsvragen uitwerking is gegeven. De
modelbenaderingen betreffen enerzijds uiteenlopende mathematische beschrijvingen van het systeem op ieder van de drie bovengenoemde niveau's, anderzijds betreffen het informatiesystemen, die gebruik maken van deze modellen en ingebed zijn in de specifieke context van het Europese goederenvervoer. Eén van de vindingen van de studie is dat, op het vlak van de interactiemodellen, een multimodale aanpak van het goederenvervoer tot dusverre nog is uitgebleven, ofschoon de hiervoor toepasbare methoden en technieken in het personenvervoer reeds langere tijd aanwezig zijn. Daarnaast wordt geconstateerd dat het in het goederenvervoer toegespaste model voor goederenstromen volgens het ruimtelijk prijsevenwicht een beperkte representatie is van het in het personenvervoer gebruikelijke interactiemodel. Er wordt aangetoond dat hier van kostenminimaliserend gedrag wordt uitgegaan, zonder rekening te houden met enige heterogeniteit in goederenkenmerken. Op het vlak van de toedelingsmethoden in unimodale, en ook multimodale netwerken wordt geconstateerd dat de stochastische routekeuze nog nauwelijks ingang heeft gevonden in modellen voor het goederenvervoer. Ook hier zal echter heterogeniteit van goederen, met name in een multimodaal kader, een grote rol blijken te spelen. De belangrijkste conclusie van dit hoofdstuk is dat met name het aspect van onzekerheid tot nog toe onderbelicht is gebleven in het onderzoek aan goederenvervoermodellen.

Hoofdstuk vier bevat een korte terugblik op de geconstateerde behoeften en mogelijkheden tot het verbeteren van het huidige instrumentarium. Als kader voor de te volgen ontwerpeggericht fase wordt het InformatieSysteem voor het Goederenvervoer (ISG) geïntroduceerd. Dit is een op een geografisch informatiesysteem gebaseerde applicatie, waarin een beschrijving van het Europese goederenvervoersysteem is opgenomen. Deze beschrijving is sterk georiënteerd op de structurele aspecten van het goederenvervoersysteem, met name de regional karakteristieken en het infrastructuurnetwerk. Hiermee vormt dit informatiesysteem het kader bij uitstek voor een specificatie van de functionele kant van het goederenvervoersysteem, d.w.z. de keuzemodellen die het mechanisme beschrijven voor het ontstaan van goederenstromen. Aan de hand van de huidige opzet van het ISG wordt aangegeven met welke specifieke modellen een uitbreiding kan plaatsvinden, die tegelijk uit praktische overwegingen (gegeven de beschikbare data) en theoretische overwegingen (gegeven de noodzaak tot nieuwe modellen) zinvol is. Deze betreffen een distributiemodel en een probabilistisch routekeuzemodel, beide opgezet binnen een multimodaal kader. Hierbij wordt uitgebreid aandacht besteed aan de keuzefactoren die in de nieuwe keuzemodellen opgenomen moeten worden; met name aan tijd en het belang ervan in het goederenvervoer wordt nadere invulling gegeven.

In hoofdstuk vijf wordt een nieuw distributiemodel geïntroduceerd, waarin het heterogene karakter van het goederenvervoer verder is uitgewerkt. Het model is een aangepaste formulering van het distributiemodel in het personenvervoer. Een belangrijk kenmerk is de beschrijving van verschillen in regionale bereikbaarheid tussen vervoerwijzen en regio's. Daarnaast wordt rekening gehouden met internationale barrières voor handel en transport voor verschillende vervoerwijzen. De rol van alternatieve vervoerwijzen in de ruimtelijke distributie komt tot uitdrukking in verschillende tijdwaarderingen. Voor het model is een schattingsmethode ontwikkeld die toepasbaar is voor de beperkte beschikbare gegevens op dit gebied.
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De parameters van het model zijn geschat voor het vervoer tussen de regio’s van de landen Nederland, België, het voormalige West-Duitsland en Frankrijk. Er blijkt een hoge correlatie te bestaan tussen de geschatte en de waargenomen vervoersstromen. De geschatte internationale barrières zijn in eerste instantie in termen van afstand uitgedrukt; via een eenvoudige aannames aangaande de tijdwaardering zijn deze echter ook in kostentermen weer te geven. De barrières blijken in het wegvervoer equivalent te zijn aan een afstand van 150 tot 300 km, in het railvervoer lopen deze op tot zo’n 1200 km; in de binnenvaart daarentegen zijn deze weerstanden nagenoeg afwezig. Uit de regionale bereikbaarheidswaarden die uit de schattingen naar voren komen blijkt gemiddeld genomen dat, in vergelijking met de overige Europese regio’s, Nederland matig bereikbaar is per spoor, en uitstekend bereikbaar is over water.

Het ontwikkelde model is een instrument waarmee ook het effect van een verandering in deze variabelen op vervoersstromen berekend kan worden. Ter illustratie wordt een projectie gemaakt van het interregionale goederenvervoer in het studiegebied, onder invloed van veranderende grenswaarden. Om de nadruk te leggen op de ruimtelijke component van veranderingen in distributiepatronen wordt in deze case studie een volledige integratie, d.w.z. het compleet wegvallen van de huidige barrières verondersteld. Voorts worden een tweetal scenario’s ontwikkeld voor de wijze waarop bedrijven kunnen reageren op toegenomen mogelijkheden voor handel en transport. In het ene scenario wordt uitgegaan van ruimtelijke en modale herdistributie van de bestaande regionale import en export. In het tweede scenario wordt ervan uitgegaan dat het kostenvoordeel resulterend uit de weerstandsverlaging op internationale relaties volledig wordt omgezet in nieuwe -internationale- uitwisseling van goederen. Beide gevallen geven een aanzienlijke verschuiving van goederenstromen weer, niet alleen in termen van volume; ook het ruimtelijk patroon en de modale verdeling blijken gevoelig te zijn. Zo groeit naar verhouding het Duits-Franse vervoer het sterkst, terwijl railvervoer enigszins in aandeel wint.

Het zesde hoofdstuk behandelt een nieuw model voor simultane vervoerwijze- en routekeuze. Het principe van het model is dat de vorming van transportketens wordt benaderd door de vervoerwijze als onderdeel van een route te zien. Dit betekent dat ook overslag tussen vervoerwijzen tot de mogelijkheid behoort. Dergelijke representaties van het netwerk in het routekeuzeprobleem hebben recentelijk ingang gevonden in het goederenvervoer; echter, de modellen voor de simultane keuze tussen vervoerwijzen en route’s op linkniveau zijn tot nog toe deterministisch van karakter geweest. Gezien de theoretische en praktische problemen die dergelijke modellen met zich meebrengen is uitbreiding naar stochastische modellen noodzakelijk. Voor de nodige uitbreidingen is wederom gekeken naar ervaringen met modellen voor het personenvervoer.

De stochastische routekeuzemodellen worden ingedeeld in drie types: in het eerste type, het conventionele random-nuts routekeuzemodel, worden alle variaties in de routekosten geregaleerd door een algemene stochastische foutterm in de kostenfunctie; het tweede type houdt in plaats daarvan uitsluitend rekening met variaties in gebruikersvoorkeuren (zoals uitgedrukt in bijvoorbeeld de tijdwaardering). Het model dat in deze studie geformuleerd wordt is van het derde type; variaties in routekosten als gevolg van spreidingen in gebruikersvoorkeuren worden hier gescheiden weergegeven van andere verstorende oorzaken. Dit modeltype geeft een
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meer volledige verklaring van het keuzgedrag. Hiermee wordt het -als uitbreiding op het model van het eerste type- mogelijk onderscheid te maken naar verschillende gebruikersgroepen. Anderzijds wordt het probleem van instabiliteit van keuzeresultaten ten aanzien van netwerkeigenschappen in het tweede modeltype ondervangen.

Van de bestaande methoden ter schatting van routekeuzeaandelen blijkt de simulatieve methode, zoals eerder toegepast in personenvervoernetwerken, het best aan te sluiten bij de eisen die dit keuzeprobleem stelt. Ter illustratie van de werking van het model wordt een schatting gemaakt van de onbekende modelparameaters voor de keuze van overslaghaven en vervoerwijze tussen een Engelse en een Duitse regio. De schattingseresultaten blijken de aannemen van het streven naar minimale gegegeneraliseerde transportkosten in het keuzeproces te ondersteunen. Hiermee wordt de specificatie en schatting van een probabilistisch multimodaal routekeuzemodel voor een specifieke keuzesituatie afgesloten.

De voornaamste conclusies en aanbevelingen waar deze studie naar modellen voor het Europese goederenvervoer aanleiding toe geeft zijn de volgende:

- Vanuit het internationaal perspectief bezien hebben de structurerende werking van internationale barrières en de balans over vervoerwijzen relatief weinig aandacht gekregen in de beleidsondersteuning van het goederenvervoer. Voor studies in deze richting dienen huidige modellen benaderingen uitgebreid te worden.

- In de keuze tussen verschillende benaderingen voor het modelleren van keuzegdrad van actoren in het goederenvervoersysteem verdienen op het hier gehanteerde aggregatienniveau van Europese regio's probabilistische keuzemodellen de voorkeur. In tegenstelling tot het goederenvervoer is in het personenvervoer ruime ervaring opgedaan met dergelijke modellen.

- Door het distributiemodel met grensweerstanden vanuit een multimodaal optiek te formuleren is gebeke te maken dat er aanzienlijke verschillen bestaan tussen vervoerwijzen in termen van de rol die ze spelen in de regionale bereikbaarheid en de huidige barrières voor uitwisseling van goederen tussen landen. Daarnaast zijn de relatieve tiijwaarderigen afgeleid die gelden voor goederen die met deze vervoerwijzen worden vervoerd.

- Het multimodaal routekeuzemodel verdient nieuwe aandacht in het licht van het belang dat wordt gehecht aan het intermodale alternatief in het goederenvervoer. Om aan deze problematiek nadere uitwerking te geven, is een stochastic alternatieve routekeuzemodel geformuleerd en geschikt voor een specifieke keuzesituatie. De resultaten blijken de aannames van kostenminimalisatie in het routekeuzeproces te ondersteunen.

- Tenslotte worden de volgende onderwerpen aangedragen voor verder onderzoek: 1) het generaliseren van het multimodaal toedelingsmodel aan aanzien van de tiijwaarderingenvariabele, 2) een causale analyse van internationale barrières voor handel en vervoer, 3) nader onderzoek naar de waardeing van andere factoren dan tijd in de beslissingen betreffende distributie en generatie van goederenstromen, 4) een integratie van de voorgestelde modellen voor distributie en simultane route- en vervoerwijzekeuze voor het modelleren van transportketens en tenslotte 5) het ontwerp van gebruikersvriendelijke applicaties zoals het gepresenteerde ISG.
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Curriculum Vitae

Lóránt Tavasszy was born in Hasselt, Belgium in 1967. He obtained his degree in Civil Engineering at the Delft University of Technology in 1991. He carried out his undergraduate thesis project in the field of transportation modelling at the Rheinisch-Westfälische Technische Hochschule in Aachen, Germany within the framework of the ERASMUS exchange program. His research on the strategic modelling of freight transportation within Europe was in part financed by the Dutch Ministry of Transport, Public Works and Watermanagement. During the research he took part in a policy analysis of Dutch freight transportation to perform an audit of the existing modelling tools in the Netherlands. Between 1991 and 1994 he was the secretary of TU-RIL, a steering group for interdisciplinary research at Delft University in the field of freight transportation and logistics. As a university staff member he assisted students throughout the Civil Engineering curriculum. At present he is a research consultant at the TNO Institute for Infrastructure, Transportation and Regional Development.