Port Investment
Towards an Integrated Planning of Port Capacity

Sander Dekker

Port Investment
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Proefschrift

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus prof. dr. ir. J.T. Fokkema,
in het openbaar te verdedigen ten overstaan van een commissie,
door het College voor Promoties aangewezen,
op woensdag 29 juni 2005 om 10:30 uur

door

Sander DEKKER

civiel ingenieur

geboren te Den Helder

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TRAIL Thesis Series no. T2005/5, The Netherlands TRAIL Research School

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ISBN 90-5584-065-3

Printed in the Netherlands

Preface

Capacity planning is an interesting point of view from which the port investment problem can be dealt with. It offers the opportunity to present the full scope of strategic design of infrastructure systems. Much of the material on this topic is to be found dispersed throughout the literature on related disciplines such as civil engineering and economics. The challenge is to combine the knowledge of these disciplines in order to develop a methodology for capacity planning. This thesis aims to do that. The present work is however not intended to solve all problems involved; luckily, there are some issues left for further study.

From my former professor of Calvinistic Philosophy, Egbert Schuurman, I learnt how important it is to make your assumptions explicitly. It forces a scientist to consider his work thoroughly and it leads to clear starting points for the academic debate. These are important conditions for further improvement of any scientific work. The present thesis starts from the assumption that the efficiency concept offers an appropriate point of view for scientific analysis of infrastructure systems and engineering of alternatives.

Extended discussions on the theoretic foundations of the economic concepts applied are not given. Although I do not want to trivialize the importance of such discussions, it is my aim to apply economic concepts in order to solve an engineering problem. The economist is doing economics and the engineer contributes to pragmatic solutions. I am and continue to be an engineer!

Since it is impossible for me to extend acknowledgments to all those who have helped me during this research effort, I will attempt to mention particularly those who have had the strongest influence on my thinking of the subject and on writing about it. In particular the members of the former Section of Infrastructure Planning and the students I guided during their graduation projects should be noted for their stimulating interest.

The secretaries Ylva de Haan, Sandra Hagman and Maaike Holland were essential in supporting me. Berry Bleijie, Michiel de Bok and Piet Opstal helped me in dealing with software issues and making some maps. Barry Zondag (RAND Europe/TUD), Maurits van Schuylenburg (Port of Rotterdam) and Paul Wiggenraad (TUD) provided me the necessary data.

Enne de Boer, professor Bovy, professor Ligteringen, professor Rietveld, professor Roos, Henrik Stevens and professor Van de Voorde commented on earlier drafts of parts of this thesis. Professor Albert Pols showed me the importance of studying the combination of capacity and utilization, pointed me at useful literature, and was co-author of some of the papers I wrote.

My supervisor professor Frank Sanders gave me his confidence, helped me with many practical advices, and encouraged me to focus on my own ideas. My daily supervisor and co-author of most of my papers, Robert Verhaeghe, read earlier drafts and provided invaluable ideas and encouragement during the research process, and often improved my English considerably.

The support of research school TRAIL was important for the completion of this thesis.

Finally, all the members of my family contributed to this thesis in many more ways than they realize. To all of them I give my gratitude. Most of all, I thank my wife Marlous. Without her love, patience and understanding, this work would have never been completed nor would it have been inspired. I dedicate this thesis therefore to her.

Delft/Leiden, April 2005 Sander Dekker

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1. Introduction

1.1 Port Investment

In recent years, rapid changes in logistics and transportation technology have been observed. For example, increasing attention for supply-chain efficiency has lead to containerization, which caused a revolution in design and operation of freight transportation modes and cargo-handling facilities. This served, in turn, as a stimulus for integration of ocean and land transportation services making logistic chains more flexible (i.e. less bound to certain transportation routes). As a result, international freight flows became more volatile causing a constant pressure on ports to remain competitive.

For example, container transport between Barcelona in Spain and the Ruhr Basin in Germany, normally via Rotterdam (Figure 1.1a), could be shorter and faster if it goes via Marseille (Figure 1.1b) (see VROM, 1997). If such a shift of container flows can be established, Rotterdam may react on this to maintain its market share.

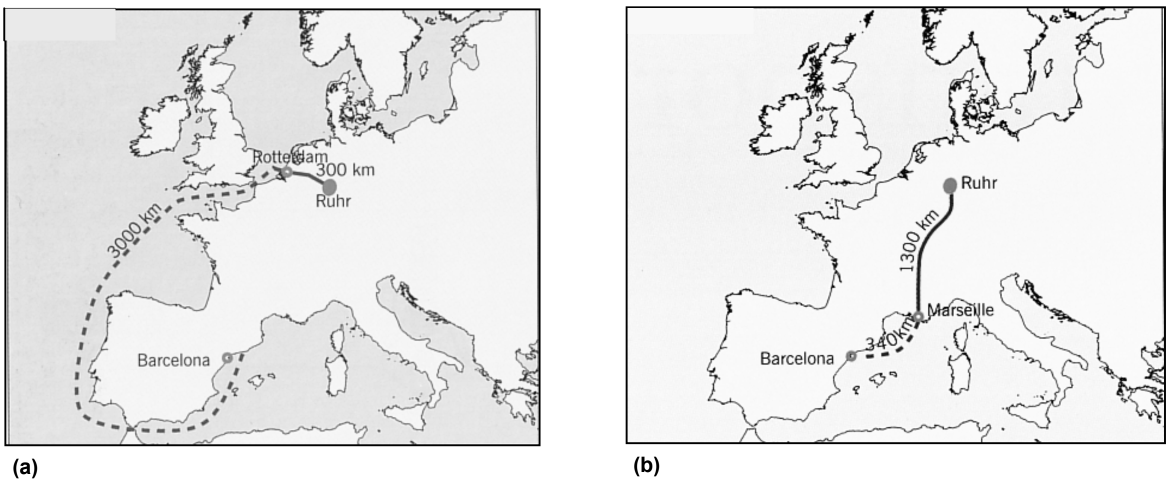

FIGURE 1.1 Hypothetical shift of container flows from Rotterdam to Marseille (adapted from VROM, 1997).

To respond to such pressure and to allow for autonomous demand growth, many maritime nations have initiated port investment programs. For example, Frankel (1998) reported about a Chinese program that entails annual investments of more than $2 billion. Luberoff and Walder (2000) presented an overview of substantial investments in U.S. ports between 1996 and 2001. With regard to the Netherlands, the construction of a freight railway between Rotterdam port and Germany - the *Betuwe freight line* – and plans for a second seaward expansion of the Rotterdam port area – the *Maasvlakte 2* project – should be noted.

Port investment essentially aims at more efficient cargo-handling processes. This causes first of all transport-efficiency gains - lower service times and costs - for port users (freight carriers) and commercial benefits for port operators representing the private goal of port investment. If transport-efficiency gains are passed on to society, it leads to the ultimate (public) goal of port investment, namely, "to increase producers' surplus of those who originate the exports passing through it, and to increase the consumers' surplus of those who ultimately consume the imports passing through it" (Goss, 1990a, p. 211).

Many governments contribute to port investments in their countries with a view on benefits for its users, operators and society. Such contributions compete however with other public investment opportunities. Subsidies for port investment in a country should only be provided if the usefulness of port investment to the nation (here: a positive net economic benefit) is demonstrated. A complicating factor is the 'leakage' of port investment benefits to other countries if a substantial part of the port's throughput comprises non-domestic (transhipment and transit) flows[1]. The question then is whether a government should also invest for the benefit of other countries.

Government subsidies are not needed if port investments are self-financing, which means essentially that port users pay the investments via the price for port services. This could take the form of surcharges (extra fees) on the use of port facilities. The fact that ports operate in a global network characterized by competition complicates this self-financing principle due to potential shifts of freight carriers to competing ports without or with lower surcharges.

A major question is to what extent large-scale port investment such as surface area expansion can be used to recover a lost market share. Important inter-related questions are what the optimal investment should be and whether such investment can be self-financing. In the present study, a methodology for planning of a port's capacity will be developed, which can be used to answer these questions. The challenge is to integrate the commercial perspective of the port owner - addressing investment recovery - with the public role of ports - addressing economic performance – in strategic port planning.

1.2 Infrastructure and Capacity

The term *infrastructure*, according to Jansson (2000a), originates from the Latin word 'infra', which means 'situated below'. Originally, it was a military term referring to the static and physical foundation of the logistical organization such as roads, bridges, storage areas and pipelines. Presently, the term infrastructure is also used for non-military facilities and is considered as a basic need for societies to support further development[2]: it provides safety against natural threats and secures the provision of services such as long-distance communication and transportation. A network-type structure can be considered for an

[1] This is particularly true for the ports in the so-called Hamburg-Le Havre range.

[2] Adam Smith pointed out to the economic function of infrastructure in his The Wealth of Nations when he noted that "good roads, canals and navigable rivers, by diminishing the expense of carriage, put the remote part of the country more nearly upon a level with those in the neighbourhood of the town" (Smith, 1999, p. 251).

infrastructure system comprising links and nodes (e.g., Cox, 1972). Examples of links are roads, railways and canals; nodes include railway stations, terminals, seaports and airports.

Capacity is an important characteristic of infrastructure indicating its capability to provide a particular service such as cargo handling services. Changes in capacity can be expressed in terms of service time and cost. According to Manheim (1984), capacity can be defined as the maximum number of items that can be 'squeezed' through a system or its components per unit of time at a certain level of service quality. For example, container port capacity can be expressed in the number of containers that can be handled per year. The effective capacity is determined by the following characteristics (see Ashford and Wright, 1992): 1) design variables such as numbers, sizes and surface areas, 2) quality and reliability of services determined by labor, applied technologies, and service schedules, 3) nature of the demand such as arrival rates and the handling characteristics of the transported items, and 4) environmental factors such as the function of the surrounding area and weather conditions.

Infrastructure is closely linked with logistic services and forms the primary component for it. Logistic services contribute significantly to a nation's economy. The results of a recent study on the contribution of logistics to the Dutch economy in 2001 (Kuipers *et al*., 2003) are illustrative. It appeared that the turnover value of the logistics sector was € 31.3 billion and the creation of value added was € 17.3 billion, representing 4.4% of Dutch gross national product (GNP). In addition, many logistic services facilitate other types of business.

Being aware of the importance of logistics for the national economy, the Dutch Advisory Board for Transport, Public Works and Water Management initiated a study on innovations in logistics. This study resulted in June 2003 in an advice addressed to the Dutch government (RVW, 2003). It emphasizes the importance of efficient logistic systems for the competitiveness of the Dutch economy, and the need to implement policy that supports the Dutch position in international logistics. The removal of infrastructure bottlenecks is considered to be a crucial challenge for such policy for the coming years.

Planning for infrastructure is essentially establishing an optimal capacity at the appropriate time and place. The type of the capacity measure (physical expansion or less capital-intensive alternatives) is a major concern. Another important but dependent concern involves the optimal utilization of the facilities being added. For example, the demand for transportation services in the links of a transportation network highly depends on the level of traffic congestion in the links, which depends, in turn, on the utilization rate.

Figure 1.2 illustrates schematically the interdependence of demand for infrastructure services, supply of infrastructure capacity, costs and the price for services. Starting with determination of the demand for services, a matching supply of capacity is to be established that results in some costs. A complete analysis would recognize that the costs influence the price charged for the services, which, in turn, affects the demand.

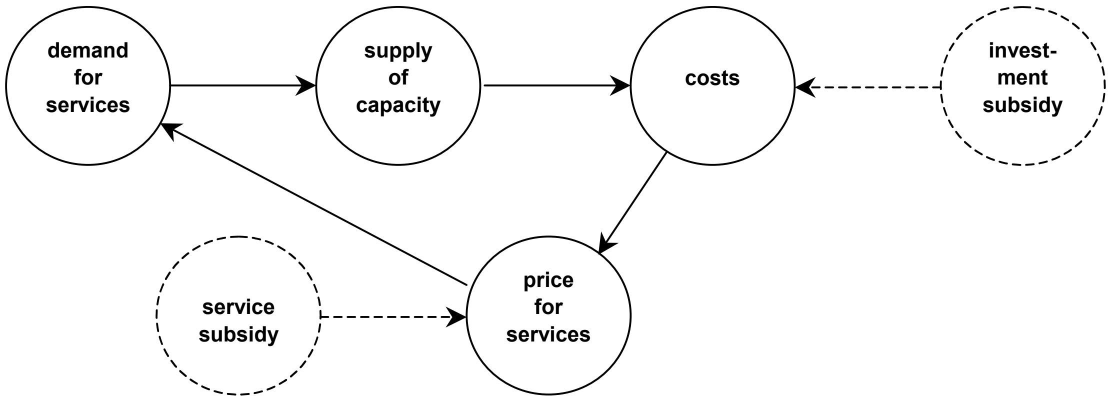

FIGURE 1.2 Interdependence of demand, supply, costs and price (adapted from Freidenfelds, 1981).

Ideally, the entire demand/supply/costs/price problem would be solved simultaneously (see Freidenfelds, 1981). However, many questions arise, for instance, with respect to pricing assumptions. Should the users pay for the infrastructure services (is the facility a private good) or not (is the facility a public good)? If so, should the price be assumed to vary with the utilization rate? Further complications may come by the question whether the government should provide subsidy to promote 'socially acceptable' costs or prices. For example, investment subsidy may lead to lower prices, which attracts additional demand, and without service subsidy, there may not be a price/demand to recover the cost of providing passenger rail services, and the whole rail operation may have to close down[3].

Implementation of infrastructure capacity measures takes place in investment projects. The economic feasibility of such projects is generally evaluated with cost-benefit analysis (e.g., Small, 1995; Eijgenraam *et al*., 2000). The question that should be answered is then: does the investment project lead to economic benefits for owner, users and the rest of society? In addition, infrastructure that combines its public role with a commercial perspective (e.g., a road that is financed by its users) requires a commercial evaluation to analyse the financial feasibility of the investment project.

1.3 Capacity Planning and Capacity Management

Several definitions of capacity planning and capacity management can be found in the literature. Manascé (1999), for instance, defines *capacity planning* as the process of predicting when adequate service levels will be violated as well as determination of the most cost-effective way of delaying system saturation. Referring to Ten Heuvelhof and Kuit (2001), *capacity management* can be defined as the set of decisions that results in a certain capacity including the rules that are used to implement capacity.

[3] See in this context the Dutch discussion on how to deal with 'non-profitable railway lines'. A general introduction on this issue can be found in Berechman (1993). The interested reader is referred to Van Vuuren (2002) for an economic analysis of optimal prices for passenger transport by train.

Here, *capacity planning* will be defined as the technical-economic analysis of matching supply of capacity with the demand for services at a certain quality, and engineering of alternative options to improve that match. A distinction should be made between *operational* planning, which emphasizes what an infrastructure operator should do to deal with short-run (e.g., daily) demand fluctuations for a given capacity, and *strategic* planning, which emphasizes longer term provision of services by the infrastructure owner (e.g., Frankel, 1987). The scope of the present study is strategic planning.

Capacity management will then be defined as the managerial response of the infrastructure owner to service problems (shortages in capacity and over-capacity). Capacity management decisions are based on the outcome of capacity planning. Such decisions can be complex due to, for instance, the difficulty in determining an acceptable level of service quality (e.g., congestion).

Different components for capacity management and planning can be found in the literature (e.g., De Neufville, 1990; Frankel, 1990; Manascé, 1999). Capacity management includes capacity planning and capacity implementation, and capacity planning comprises design, evaluation and financing. The components and inter-relations of capacity management and capacity planning are illustrated in Figure 1.3.

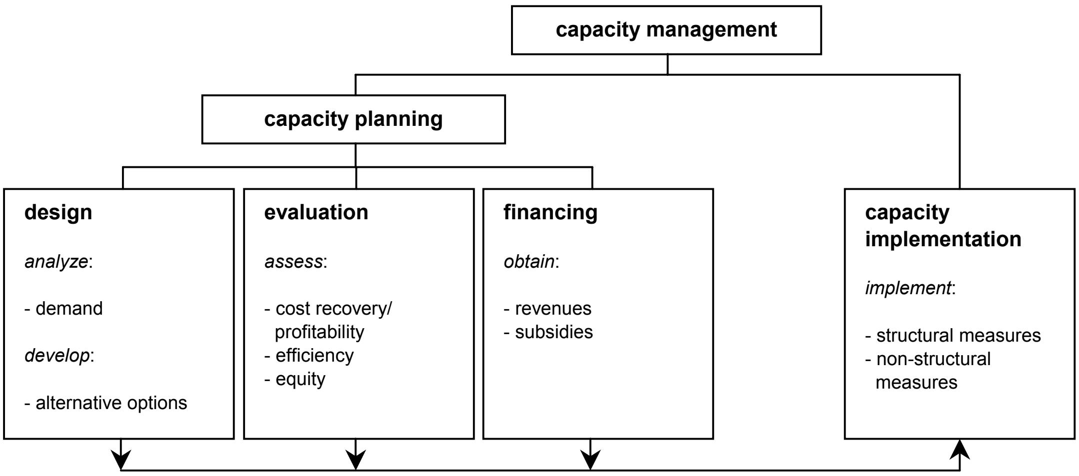

FIGURE 1.3 Components of capacity management and capacity planning.

Design entails the process of demand analysis, and the development of alternative options to affect demand.

Evaluation concerns the process of assessing cost recovery/profitability, efficiency and equity associated with the alternative options.

In general, three scopes of evaluation can be distinguished: financial, economic and social (see Figure 1.4). In this order, they represent an increasingly complex owner/beneficiary situation. For alternatives that are considered from a purely commercial perspective, the financial scope will be sufficient in which cash flow balance and liquidity are most relevant aspects to obtain cost recovery/profitability.

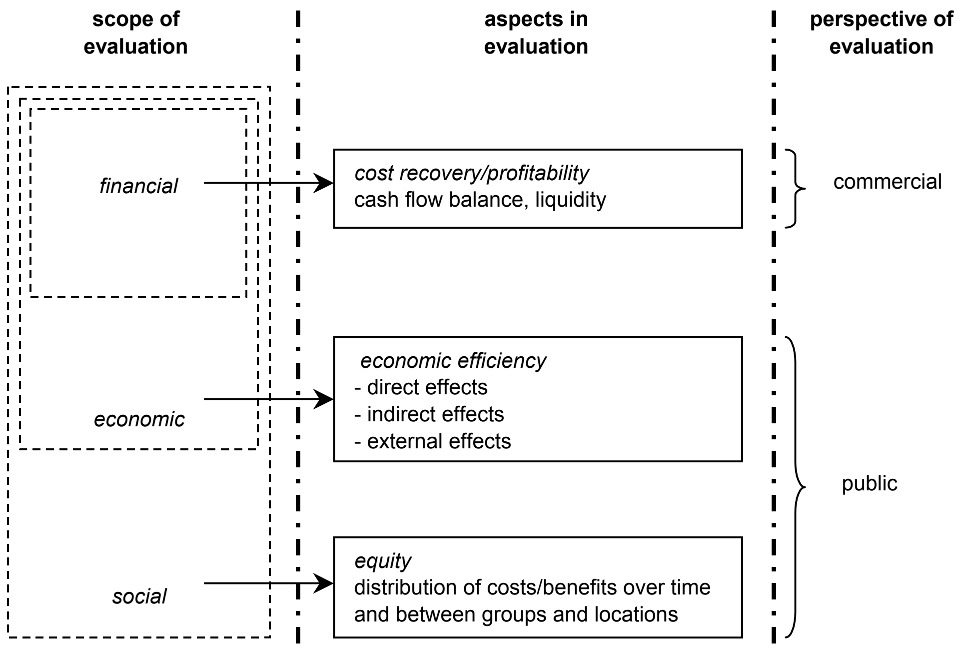

FIGURE 1.4 Scopes and perspectives of evaluation.

For investment projects that are funded by the government, the public perspective should also be accounted for and includes the economic and social scopes[4]. The economic scope addresses the economic-efficiency issue[5], which entails: 1) direct effects (cost savings for users and operator), 2) indirect effects (effects that are passed on to third parties via the pricing mechanism such as multiplier effects), and 3) external effects (effects passed on beyond the pricing mechanism due to, e.g., traffic congestion and environmental pollution). The social scope addresses the equity issue, which comprises the distribution of costs and benefits over time and between groups and locations.

A research effort on the evaluation of infrastructure investments (OEI; Overzicht Effecten Infrastructuur), initiated by the Dutch government, has recently been finalized (Eijgenraam *et al.*, 2000), of which the ultimate goal has been to improve decision-making on such investments. During the last decade, some infrastructure projects have generated quite some controversy about their feasibility and value to the nation's welfare, which spurred this research effort. Although OEI has contributed to a more transparent and systematic framework for evaluation, further research should focus on the estimation of indirect effects (CPB, 2003), and attention should be paid to a clear definition of the reference situation/development (Zondag and Verhaeghe, 2003).

Financing is the activity of obtaining revenues and subsidies to pay for the selected capacity measure, and should be based on the outcome of the evaluation.

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[4] A further (geographical) distinction can be made between the national and international scope of large-scale investment projects. This is interesting with a view on the leakage-issue of investment benefits.

[5] The economic-efficiency issue requires that at least one individual becomes better off without making any other individual worse off (Pareto efficiency).

Capacity implementation comprises the implementation of capacity measures (structural or non-structural according to Frechione and Walker, 2004; capital-intensive or less capital-intensive according to Dekker *et al*., 2002) to reduce service (quality) problems.

It is the planner's task to determine the optimal capacity measure. His aim is financial and economic viability of the associated investment project.

1.4 Issues in Planning of Seaport Capacity

1.4.1 Seaport Capacity

A seaport is basically an area of land and water where ocean vessels can be loaded and unloaded, cargo can be stored, and where hinterland transportation modes can collect and deliver cargo (see Van de Voorde and Winkelmans, 2002). A seaport can further be considered as a link in global transport-logistic chains connecting origins and destinations for freight flows (Suykens and Van de Voorde, 1998).

Port capacity, here defined as a seaport's maximum cargo handling capability, is the combined product of a port's facilities and associated services. Port facilities include land, infrastructure, superstructure, and maritime and hinterland access infrastructure. Port services comprise mainly cargo handling services, which are provided with the help of port facilities.

Planning of a port's capacity is complicated by the presence of the following issues: 1) port-commercial and public interests, 2) competition, 3) economies of scale, 4) capacity problems, and 5) port market and technological development. Particularly interactions between these issues make planning for ports complicated.

1.4.2 Port-Commercial and Public Interests

Planning of a port's capacity requires distinguishing three port actors. First, there is the port owner who provides port capacity. His interests can be considered from the port-commercial perspective. Second, there are port users who demand efficient (i.e. cheap and fast) port services. They represent the freight carriers of which the ocean carriers are considered to be most important (e.g., Malchow, 2001). The third actor is society, which desires the presence of ports due to their contribution to quality of life and economic development, and sets limits for negative effects of port usage such as environmental pollution. Government represents society. For the purpose of this study, the interests of port users and society are considered from the public perspective.

From the public perspective, port capacity can be determined by finding a balance between improved service quality for the port users and (induced) welfare effects on society on one hand, and the associated investment cost of capacity improvement on the other hand. A realistic planning has further to consider the commercial interests of the port owner[6] (Dekker *et al.*, 2002).

The interests associated with the port-commercial perspective include:
- maximization of profit;
- maximization of throughput; and
- investment recovery.

Considering the investment scope of the present study, investment recovery is emphasized in the remainder of this study.

The interests associated with the public perspective are:
- increase of producers' surplus in terms of financial revenues for the port owner;
- increase of consumers' surplus in terms of improved service quality for the port users;
- efficient utilization of scarce resources (e.g., public funds);
- increase of value added and employment, and reduction of environmental pollution; and
- equitable and transparent distribution of costs and benefits.

Within ports, a distinction can be made between public institutions (in some ports the port authority) and private firms (e.g., terminal operators). This is interesting with a view on further disentangling of public and private interests.

1.4.3 Competition

In general, port competition can be categorized into six categories (Goss, 1990b; Meersman and Van de Voorde, 1994; Robinson, 2002) comprising competition between:
- port ranges or coast lines;
- ports in different countries;
- individual ports in the same country;
- operators or providers of facilities within the same port;
- different (access/egress) modes of transport; and
- supply chains.

With a view on the overall objective of this study - to support strategic planning of a node in a (transportation) service network -, this study focuses on the last category in which ports operate as nodes embedded in global transport-logistic chains.

Ports constitute nodes in an elaborate network connecting origins and hinterland destinations for freight flows as conceptually shown in Figure 1.5[7]. Determination of demand for port services is essentially based on competition between alternative routes. Ports should constantly be on the alert for potential route shifts, because, for instance, freight

[6] It is assumed here that 1) owner and operator of the port are the same, which is not necessarily true for freight transportation systems (see, e.g., Van Binsbergen and Visser, 2001), and 2) the port owner is a *private* owner, which is not always the case, because there are also *public* port owners.

[7] For the sake of simplicity, it is assumed that there are no land sections at the origins-side.

transportation via the geographically closest port can no longer be guaranteed (e.g., Foggin and Dicer, 1985). Port development programs must also take into account the possibilities the port offers for the entire transport-logistic chain, including intermodal facilities and adequate hinterland connections.

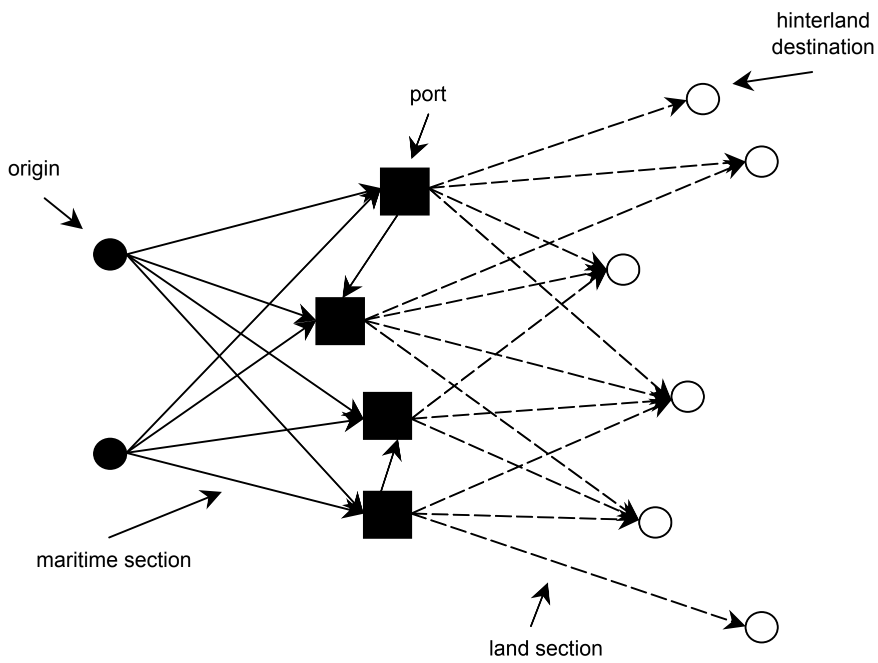

FIGURE 1.5 Ports as nodes in a transportation network.

Many routes could be used for transporting cargo between, for instance, origins in Asia and destinations in Europe. Some routes may use more maritime transportation but less land transportation, so the transportation cost is low, but may take a longer time to the destination. Other routes use a shorter maritime section but a longer land section. These cost and time patterns become more complicated by the service times and durations experienced in the ports.

Various trade offs have to be made for a route selection decision by a carrier. Assuming that freight carriers have perfect information on the available options for route selection, a particular port can affect this decision with different competition strategies. Physical expansion of port capacity is an interesting strategy, because it leads to an improvement of service quality (here: reduction of port-congestion costs), making the port more attractive for freight carriers, and it allows autonomous growth of port demand.

1.4.4 Economies of Scale

In general, infrastructure systems are characterized by economies of scale (e.g., De Neufville, 1990). Economies of scale mean that enlarged capacity increases the investment cost at a decreasing rate, which exists due to the distribution of 'fixed' cost components. For example, adding a hectare in surface area to an existing port expansion plan leaves equipment mobilization costs unchanged.

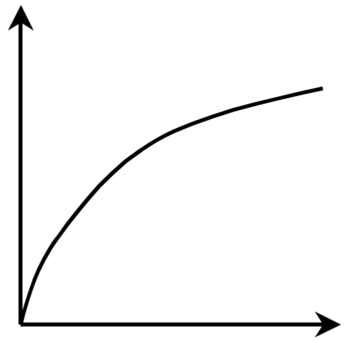

FIGURE 1.6 Investment cost function characterized by economies of scale.

Figure 1.6 shows the typical shape of an investment cost function that is characterized by economies of scale. The proposed function is:

$$C(x) = ax^b \tag{1.1}$$

with:

C	:	total investment cost (usually in millions of euros)
a	:	parameter
x	:	expansion size (in hectares)
b	:	scale factor

This function exhibits economies of scale for values of scale factor b between zero and one. Observe that the function is continuous, suggesting that expansion is available in any size; in other words, there are no indivisibilities. In practice, standardization of components or site irregularities may preclude continuous port expansion but the assumption helps to improve analytic tractability.

Economies of scale in port operation may be observed for higher throughputs; the investment cost is then distributed over a larger number of handled items resulting in lower unit costs for higher throughputs and (if passed-on to the users) lower port dues and terminal charges. Economies of scope in port operation exist if port facilities are used for the handling of more than one cargo type (e.g., handling of containers and other general cargo types).

1.4.5 Capacity Problems

In deciding upon a port's capacity, there is a need to strike a balance between (occasional) shortages in capacity and over-capacity. Both types of capacity problems interact with the dynamics of competition. Particularly over-capacity is affected by economies of scale.

Shortages in capacity indicate scarcity in the port market, which will lead to higher prices, port congestion and associated delays for port users. Other - cheaper and less congested - ports may become more attractive then. In a competitive port market, this leads to a decreased demand for the congested port. In the short run, port demand may fluctuate causing temporary shortages in capacity due to peak loads.

Over-capacity indicates the presence of too much supply in the port market, which will lead to more competition between ports and lower prices making investment recovery difficult. At the same time, a port with over-capacity is more attractive for potential users due to its low level of congestion. A growing demand combined with economies of scale in investment cost lead to an expansion strategy with substantial capacity increases; over-capacity is then a time-varying phenomenon.

With a view on a port's competitiveness, a certain amount of over-capacity per port is required. Peak loads can then be accommodated by which it is not necessary to refuse a temporary demand surplus and, consequently, to deter (potential) freight carriers (e.g., Sengers, 2004).

1.4.6 Port Market and Technological Development

With a view on port-price making and the price elasticity of port service demand, the economic characterization of the port market is most relevant but difficult to determine unambiguously. Given entry barriers such as their expensive specialized assets, sunk costs[8], indivisibilities and economies of scale, ports possess a certain degree of (government) monopoly (e.g., UNESCAP, 2001). This enables them to determine the price for transport flows associated with their natural hinterlands. For a hinterland destination that is subject to competition between a limited number of ports (a so-called competition area or common hinterland), the associated port market (e.g., for a specific cargo type such as containers) can be characterized as oligopolistic.

A number of technological developments contributed to a more competitive port market, because they served as a stimulus for transport flows to become more volatile (i.e. less bound to a particular port). The most important developments are (e.g., Hayuth and Hilling, 1992; Luberoff and Walder, 2000):

- Increasing integration of transportation chains due to the development of more efficient logistic concepts. This has reduced generalized transportation costs such that it may now be preferable for a carrier to call at a distant port instead of at a closer one, provided that the former has lower generalized costs than the latter;
- Increasing capital intensity in cargo-handling operations. Unitization and containerization, in particular, have produced significant reductions in the costs of cargo handling, but have created significant investment financing requirements for specialized

[8] Sunk costs are costs that cannot be recovered when a firm decides to leave the market. A breakwater is an example of sunk costs. Fixed costs, in contrast, are costs that do not vary with output. A sunk cost can be variable such as advertising costs, while a fixed cost, such as that of a gantry crane, does not necessarily has to be sunk, as the asset could be sold to an other port (Haralambides, 2002).

facilities. Higher port prices to recover the investments lead however to lower market shares;

- Increasingly large ocean vessels to realize economies of scale due to transporting large quantities of bulk cargoes and containers. Substantial port investments are needed to accommodate such vessels and to meet the demand for lower turnaround times. Ports that do not invest accordingly may lose their market shares.

Particularly container transportation is a competitive sector. In addition to the above technological developments, it is characterized by a consolidation of container flows at a relatively small number of ports. This is putting intense pressure on ports to assure an efficient container transfer process by providing sufficient capacity in order to continue their throughputs.

1.5 Brief Review of Existing Approaches

The focus of this study is deciding upon expansion of a single port, which is in fact physical expansion of the port's capacity. This will be studied from the viewpoint of the port planner whose aim is overall viability of the port investment project. A major question then is if port expansion can be self-financing, which means here that port expansion is paid for only by the revenues generated from congestion pricing. To capture the full complexity of this planning problem, a combination of approaches for 1) network design, 2) capacity expansion, 3) transportation demand modeling, and 4) investment financing is required. Existing approaches in infrastructure planning and transportation planning are briefly reviewed below.

1.5.1 Network Design

The port expansion problem at hand can be characterized as a network design problem. Each port in a network can be considered as a link with capacity and an investment cost function. The objective is to determine the optimal capacity of one of these links given the local demand pattern or demand function. The port-link has further a demand-dependent toll: the port congestion price. The port planner determines the optimal design capacity such that 1) the increase of consumers' surplus for the users of the port is maximized, and 2) the investment cost of the port owner is recovered with the revenues from the port congestion price.

The demand pattern is characterized by equilibrium given the user-cost functions for each of the links. Equilibrium is a theoretical situation in which (service) prices are minimal and equal for homogeneous services (here: transportation routes between origins and destinations). In practice, continuous shifts of freight flows and associated changes in port congestion may preclude equilibrium analysis. The assumption of equilibrium supports however the development of clear benchmarks to analyze the impact of competition and expansion.

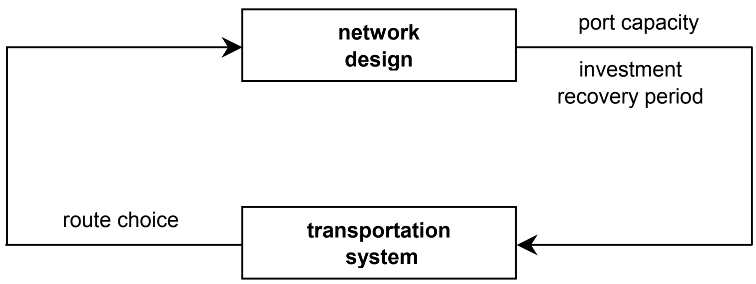

FIGURE 1.7 Network design problem as bi-level optimization problem.

In Figure 1.7, the above-described network design problem, applied to port expansion, is represented as a so-called bi-level optimization problem (see, e.g., Van Nes, 2001). In the upper level, the planner tries to optimize the design variables (here: port capacity and investment recovery period). In the lower level, carriers make their decisions (here: route choice), which leads to an equilibrium that serves as condition for the design problem.

1.5.2 Capacity Expansion

An engineering approach in infrastructure planning to deal with capacity expansion is based on minimizing the present value of the investment cost of an expansion strategy, which comprises the adding of capacity increments with regular time intervals. The growth rate of the predicted demand in addition to the scale characteristics of the investment cost function determines the size of the capacity increments (x) at instant time t and the length of the time intervals (τ). The resulting capacity expansion pattern to meet growing demand is illustrated in Figure 1.8. The basics of this approach and extensions to non-linearly growing and stochastic demand can be found in various textbooks such as Manne (1967) and Freidenfelds (1981).

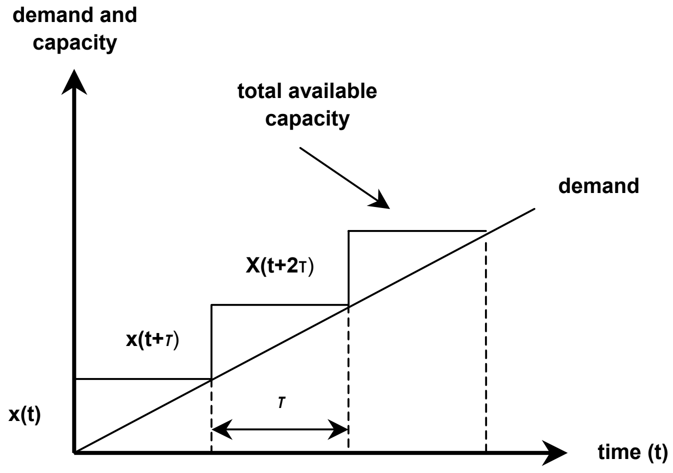

FIGURE 1.8 Capacity expansion pattern to meet growing demand.

Although this approach incorporates the aspect of economies of scale, other aspects, which are essential for deciding upon port expansion, are not included. First, the decision criterion is the present value of the investment cost. Accounting for the public role and the commercial perspective of ports requires, however, the net present value of the economic benefit and the investment recovery period, respectively, as decision criteria for port expansion projects. Second, demand is predicted independently of the expansion strategy. The port expansion problem requires however capturing the interaction between demand and expansion strategy in order to analyze the effect of the strategy on the port's competitiveness.

1.5.3 Transportation Demand Modeling

Planning of port capacity requires schematization of each port as a node in a transportation network. A port reacts on developments elsewhere in the network such as the entering of a new route via a competing port or port expansion elsewhere. The effect of the reaction (here: expansion) on the port's competitiveness can then be analyzed by transportation demand modeling.

With a view on the port expansion problem at hand, roughly two approaches for modeling transportation demand can be distinguished in transportation planning:
1) Simulation of traffic assignment in a network. An example is the SMILE model (Strategic Model for Integrated Logistics and Evaluation) as developed by the Dutch institute TNO, which simulates the assignment of freight flows for different commodity types and transportation modes (see, e.g., Tavasszy, 2003);
2) Projection of port demand based on macro-economic relationships with a more or less fixed market share for the particular port. An example is the GSM model (GoederenStromenModel) as used by the Port of Rotterdam for long-term demand projections, particularly for container flows.

The first approach does not account for port investment characteristics (economies of scale). The second approach accounts for port development, but does not incorporate potential changes in a port's market share due to, for instance, competition between transportation routes. A combination of both approaches can be used to simulate the effect of competition and to incorporate autonomous demand growth.

What still lacks, is an approach for port investment financing. This will be discussed below.

1.5.4 Investment Financing

In infrastructure planning, the 'user pays'-principle is receiving increasing attention (see, e.g., Dings, 2002). Road investment financing via the revenues from congestion pricing is an interesting option to establish this principle. The concept of congestion pricing is that the external congestion cost (i.e. the congestion cost imposed on other users of the road) is internalized in the cost as perceived by the individual road user. The user receives for that price extra road capacity.

Congestion pricing would typically take the form of a surcharge (a toll that is set equal to the marginal external cost) on the use of roads according to the level of congestion. It is here considered to be a form of 'pricing according to usage' and reflects the scarcity of capacity, because higher prices are charged under congested conditions (high utilization rates) and lower prices under less congested conditions (low utilization rates). The congestion price can be based on a fixed schedule, or can be dynamic, meaning that rates change depending on the level of congestion that exists at a particular time.

Congestion pricing, if combined with physical expansion, is an interesting option for financing port expansion. The assumptions are then that 1) port congestion exists[9], 2) it can be defined as higher service times than ideally can be achieved by the port (a reasonable assumption with a view on the high investment cost of maritime vessels that therefore want be handled within the shortest possible service time), 3) the mechanism of port congestion is similar to that of road congestion under stationary conditions, namely, that service times increase if demand approaches system capacity[10], and 4) pricing of port congestion is similar to pricing of road congestion, namely, internalizing the marginal external cost of congestion.

Practical problems in determining the port-congestion price include difficulties in determining the actual level of port congestion and collecting the toll (how, where and when?). An other but interrelated question is *who* should pay the toll: all users or only those who cause the waiting times? In the present study, it is assumed that all port users pay the toll. Further research on the practical problems in determining the port-congestion price is indicated.

The present study focuses on the development of a modeling approach for deciding upon expansion of a single port, which operates in a transportation network characterized by route competition. Based on the above review of existing approaches, this study can be distinguished from other research in the fields of infrastructure planning and transportation planning by the following issues:

- the port expansion problem is characterized as a network design problem with the aim to determine the optimal set of 'design capacity' and 'investment recovery period' of one of the ports in the network given its demand pattern or demand function;
- this problem is considered from the viewpoint of the port planner whose aim is overall viability of the port investment project by integrating port-commercial interests (investment recovery) and public interests (increase of consumers' surplus and economic efficiency);
- the full complexity of the port expansion problem requires a network modeling approach to model transportation demand;
- this should be extended with the possibility to simulate the effect of a port's expansion strategy on its competitive position in a network as a function of investment characteristics (economies of scale), service characteristics (tariffs and productivities) and financing (based on congestion pricing); and

[9] This is, according to Van der Jagt (2004), particularly true for the large North-European ports.

[10] The measurement of port congestion should in fact be in terms of waiting time between the different stages or links in the port. This system is sensitive for disturbances in one or more of these links causing overall port congestion.

- determination of the optimal expansion strategy requires application of optimization based on interaction between port supply and demand and accounting for growth of demand.

The present study will focus on simulating the reaction of a single port with a partial equilibrium model instead of simulating changes in the port market with a general equilibrium model[11]. This modeling approach produces approximate results for three reasons: 1) it assumes that other ports develop no strategies; the full dynamics of port competition is not incorporated, 2) it assumes that the users of the port considered are representative for all users of the network; all users base their route (thus port) selection decision on generalized transportation costs, and 3) it by-passes discussions on an accurate economic characterization of the port market; the port market in the present study has a combination of monopolistic/oligopolistic characteristics (an individual port can affect its price; a limited number of competing ports is considered) and perfect-competition characteristics (transport flows are completely volatile; freight carriers have perfect information on the available options for route selection).

The influence of technological development is also interesting to incorporate in the modeling approach. This is especially relevant for ports, which have to deal with technological development over the network as well as in the port. Particularly developments in container transportation technology continue to have a drastic influence on port development.

1.6 A Conceptual Framework for Planning of Port Capacity

Port investments are only fully feasible if their financing is arranged and if their economic benefits are greater than their costs. The necessity of making a port investment project viable, which means that port-commercial and public interests are accounted for (Dekker *et al*., 2004; Dekker and Verhaeghe, 2004), motivates the development of an appropriate methodology for planning of a port's capacity in order to integrate these interests. A conceptual framework for such planning is discussed below.

Planning of port capacity, here essentially decision-making on investment in a single port, should address the following six questions: 1) what is the expected demand for services in terms of types and volumes of the transport flows, 2) what is the required supply of capacity in terms of physical characteristics (sizes and numbers) and service characteristics (tariffs and productivities), 3) what is the utilization rate and equilibrium demand, 4) what are investment cost and service price, 5) what are the economic benefits, and 6) what is the overall viability of the port investment project. These components are included in a flow diagram for planning of a port's capacity under competition as presented in Figure 1.9.

[11] *Partial equilibrium models* are models that concentrate on a single market or industry (here: a single port) and ignore effects on other markets (that is why they are called partial). Such models are often used in transportation system analysis. *General equilibrium models*, on the other hand, provide a simplified representation of the entire economy, i.e., of the many markets that constitute the economy. Such models are often costly to develop and very complex.

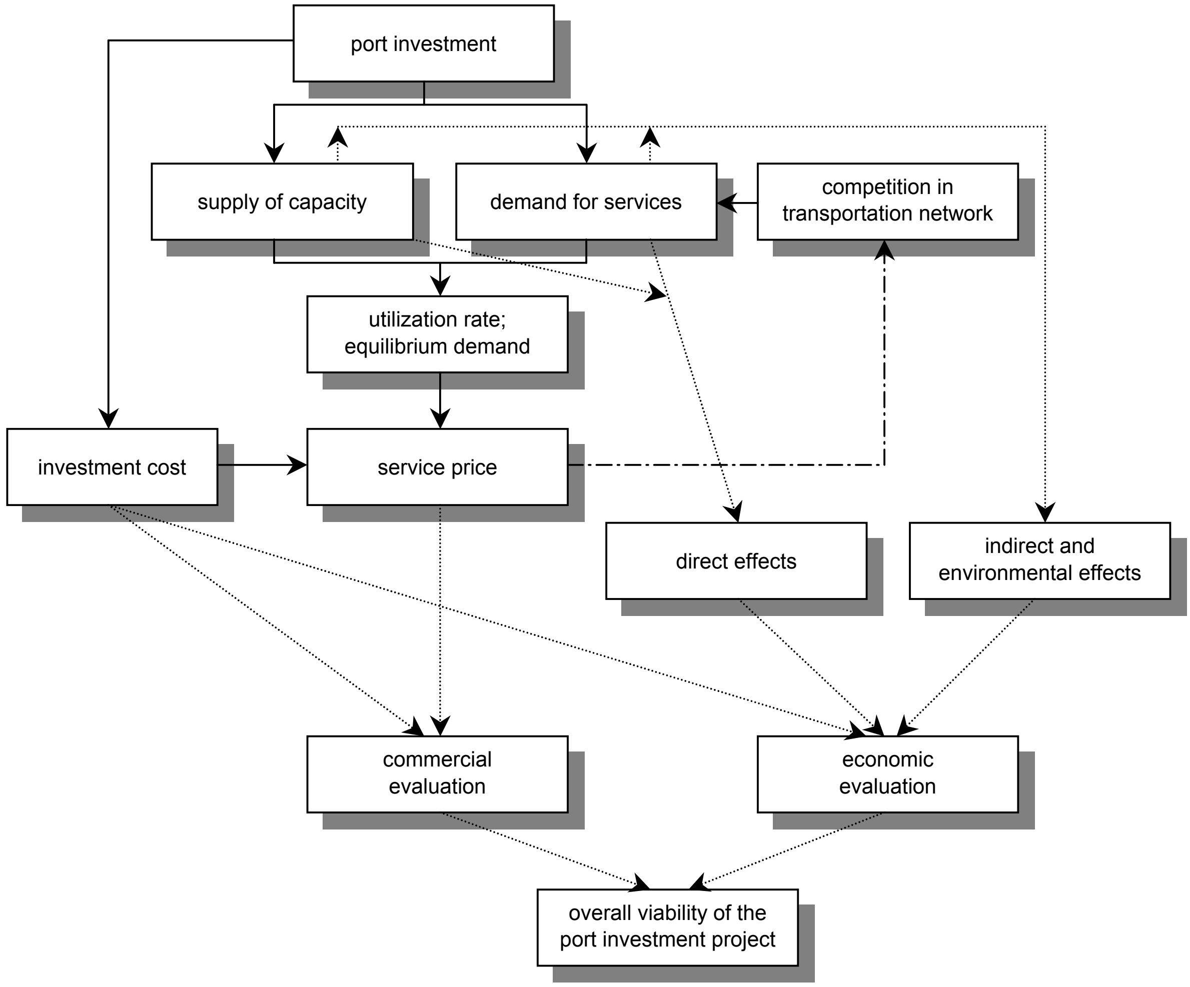

FIGURE 1.9 Planning of a port's capacity under competition.

As indicated in Figure 1.9, port investment aims at affecting supply of capacity and/or demand for services. The interaction between supply and demand leads to a certain utilization rate and equilibrium demand that determine, together with the investment cost, the service price. The service price affects, in turn, the competitive position of the port in the transportation network. Because self-financing of port investment is worked out in this study, the service price should balance port investment cost.

Assessing the overall viability of port investment requires a commercial and an economic evaluation. The investment cost and the service price, which determines the financial revenues, are the inputs to the commercial evaluation. In addition to the investment cost, the direct, indirect and environmental effects (economic benefits) are important inputs to the economic evaluation. The economic benefits are determined by the match between the supply of capacity and the demand for services.

The above approach offers a conceptual framework for planning of a port's capacity that fits well in the present time of increasing concerns of efficiency issues[12]. It allows for the scientific contribution of this thesis: integration of port-commercial and public interests, and incorporation of competition, autonomous growth of demand, economies of scale and technological development in planning of a port's capacity. The objective and research questions that will be addressed with the help of this framework are discussed in the next section.

1.7 Objective and Research Questions

The overall objective of this study is to support strategic planning of a (single) node in a (transportation) service network, which is characterized by competition. The present thesis contributes to this objective by the development of a methodology for planning of a port's capacity in which modeling of the system, based on (pragmatic) application of economic concepts, is a major component. The challenge is to integrate port-commercial and public interests in such methodology, and to incorporate competition, autonomous growth of demand, economies of scale and technological development.

Regarding the competition aspect, the focus of this study is the reaction of a particular port on a change in the transportation network. A scenario for such change is the entry of new routes via a competing port. This leads to decreased demands and benefits for the particular port and the nation in which the port is located. Potential reactions of the port on this change include investment in port expansion and improvement of hinterland connections. The reaction that will be worked out in this study is expansion of the port's surface area, which allows also for autonomous growth of port demand due to, for instance, economic growth. In practice, other ports develop also competition strategies but this is not accounted for in the present study.

The port expansion problem will be considered from the viewpoint of the port planner. His aim is overall viability of the port investment project by integrating port-commercial interests (here investment recovery) and public interests (increase of consumers' surplus and economic efficiency). Interests of society need only to be integrated if government contributions (subsidies) are involved.

Although there are various interesting questions that might arise while considering the proposed focus from legal, economic and technological viewpoints, this study addresses in particular the following two research questions:

1) What is the optimal expansion strategy for a single port to deal with route competition and to facilitate further growth of the port's demand?
2) Can the expansion strategy be self-financing?

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[12] Efficiency indicates the skillfulness in reducing the use of scarce resources, and can be measured by the ratio of the output to the input of any system. Important efficiency issues include optimal capacity utilization, economic efficiency, and application of the 'user pays'-principle, which avoids the use of public funds.

The present study addresses further the issue of 'leakage' of port investment benefits to other countries and relates this with economies of scale and scope in port operation.

It is clear that capacity expansion is not the only strategy available to a port for dealing with competition. Alternative (less capital-intensive) strategies for ports to deal with competition include:

- lower tariffs to reduce port-related costs for freight carriers;
- introduction of fast cargo-handling facilities to reduce port service times; and
- cooperation between ports to develop competitive strategies together.

The decision of a port to implement a capacity expansion strategy will only be made if it is considered to be the most effective strategy from the port-commercial perspective and also beneficial from the public perspective. This requires a comparison between costs and benefits of all potential strategies to deal with competition. However, with a view on the investment-scope of this thesis, only the expansion strategy of a port is worked out in more detail in the present study.

In brief, this contribution can be differentiated from other similar research in the field of port planning and development, based on the following:

a) It combines existing partial approaches in infrastructure planning and transportation planning for 1) network design, 2) capacity expansion, 3) transportation modeling, and 4) investment financing. The resulting modeling approach can be used to analyze the effect of investment strategies on a port's competitive position in a transportation network within a supply-demand framework. This will prove to be useful in port planning.
b) It considers a port as a point entity with an overall capacity instead of as a set of inter-dependent stages or links, which need to be optimally tuned to each other. Any inefficiencies in these links and their joint functioning lead to higher service times than ideally can be achieved by the port. These higher service times are interpreted in this study as port congestion. Such schematization will prove to be useful in strategic design of port expansion.
c) It assumes that a port operates as an organizational entity instead of as a combination of public institutions and private firms (in particular the port authority and terminals, respectively) having their own specific interests and responsibilities in port operation. The premise is then that the different parties cooperate optimally, which supports the assumption of a quick implementation of competition strategies in a dynamic network.
d) It deals with physical expansion as strategy to deal with competition. The premise is that expansion activates latent demand (i.e. demand deterred by congestion) by a demand shift between routes, which assumes that demand 'automatically' follows supply. Physical expansion allows also for autonomous growth of demand. This will support the incorporation of route competition and autonomous growth of demand in the port-planning problem.
e) It demonstrates the methodology for planning of port capacity with an application to the Port of Rotterdam, which operates within the context of 1) competition in the European transportation network, and 2) Dutch and European port policies regarding pricing, financing and investment. The emphasis in the application is on the trade offs in a port's

investment planning rather than the choice of the most effective strategy to deal with competition. Such emphasis is useful for discussing some implications for port planning.

1.8 Outline of this Thesis

The remainder of this thesis is divided into four parts. The first part, *Background*, includes Chapters 2 and 3. Chapter 2 reviews present European and Dutch port policy regarding financing of port investment and port pricing in order to find out if self-financing of port expansion fits within present port policies. It sets further the stage for the application case of this study by discussing issues and developments in the Port of Rotterdam. In Chapter 3, concepts for planning of port capacity, applied to port expansion, are reviewed and developed.

The second part, *Methodology*, includes Chapters 4, 5 and 6. In Chapter 4, an approach for planning of port capacity is developed. After a brief summary of the scope of the methodology, an operational framework for planning of port capacity is presented. This is followed by an elaboration on a practical solution for the planning problem comprising a modeling approach for port planning. Chapter 5 provides elaborations on establishing port demand and supply, and includes a pragmatic solution for port-congestion pricing. Chapter 6 reviews developments in container transportation technology and discusses an approach to incorporate these developments in the modeling approach as developed in previous chapters.

The third part, *Application*, is Chapter 7. In this chapter, the methodology is demonstrated with an application to the Port of Rotterdam in the Netherlands. This (explorative) study focuses on a hypothetical port expansion by means of expansion of the port surface area by land reclamation, and emphasizes the trade offs in planning of port capacity. To address port-commercial and public issues of port investment, including the ‘leakage’ of port investment benefits to other countries, the financial and economic results of the application case are discussed in detail.

The last part of this thesis, *Findings*, is Chapter 8. It reflects on the main findings of this study and gives some recommendations for further research in the field of planning of port capacity.

I. Background

2. Port Investment and Financing in the Netherlands

2.1 Introduction

The Port of Rotterdam, the largest European port in terms of throughput volume, operates under strong competition with other European ports such as Antwerp and Hamburg. To maintain its competitiveness, particularly its hub position in container transportation, substantial investments in the port and its railway connections are being made.

Self-financing of such large-scale investments, based on the revenues from congestion pricing, is a major issue in this study. In this chapter, the European and Dutch policy regarding port pricing, financing and investment will be reviewed in order to find out if this self-financing principle is in accordance with present port policy. With a view on the application case, issues and developments in the Port of Rotterdam will receive particular attention.

The remainder of the chapter is divided into six sections. Section 2.2 gives an overview of the Dutch seaports. Section 2.3 makes a comparison between European and Dutch port policy particularly regarding pricing and investment financing. A discussion of issues and developments in the Port of Rotterdam is given in Section 2.4. Section 2.5 provides an overview of the debate on (government contributions to) Rotterdam port investments. Section 2.6 summarizes the findings of this chapter and Section 2.7 gives the further perspective of the remainder of this study.

2.2 Dutch Seaports

The Netherlands has 15 seaports, mainly located in the western part of the Netherlands (see the map in Figure 2.1). These ports have varying throughputs (see Table 2.1); their hinterland transportation and contributions to Dutch economy differ accordingly. An elaborate discussion of the economic significance of the Dutch seaport sector can, for instance, be found in Peeters *et al*. (1999).

In policy documents, Dutch seaports are often clustered in five groups within which the individual ports cooperate with each other. These groups are:

1) Northern Seaports, comprising Groningen Seaports (i.e. the cooperation between Delfzijl and Eemshaven), Harlingen and Den Helder;
2) Amsterdam/North Sea Channel ports, comprising Amsterdam, Zaanstad, Beverwijk and Velsen/IJmuiden;
3) the port of Scheveningen;
4) Rotterdam/Rhine and Meuse estuary ports, comprising the port of Rotterdam (including Maassluis, Vlaardingen and Schiedam), Dordrecht and Moerdijk; and
5) the Scheldt basin ports, comprising Flushing and Terneuzen.

FIGURE 2.1 Location of the Dutch seaports.

TABLE 2.1 Throughputs of Dutch seaports in 1996 and 2001 (in millions of tons)

Port group	Port	1996	2001
Northern Seaports	Delfzijl/Eemshaven	3.3	3.6
	Harlingen	0.6	1.0
	Den Helder	0.1	0.2
Amsterdam/North Sea Channel ports	Amsterdam	36.7	49.4
	Zaanstad	0.7	0.3
	Beverwijk	0.3	0.3
	Velsen/IJmuiden	17.1	18.4
Scheveningen	Scheveningen	1.7	4.8
Rotterdam/Rhine and Meuse estuary ports	Rotterdam	292.0	314.6
	Dordrecht	2.5	2.3
	Moerdijk	2.2	4.4
Scheldt basin ports	Flushing	13.1	13.4
	Terneuzen	11.3	11.8
	Total throughput	381.6	424.5

Sources: NHR (1997) and NHR (2002)

Along with the economic development of the Ruhr basin in Germany and since the construction of a direct connection (channel) between Rotterdam and the North Sea – the *New Waterway* – in the 19th century, the Port of Rotterdam has become the most important port of the Netherlands and, measured in total throughput volume, the largest port of Europe[13]. Due to the dominant role of the Port of Rotterdam in Dutch port policy and its specific issues such as large-scale investment projects, the remainder of this study will mainly focus on the Port of Rotterdam.

2.3 Port Policy in Europe and the Netherlands

This section provides on overview of European and Dutch port policies. Particularly issues of port investment financing and pricing are discussed. Section 2.3.1 summarizes European port policy, while Section 2.3.2 summarizes Dutch port policy. Section 2.3.3 discusses some frictions between European and Dutch port policies.

2.3.1 European Port Policy

Since the early 1990s, the development of a common European port policy has been in the center of attention. Policy makers recognized the strategic importance of integrating efficient and competing ports within a multimodal European transportation system. Consequently, European Union (EU) institutions have contributed to policy proposals and the definition of a long-term European strategy regarding the port industry.

Current EU port policy aims at promoting the competitiveness of the European port industry within the context of a long-term sustainable mobility strategy, which refers to an efficient use of natural resources (Chlomoudis and Pallis, 2002). In accordance with the principle of

[13] With a view on the world ranking, Rotterdam has to compete with the Chinese port of Shanghai.

subsidiarity[14], local and national governments, and private parties remain responsible for specific port investments. A specific bank (the *European Investment Bank*) is established for pre-financing of large-scale investments such as port investments.

During the last decade, various EU policies were formulated that integrate policies of multiple levels and issues to the port industry and its production. The most important policies refer to the following issues (Chlomoudis and Pallis, 2002):

- transport infrastructure, financing and charging methods;
- combined transport;
- Trans-European Transport Networks;
- infrastructure and telematics for administration systems and pilotage;
- sustainable mobility and transport;
- safety issues; and
- systematical statistical recording of transport activities.

In 1991, the EU formulated the guidelines for the development of a Trans-European Transport Network (TEN-T). Such a network will never become fully operational without sufficient European standardization. Examples of European standardization are the development of Trans-European Rail Freight Freeways (technical harmonization), and the introduction of standardized load units to reduce friction costs.

In 1997, the European Commission (EC) published the so-called *Green Paper on seaports and maritime infrastructure* (EC, 1997). Port investments would increasingly be demand driven and, in the long-term, there should be fair competition among ports. This publication addressed further the issue of integration of ports into an intermodal trans-European network. EU transport policy in general focuses on establishing a level playing field[15] between modes and users based on pricing according to usage. This would also include external costs of infrastructure usage. The Green Paper supported the view that also a level playing field has to be established between modes in favor of more efficient alternatives.

In 2001, the EC presented a proposals package regarding ports, known as the '*port package*' (EC, 2001a,b). This package comprises the results of research, initiated by the EC, on public funding and charging practices in EU ports, proposals for the transparency of port financial accounts, port competition, unrestricted access to port services, and an update of the above-discussed *Green Paper*.

[14] The principle of subsidiarity means that a higher level government should only perform those tasks that cannot be performed effectively at lower levels.

[15] A level playing field can be defined as an environment in which all players in a given market must follow the same rules and are given an equal ability to compete.

2.3.2 Dutch Port Policy

The main objective of Dutch port policy is to strengthen the competitive position of the ports. The basic assumption is that the national government creates the right conditions but that private parties must take it from there. Additional goals and assumptions are (Van Vark, 1987):

- conservation and further development of two 'multi-purpose' port groups: the Amsterdam/North Sea Channel ports and the Rotterdam/Rhine and Meuse estuary ports;
- no (government) support for non-profitable economic activities;
- no rigid funding of investments in maritime access infrastructure: cost sharing between national and local governments is determined on a project basis. Port authorities have the possibility to determine the port dues;
- private funding of port superstructure although private parties may claim certain government subsidies to stimulate employment and industrial or regional development;
- decentralized port management (including the allocation of port investments); and
- no rigid capacity management in order to provide opportunities for ports to fully utilize their own potential.

Ports and associated transport, distribution and industrial activities constitute an integral part of Dutch socio-economic policy. National port policy, therefore, covers a wide field and interacts with numerous policy sectors. Within this complex area, the main policy outlines are clearly delineated, but the detailed workings are often more difficult to follow.

The national government has a dual task: 1) initiating, and 2) responding to initiatives of port authorities and port industries. Furthermore, fair competition is encouraged and protectionism rejected on the grounds that fair competition encourages innovation, improves quality and assures maximum effort on the part of all involved, whereas protectionism results – certainly on the long term – in undercutting, inefficiency and declining standards.

Several national ministries are involved in Dutch port policy. Stevens (1997) gives a detailed description of the different ministries and organizations involved. The most important ministry concerning Dutch seaport policy is the *Ministry of Transport, Public Works and Water Management*. It has an important role in taking care and providing of infrastructure, traffic management and checking safety. Each five years, this ministry publishes a 'Progress Note on Seaport Policy' that contains the evaluation and (re-) formulation of Dutch national seaport policy. The most recent note has been published in 2004 (MVW, 2004).

An important platform is the *National Port Council* (NPC). It serves as a consultative body for the port sector and as an advisory board for the government. The NPC has an independent chairman and represents port authorities and industries.

Most of the ports are managed by municipal authorities. Three organizational models can be identified: 1) *direct management* by the municipal authority; 2) the *havenbedrijf*, a port authority separate from but controlled by the municipal authority; and 3) the *havenschap*, a public board representing the various levels of government, appointing a director for daily management.

Private companies are responsible for cargo handling. In the case of moorage (tying up a vessel), a distinction has to be made between berths in common use that are managed by port authorities, and those in zones allocated to a single user, which are managed by that user. It should further be noted that pilotage (taking vessels into or out of a port) is also a completely privatized service. Fees for it are paid to the company that provides it and depend on the draught of the vessels.

In Dutch port investment policy, four types of investment can be distinguished (Roos *et al*., 2003), namely, investment in 1) basic infrastructure (maritime access channels, sea defense structures, port land and hinterland connections), 2) port infrastructure (e.g., port basins, quays and docks), 3) infrastructure-plus (e.g., surface hardening and tracks on the terminals), and 4) superstructure (sheds, cranes, vehicles and other equipment). The distribution of investments and expenditures between national government and port authorities usually follows the division line between basic infrastructure from one end, and port infrastructure and infrastructure-plus from the other end. Table 2.2 gives an overview of port investment types, responsibilities and financial resources.

TABLE 2.2 Port investment types, responsibilities and financial resources

Port investment type	Responsibility of	Financing via
basic infrastructure	national government	public funds
port infrastructure and infrastructure-plus	port authority	rent, quay charges and port dues
superstructure	terminal operator	terminal charges

The national government funds investment in basic infrastructure as far as it contributes to economic growth and benefits to national welfare. There is however a tendency that the national government sees itself no longer fully responsible for maritime access channels and port land. Joint funding with private parties is increasingly being a condition for making such investments (NHR, 2001a). Specific agreements with Belgium divide the costs of the access channels when these are of value to both countries (Chlomoudis and Pallis, 2002). The national government takes also care for investment in (and maintenance of) hinterland infrastructure.

Port authorities determine rent (long-term lease), quay charges and port dues to finance investments in port infrastructure and infrastructure-plus. The port dues are only paid by ships entering from or leaving for the open sea as a function of gross tonnage, cargo loaded and/or unloaded and, in some ports, number of passengers. The wharf and land dues are calculated in accordance with the intensity of use. Municipal ports apply for general loans for investment financing. A specific fund of the national government (the so-called *Algemeen Leningfonds*) is reserved for this purpose.

Superstructure is generally privately owned and financed with the revenues from terminal charges. The owner (the terminal operator) is responsible for specific adaptations of the terminal area by, for instance, constructing pavements and crane tracks, and investments in sheds and equipment. Sometimes, these investments are (partly) funded by the port authority and passed on cost-effectively to the users (NHR, 2001a).

2.3.3 Frictions between European and Dutch Policy

Although the European port policy should serve as a context and guideline for the Dutch national port policy, some frictions between both policy levels can be observed. The main frictions comprise 1) the scope of port policy, 2) port investment financing, and 3) port pricing (see Table 2.3).

TABLE 2.3 Frictions between European and Dutch port policy

Policy level	Scope	Financing	Pricing
Dutch	International competitiveness of port sector	Contribution of national government	Quay charges and port dues
European	Development of efficient transportation system	No funding by government	Pricing according to usage

Dutch port policy is focused on the international competitiveness of the Dutch port sector and less directed at supporting the development of an efficient transportation system. The national government contributes to port investments; full introduction of cost-effective port pricing is less likely then.

European port policy reveals a broader scope, namely, port policy framed into the development of an efficient European transportation system. It rejects any government funding of port investments and supports cost-effective port pricing. Introduction of pricing according to usage aims at internalization of external costs of transportation. The revenues from such pricing can, for instance, be used to finance investment in basic infrastructure.

2.4 The Port of Rotterdam

2.4.1 Characteristics

The Port of Rotterdam is located in the southwestern corner of the Netherlands and stretches over about 40 kilometers between the city of Rotterdam and the North Sea (see Figure 2.2). It comprises a total area of 10,500 hectares, of which circa 3,500 hectares consists of water (channels and basins). The port is a tidal port with an average tidal range of about 1.7 meter and is accessible for vessels with draughts up to 23 meters (75 feet). The port has further 80 km of quay length and the maximum berthing depth is 16.6 m.

The port receives about 30,000 seagoing vessels annually and 133,000 inland vessels (Mollema, 2003). The total throughput volume of Rotterdam in 2001 was approximately 315 million tons. The container throughput in 2001 was about 6.1 million TEU[16] (Port of Rotterdam, 2002).

[16] TEU = Twenty Feet Equivalent Unit; i.e. a standard measure for containers.

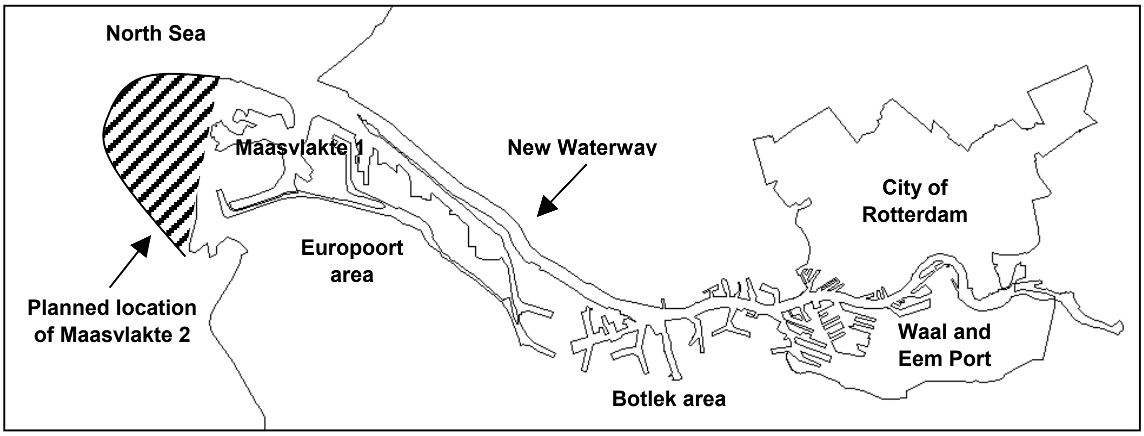

FIGURE 2.2 The Rotterdam port area.

The employment in the Rotterdam port area is about 61,000 employees (Port of Rotterdam, 2002). This figure includes the employment associated with the sectors stevedoring, transport and transport-related services, storage and distribution, intermediates, port-related industries (e.g., oil refineries, chemical industries and shipbuilding), maritime services and the port authority. The direct added value of all commercial activities in the port area fluctuates around 2% of Dutch Gross Domestic Product (GDP) and around 23% of Rotterdam Gross Regional Product (Port of Rotterdam, 2002).

The Rotterdam Port Management (RPM), since January 2004 a private company with the municipality of Rotterdam (for the time being) as only stakeholder, is responsible for a well-functioning nautical management and efficient economic development of the port. On the one hand, the RPM is taking care of an accessible, safe and clean, and competing port. On the other hand, the RPM is responsible for a well-considered and efficient cost recovery. These are two sometimes conflicting tasks.

Besides exploitation and maintenance of port area and infrastructure, the RPM is responsible for planning and construction as well as the funding of the necessary investments. Generally, the Dutch national government does not contribute directly to such investments. The exact funding and cost sharing of investments in maritime access channels, hinterland connections, and port area expansion are determined per project.

Companies and industries in the port area are responsible for their superstructure and transport means. From an efficiency perspective, however, the RPM has the power to stimulate cooperation in the expansion of superstructure. For example, a number of stevedoring companies were encouraged by the RPM to constitute ECT (European Combined Terminals) by which less surface area and berths were needed for container handling (Stevens, 1999). In 2002, ECT handled about 3.8 million TEU representing 60% of the port's total container throughput (Beddow, 2003).

2.4.2 Historic Development

After a period of growth during the so-called Golden Age (the 17th century), the development of Rotterdam stabilized for two centuries. At the end of the 19th century, however, port development received a renewed impulse by substantial investments in port infrastructure (e.g., the New Waterway, the Waal and Eem Port basins). The investments were made with help of the national government.

Until World War II, the port had mainly a transfer function for the German Ruhr basin industrial area. During the war, large parts of the port were systematically destroyed and it took a long period to reconstruct the facilities. After the war, the Port of Rotterdam became also an industrial complex with oil and chemical industries (Botlek and Europoort areas). To support this development, the first seaward expansion of the port (Maasvlakte 1) was constructed and introduced in 1968. The location of oil and chemical industries established Rotterdam as the most important port for wet bulk goods in Western Europe.

Since 1970, Rotterdam is trying to improve its position in transport-logistic chains for container flows. Expansion of hinterland connections such as the construction of a rail connection between Maasvlakte 1 and Germany (the so-called Betuwe line; investment cost about € 4.7 billion) is considered to be critical.

In the 1990's, a large-scale port development program (the so-called Rotterdam Mainport Development Project) has been initiated to support both port competitiveness and regional economic development. A major part of this program is a second seaward expansion of the port (the Maasvlakte 2 project; see Figure 2.2) with 1,000 hectares; sixty percent is reserved for container activities. The need for port expansion strongly depends on efficiency improvements that can be realized by the container terminals. The relatively low land price in the Rotterdam port area, as suggested by, for instance, Van Gelder (1999), may be a decisive factor to manage such efficiency improvements.

The estimated costs for the Maasvlakte 2 project are about € 2.6 billion. According to the present plans, the national government will contribute € 0.5 billion to the investment by taking a 33.3% interest in the RPM. The municipality of Rotterdam will keep the remaining part of 66.7%. In addition, the national government will contribute in 2011-2012 € 0.73 billion to the investment in sea defense structures (Scheepvaartkrant, 2004).

Van Klink (1995) expected that due to a lack of space within the Rotterdam port area and the spreading of port-related activities to other regions in the Netherlands, the Port of Rotterdam would increasingly become a port network. For example, Rotterdam has reached a cooperation agreement with Flushing – a port accessible for even the largest container vessels - including joint investment programs (Dekkers, 2003).

2.4.3 Rotterdam's Competitive Position

The Port of Rotterdam serves a hinterland that includes the industrial heart of Europe (the Ruhr basin area, Southern Germany and the area of the Alps). Its main competitors for this hinterland are the North Sea ports Hamburg and Bremen in North-Germany, and, particularly, Antwerp in Belgium (CPB/Port of Rotterdam, 1999; Loyen *et al*., 2002). The ports of Felixstowe and Southampton (UK) are considered to be major competitors in the container transshipment market.

The ongoing competition between these ports triggered a spiral of investment decisions. The investment plans involved mainly capacity expansion, which increased their container-handling capability with 50% by the year 2000, while in the planning period these ports were using only 67% of their capacity (Chlomoudis and Pallis, 2002).

A fast development of the South-European ports, such as those in Italy, might become an additional threat for Rotterdam, particularly if their hinterland connections are developed as well[17]. Alternative container routes between, for instance, Japan and Germany are shown in Figure 2.3. The rising demand for the Trans-Siberian railway (see Beddow, 2004a) is another potential threat for Rotterdam. This railway connection bypasses the maritime section via, for instance, the Indian Ocean and the Mediterranean Sea and may serve as a faster alternative for container shipments between Asia and Europe.

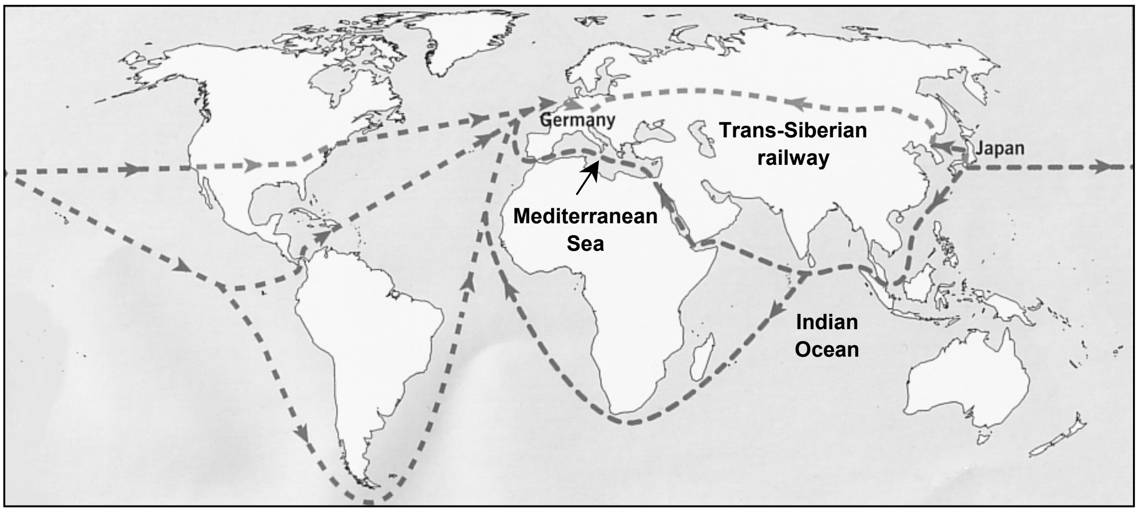

FIGURE 2.3 Alternative container routes between Japan and Germany (adapted from VROM, 1997).

Despite of the threats, Rotterdam is still the leading port for container traffic in Northern Europe[18]. In 1997, it accounted for 21.7% of all North European container port throughputs (DSC, 1999). The proportions of transshipment (mainly to short-sea shipping) and non-

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[17] The development of the Italian port Gioia Tauro is used as application case for this thesis.

[18] Although there is continuous competition, particularly with the port of Antwerp (see Loyen *et al*., 2002). Particularly the development of the Chinese economy causes a substantial growth of the Rotterdam container throughput (see, e.g., Boyes, 2004).

domestic transit flows through Rotterdam were 24% and 39%, respectively, of the total Rotterdam container traffic in 1998 (NHR, 2001b).

The modal split of the total container traffic through Rotterdam in 2000 is presented in Table 2.4. The figures are based on figures for Maasvlakte 1 and the Waal and Eem Port, which represent together 94% of the total container traffic (ARCADIS *et al.,* 2001),

TABLE 2.4 Modal split of the Rotterdam container traffic in 2000

Modality	Share of total container traffic (%)
Transshipment	22
Truck	46
Barge	23
Rail	9

Source: ARCADIS *et al.* (2001)

It can be observed that the truck is the dominant access/egress mode. This is supported by relatively good highway connections. Traffic congestion, particularly in the Netherlands, is however a major concern. Transport by barge, after the truck the most frequently used mode, may serve as an alternative. More than 30 regular barge transport services to about 50 destinations were offered in 1998 (DSC, 1999). Responding to this, ECT developed its own Rhine container terminal at the German inland port of Duisburg with a capacity of 100,000 TEU/year.

Rail transport is considered as extremely important to Rotterdam although it accounts for only 9% of Rotterdam's total container traffic. A number of trains operate with regular services. DSC (1999), for instance, reported about daily shuttle services between Rotterdam and Milan in Northern Italy, and between Rotterdam and Venlo, which is located at the Dutch-German border.

2.5 Debate on Rotterdam Port Investments

The most import reason to subsidize large-scale port investment projects such as the Betuwe line and the Maasvlakte 2 is to promote national welfare because subsidies lead, via port-price reduction, to a higher demand[19]. In the case of Maasvlakte 2, the indication is that commercial exploitation with full cost recovery will hardly be possible because the industries that the authorities want to attract are not willing to pay a sufficient price for the land (e.g., Dekker *et al*., 2002). Government subsidies are then required, but have initiated a heated debate in the Netherlands. This debate concerns the potential and desired role of the Dutch ports in international transportation, cost overruns, contribution of ports to national welfare (including environmental impacts), demand projections, and cost-effectiveness.

The advocates of such subsidies (e.g., BCI, 1996) point at the potential attractiveness of port development for companies, and the radiation effect on the regional and national economy. Others note the importance of port investment for timesavings for transport flows (Bosch and

[19] See also Chapter 3, Section 3.6.2.

Heldeweg, 1999) or the contribution of the transport sector to value added and employment for the nation (see Kuipers, 2000).

Some authors criticize however subsidies for large-scale port investments. Pols (1997; 1999), for instance, noted the lack of development of policy alternatives and a well founded and coherent policy vision on port development in the Netherlands. The one-sided focus on increasing vessel sizes in container transportation leading to economies of scale disregards logistic disadvantages of lower frequencies and increasing transport distances, which may affect the competitive position of Dutch ports. It disregards also the high investment and exploitation costs of specialized cargo-handling facilities with relatively low capacity utilization rates. Pols noted further the lack of coordination at a more operational level between transport, spatial and environmental policy. An adequate trade off between costs and benefits of port investment is necessary.

Cost overruns are a major concern in port investment projects. Based on empirical analyses, Bruzelius *et al*. (2002), Flyvbjerg *et al*. (2003a) and Flyvbjerg *et al*. (2003b) conclude that substantial cost overruns, in addition to overestimated demands, are typical for large-scale transport infrastructure investment in general. In the Netherlands, experiences with the Betuwe line-project showed similar results: in 1992, the investment cost was estimated to be € 2.3 billion, by the end of 2000, it was about € 4.7 billion (Van Eijk and Pama, 2003)[20].

A most important aspect in the debate is the determination of added value for the national economy and, in particular, the indirect effects. Some studies (e.g., Kuipers, 1999) suggested that the Port of Rotterdam contributes significantly to total Dutch employment and GDP. However, a considerable amount of double counting is suspected in calculating such figures (see Pols, 1997). Furthermore, the contribution of the entire Dutch freight transport sector to the national economy is to be questioned (see Kuipers, 2000).

Another aspect in the port investment debate, strongly related to the issue of economic effects, concerns future port demand. Some parties propose essentially an extrapolation of past trends, while others point to the (potential) changing structure of the economy and composition of trade flows, the possible changing competitive position of the Dutch ports, and the likelihood of route and modal shifts (see, e.g., Van de Voorde and Witlox, 2000; Dekker *et al*., 2002). The development and choice of economic scenarios has considerable influence on capacity requirements of ports.

The debate about government subsidies for port investments and associated costs and benefits continues to date. It hinges on aspects that are difficult to resolve such as a the ‘leakage’ of port investment benefits to other countries (see Dekker and Verhaeghe, 2005), prediction of technological development in freight transportation, improved efficiency in the use of space, and prediction of port demand (Dekker *et al*., 2002; Dekker *et al*., 2004).

[20]The interested reader is referred to Tweede Kamer (2004) for an elaborate overview of experiences in Dutch policy-making regarding cost overruns and demand projections in large-scale transport infrastructure projects.

2.6 Observations and Discussions

A comparison between European and Dutch port policy regarding port pricing and investment financing indicates some friction between both policies. Where European port policy tends towards pricing according to usage and no investment funding by governments, Dutch port pricing practice is based on quay charges and port dues (in addition to terminal charges) and contributions of the national government to port investments are still adopted. Application of self-financing of port investment in basic infrastructure, based on the revenues from congestion pricing, is therefore in accordance with European port policy.

The Rotterdam port operates under strong competition. In addition to ports in the North Sea region such as Antwerp, the development of the Mediterranean ports may become an additional threat for Rotterdam. The development of the Italian port Gioia Tauro will therefore be used in this thesis as an illustrative example of port competition in an international network.

Government subsidies for large-scale Rotterdam port investment projects such as the Betuwe line and the Maasvlakte 2 have initiated a heated debate in the Netherlands. This debate concerns the potential and desired role of the Dutch ports in international freight transportation, their contribution to national welfare and further enhancement by physical expansion.

An interesting economic issue for planning of port capacity is the 'leakage' of port investment benefits to other countries. Furthermore, the potential sensitivity for changing costs and demands is to be accounted for.

2.7 Further Perspective

The remainder of this study focuses on the following aspects, which are derived from discussions in this and the previous chapter:

1) Concepts for planning, applied to port expansion, will be reviewed and developed. This will lead to a capacity-planning approach for a single port that determines the optimal design capacity by integrating port-commercial and public interests, and to incorporate competition, autonomous demand growth and economies of scale.
2) A modeling approach for planning of a port's capacity will be developed that leads to self-financing of port investment. It will focus on deciding upon port expansion for a single port to deal with competition. The competition scenario that will be worked out is a change in the transportation network by means of the entry of a new route via a competing port. The port expansion problem will be formulated as an optimization problem; the optimal solution comprises the optimum expansion size and the associated investment recovery period.
3) Modeling capacity demand and supply of a port will be established for a port in an international network of competitive transportation routes. To account for uncertainties in route choice by freight carriers, a probabilistic equilibrium modeling will be used.

4) Developments in container transportation technology will be reviewed. The findings will be used for a practical approach to incorporate technological development in planning of port capacity.
5) The methodology for planning of a port's capacity will be demonstrated with an application to the Port of Rotterdam, which will focus on a hypothetical port expansion for non-domestic container flows by means of land reclamation. The question then is: what should be the optimal expansion strategy for Rotterdam to deal with competition? And: can the expansion strategy be self-financing?

In the next chapter, planning concepts, applied to port expansion, will be reviewed and developed.

3. Review and Development of Planning Concepts - Application to Port Expansion

3.1 Introduction

Two perspectives on port development can be distinguished, namely 1) the port-commercial perspective, representing the interests of the port owner, and 2) the public perspective, representing the interests of port users and society. The port planner needs to integrate the interests of both perspectives to obtain a viable setup of large-scale port investments such as port expansion.

Furthermore, port development requires considering the fact that a port constitutes a node in a transportation network, which is characterized by competing routes and autonomous growth of freight flows. A port's competitive position in such a network can be enhanced by investment in port capacity improvement. This reduces generalized transportation costs leading to increased port competitiveness, and allows for autonomous growth of port demand.

Planning of a port's capacity comprises 1) design, 2) evaluation, and 3) financing. The concepts that support the planner to work out decisions on the options are reviewed and developed in this chapter[21]. The findings are used to set the stage for the next part of this study, namely, development of a methodology for planning of a port's capacity. The main questions of this study – what is the optimal expansion strategy for a single port to deal with route competition and to facilitate further growth of the port's demand, and: can the expansion strategy be self-financing – serve as a guideline.

The remainder of this chapter is divided into six sections. Section 3.2 presents an inventory of alternatives for port capacity improvement using the container transfer process as illustrative example. Schematization of a port system with a view on strategic planning of port capacity is given in Section 3.3. Section 3.4 discusses design levels and design variables for port expansion, which is the focus of this study. More detailed concepts to support port expansion design are reviewed and further developed in Section 3.5. This sets the stage for the last step towards integrated planning of port capacity, namely, integration of port-commercial and public interests and incorporating self-financing of port expansion, which is discussed in Section 3.6. Section 3.7 summarizes the findings.

[21] In the present study, the concepts are not empirically founded; this may be an interesting topic for further research.

3.2 Alternatives for Port Capacity Improvement

3.2.1 Schematization of the Container Transfer Process

Ideally, one would like ocean vessels to sail as directly as possible to their final destinations because each cargo handling activity entails friction costs and the risk of damage to the cargo. Three types of constraints enter into this process making the usage of ports necessary. First, vessels carry cargo with different final destinations, which causes the need for more complex service networks (e.g., hub-and-spoke). Second, the final destination of cargo is usually not located at the banks of inland waterways. Additional transport modes are needed to provide the connection between vessel and hinterland destination. Third, ocean vessels are too big to enter inland waterways.

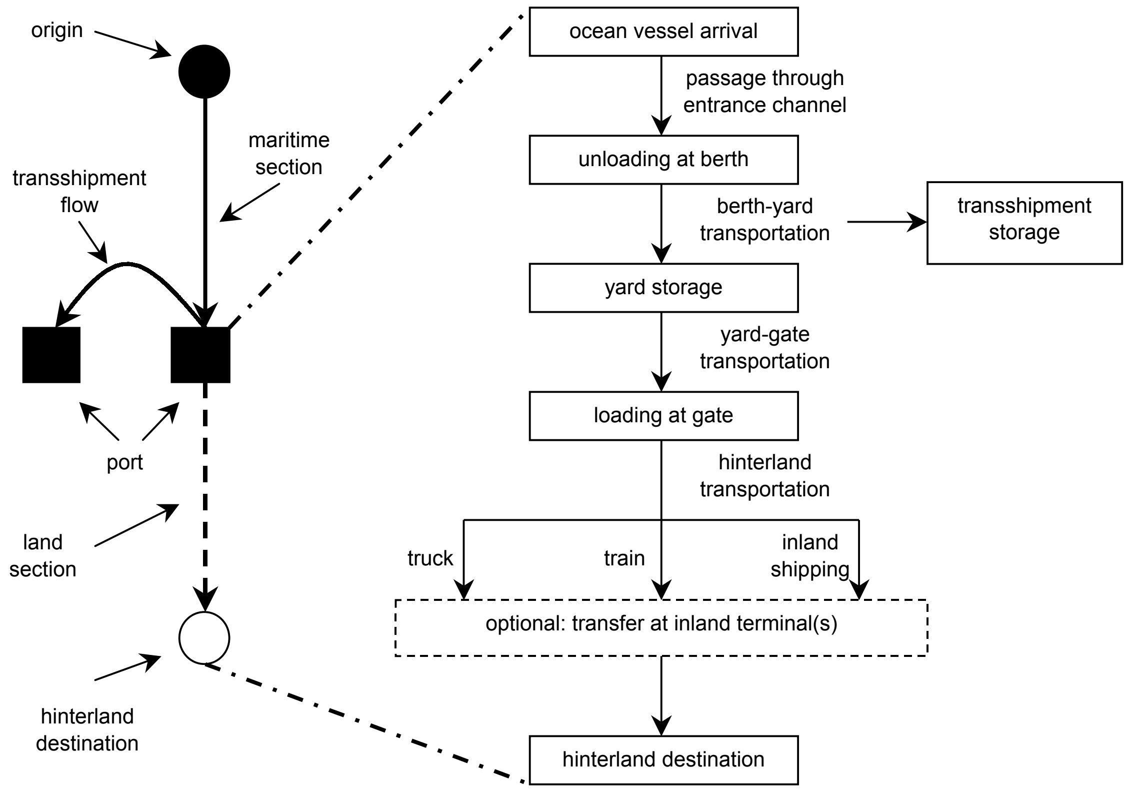

FIGURE 3.1 Schematization of the container transfer process at a seaport.

A port can be considered as a link in transportation routes connecting origins and destinations for freight flows. Focusing on the land section and the port and using container transfer as illustrative example, the container transfer process can be schematized into a set of inter-dependent stages or links as indicated in Figure 3.1. Inefficiencies in this process lead to higher service times than ideally can be performed by the port (i.e. here port congestion; see Section 3.5).

Each of the links in a port can be modified to improve the efficiency of the total transfer process. To realize the full potential of a port capacity measure, all links in a port should be modified to obtain a chain of mutually balanced link capacities (Jansson and Shneerson, 1982; Brennan, 2001). Dealing with port congestion requires therefore tracing the bottlenecks in port system capacity. A major cause of shortages in port capacity - peak loads due to the arrival of large vessels that have to be handled in the shortest possible time - remains however difficult to solve.

Capacity problems in the container transfer process can be solved by (a combination of) ‘structural’ measures leading to facility expansion, and ‘non-structural’ measures leading to an improved utilization of existing facilities (see Figure 3.2). An inventory of the different alternatives for port capacity improvement is given below.

3.2.2 Structural and Non-Structural Port Capacity Measures

Structural measures

Structural capacity measures aim at ‘more’ or ‘bigger’. Different types of measures can be applied in the different links of the container transfer process, such as dredging works making entrance channels and basins deeper to be able to receive bigger vessels; obstacles constraining waterways (e.g., low bridges) can be removed; application of locks to assure a constant water level in ports that are otherwise affected by the tide; more cranes per berth increasing berth productivity; and additional road and rail connections expanding hinterland transportation capacity and shortening travel times.

Seawards expansion of the port by land reclamation is often applied. It expands the surface area of the port and bigger ships can be handled as well, because channels and basins become deeper in seawards direction. Similar to Rotterdam, examples of such expansion projects can be found in various ports such as Singapore and Houston.

Structural capacity measures have four important characteristics. First, they are capital intensive; such investments may be at the expense of other investment priorities (crowding-out effect). Second, they show economies of scale in investment cost, which makes expansion with larger increments more attractive. Third, large-scale expansion works require time by planning. This may put the particular port at a disadvantage compared to other, competing ports. Fourth, structural measures may activate latent demand (i.e. demand that is deterred by congestion) due to improved accessibility (Small, 1995; Rietveld, 1996), which leads to demand shifts between routes and induced demand due to a better network. As a result, port demand may tend to increase after expansion, which makes it an interesting strategy for ports to deal with competition.

Since the 1970’s, global transport policies regarding infrastructure capacity generally shifted from a primary orientation on structural measures to a broader scope including non-structural measures (e.g., Freilich and White, 1994; Sussman, 2002). Referring to Frechione and Walker (2004), one of the lessons that can be learnt from the Ohio River Navigation System-project is the need to look beyond structural measures in dealing with infrastructure capacity problems. The recent debate on the usefulness and necessity of large-scale investments in the Port of Rotterdam (see Chapter 2) has emphasized the need for a broader scope as well.

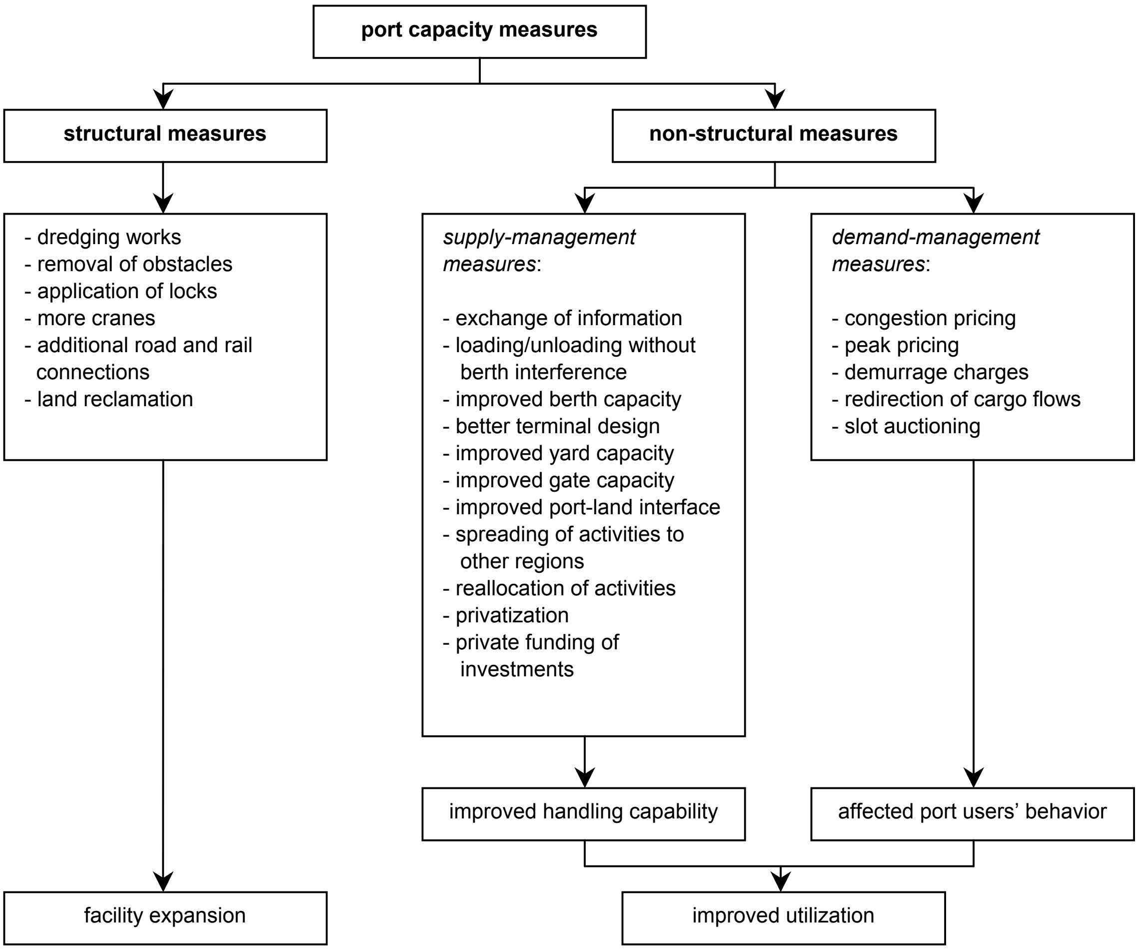

FIGURE 3.2 Overview of port capacity measures.

Non-structural measures

Non-structural alternatives relate to technological, managerial, economic and regulatory measures that 1) improve the handling capability of the port, or 2) affect port users' behavior. The first group is referred to as supply management measures and the second as demand management measures.

<u>Supply management measures</u>

Examples of supply management measures are briefly discussed below.

Exchange of information between ocean vessels and port during the voyage is used to predict the arrival times of ocean vessels in order to be able to make better berth reservations. Generally, better exchange of information contributes to better-integrated transportation chains.

Loading and unloading without berth interference means that containers are directly transferred between the ocean vessel and other vessels. This leads to a reduced need for storage requirements (e.g., Roscam Abbing, 1999).

Improved berth capacity comprises mainly anticipating on the random nature of vessel arrivals, the growth of vessel sizes and the uneven flows between vessels and the yard. The measures include berth assignment flexibility, better stow plans, better connections between working shifts, and better truck-crane interactions. Dommershuijzen *et al*. (2000) report about the design of innovative berths that can be used for more than one cargo type. The aim of such berths is efficiency gains via economies of scope.

Better terminal design aims at an improved layout of the terminal in order to make the transport process between berths and yards more fluent.

Improved yard capacity can be obtained through a better utilization of the yard area. Higher stacking in combination with higher storage modes is relatively simple to obtain. However, the strength limit of containers is about nine full boxes and the wind limit is about five empty containers (Ward, 2002). This can be solved with warehouse-type structures. Other examples are storage of empties at other locations, real-time inventory control to prevent the use of extra space for rehandling, and inventory mapping based on forecasted future transactions. The main cause of inefficiencies, dwell times, is difficult to control by the operator, because market forces highly determine dwell times.

Improved gate capacity includes faster data exchange and inspection (e.g., with video inspection), expansion of gate hours and establishing an appointment system to distribute arrivals and to enforce arrival discipline.

Improved port-inland interface aims at enhancing the connection between the port and its hinterland connections. The associated measures comprise 1) improved rail capacity such as longer working tracks to limit the number of ‘cuts’, track use flexibility and grade separation to prevent the crossing of rail traffic by gate traffic; 2) improved road capacity such as broad curves, long sight distances and traffic management techniques; and 3) improved inland waterway capacity such as improved lock operation (Frechione and Walker, 2004).

Spreading of activities to other regions concerns the transfer of transport-logistic activities that are not necessarily to be located in the main port area to hinterland regions. The continuous development of inland terminals serves as an illustrative example.

Reallocation of activities within the existing port area focuses on a more intensive use of existing port areas. For example, old harbor basins can be filled up and used for industrial activities.

Privatization and *private funding of investments* are widely considered to have a positive impact on efficiency (e.g., Gómez-Ibáñez and Meyer, 1993; Trujillo and Nombela, 2000). However, Baird (1999) concluded that privately owned ports experience just as much trouble recovering capital investments as publicly owned ports. Cullinane and Song (2002) noted that it is extremely difficult to conclude that ownership constitutes a significant factor in port performance and efficiency. Private funding of port investments may be effective in assuring the commitment of shareholders to use cargo-handling facilities.

Demand management measures

Demand management measures include pricing, slot auctioning and redirection of cargo flows. Such measures aim at reduction of demand at a particular port by suppressing demand or shifting a portion of it to alternative locations.

Congestion pricing is an economic approach that uses the price mechanism as an instrument for modulating traffic demand. It would typically take the form of a surcharge (a toll that is set equal to the marginal external cost) on the use of facilities according to the level of congestion. Special forms of congestion pricing are peak pricing (i.e. pricing during busy hours with the aim of encouraging users to shift to less busy times or facilities) and demurrage charges (i.e. charges imposed by terminal operators to deter long dwells).

Slot auctioning is based on selling the right to use facilities at a certain time during the day (slot) to the highest bidders. The free market forces determine the cost, which are simply what users are willing to pay for using a scarce resource such as capacity at a certain time. Applications of slot auctioning can be found in some Asian ports (Sengers, 2004).

Redirection of cargo flows helps to reduce the demand on the original port facilities by serving part of it at complementary facilities or secondary ports. At the seaside of the port, it could be applied to the redirection of (parts of) transshipment flows.

3.2.3 Operational and Strategic Port Capacity Measures

With a view on the scope of this study - strategic rather than operational planning -, port capacity measures can further be divided in operational measures, which particularly deal with short-run demand fluctuations, and strategic measures focusing on long-run continuation of port operation. Table 3.1 presents an overview of operational and strategic measures based on the inventory of structural and non-structural measures as discussed above.

TABLE 3.1: Operational and strategic port capacity measures

		Operational measures	**Strategic measures**
Structural measures			Dredging works Removal of obstacles Application of locks More cranes Additional road and rail connections Land reclamation
Non-structural measures	**Supply management**	Improved berth capacity Improved yard capacity Improved gate capacity	Exchange of information Loading/unloading without berth interference Better terminal design Improved port-land interface Spreading of activities to other regions Reallocation of activities Privatization Private funding of investments
	Demand management	Peak pricing Demurrage charges Slot auctioning	Congestion pricing Redirection of cargo flows

Another distinction can be based on *who* implements the measures. The government, for instance, mostly implements congestion pricing. The terminals implement demurrage charges. See, for instance, Dekker *et al*. (2002) for a brief discussion on this topic.

Some port capacity measures are inter-dependent. For example, if a port selects spreading of its activities to other regions, it is less likely to support land reclamation works. If the port already benefits from land reclamation, investment in better terminal design would be less likely to be established.

Structural and non-structural measures can be combined to reduce port capacity problems effectively as suggested by Dekker *et al*. (2004). Congestion pricing, for instance, could help to reduce activated latent demand and the revenues from congestion pricing could be used to recover investments in basic infrastructure such as expansion works (see Section 3.6). The latter is justified on the grounds that the incremental cost of providing additional facilities to accommodate additional demand ought to be paid for by those demanding for and benefiting from these facilities.

3.3 Schematization for Planning of Port Capacity

Figure 3.3 presents a schematization of the components and their inter-relationships, relevant for strategic planning of port capacity. This schematization essentially identifies the different potential investments and effects associated with the cargo flows through a port system. The volumes of the cargo flows through a port are strongly determined by a port's position within the service networks of ocean carriers. If ports have an important hinterland function, the cargo flows depend also on the performance of their hinterland connections (e.g., De Langen and Chouly, 2004).

The following two types of port investment with a view on minimizing the generalized cost of transport-logistic chains can be distinguished:

1) *investment in port expansion* aiming at reduced generalized cost of cargo handling in the port; and
2) *improvement of hinterland connections* aiming at reduced generalized cost of hinterland transport.

Reduced generalized cost in the port system enhances the attractiveness of the transport-logistic chains of which the port is part of and, as a result, increases the volume of cargo flows through the port. Increased cargo volumes affect the environment and create employment and value added by the cargo handling industries.

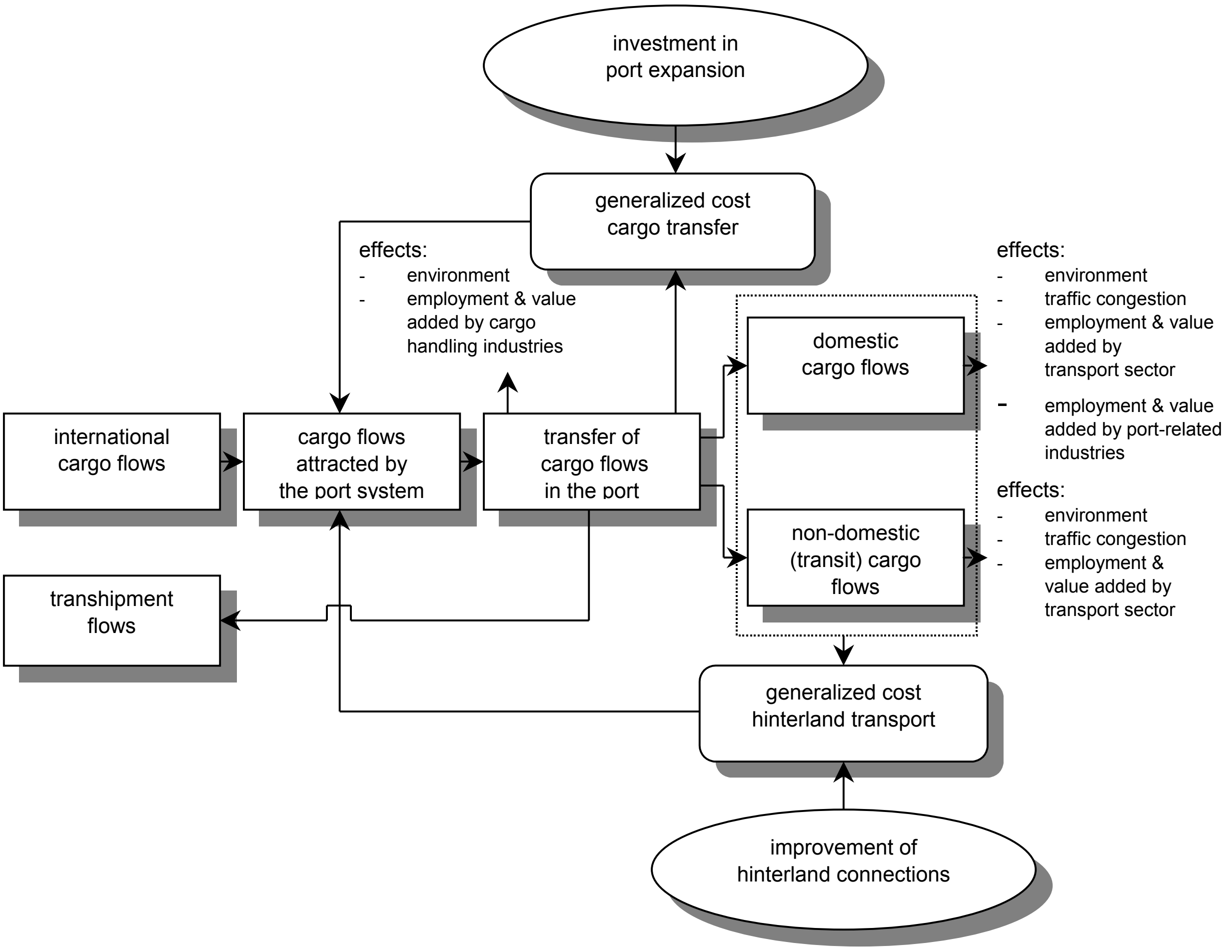

FIGURE 3.3 Schematization of a port system from national-economic perspective.

For hinterland transportation, a major differentiation should be made into domestic cargo flows (i.e. cargo flows with the country in which the port is located as destination) and non-domestic flows (i.e. transit flows to foreign countries). They have a strongly different impact on national welfare. Both flows have impact on the environment and traffic congestion. Domestic flows however have a strong relation with the creation of employment and value added in port-related industries in the nation while non-domestic flows contribute primarily to an increase in employment and added value in the transport sector.

Particularly non-domestic and transhipment flows occur in competition with other ports and constitute therefore a relatively volatile part of the total flow. At the same time, these flows are crucially important to maintain the hub-status of ports because sufficiently large cargo volumes are needed to create efficiency gains for domestic flows. These efficiency gains (represented by the shaded area in Figure 3.4) are obtained via a reduction of the port price for domestic flows due to economies of scale in port operation. For the application case, it is assumed that it is possible to split domestic and non-domestic cargo flows in a port context.

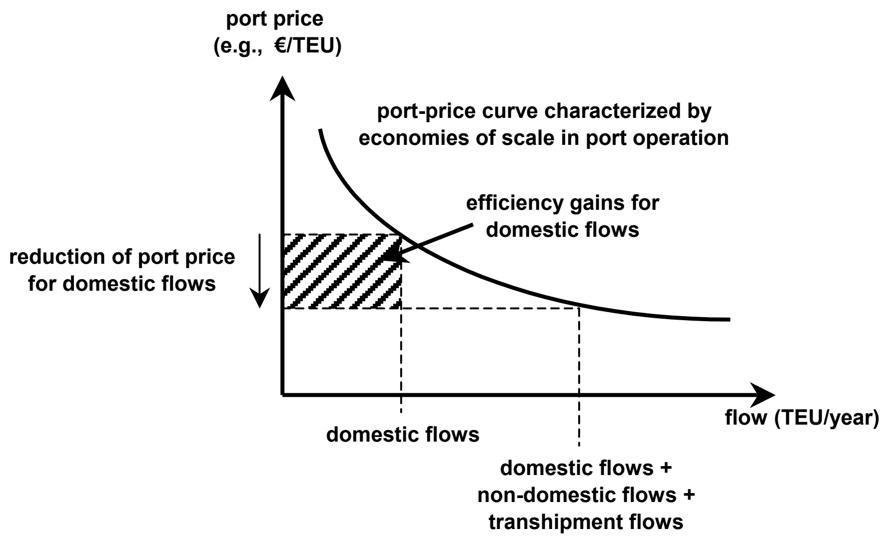

FIGURE 3.4 Concept of efficiency gains due to economies of scale in port operation.

The remainder of this chapter emphasizes planning for port expansion, which can be considered as a strategy for ports to deal with competition and to facilitate further growth of port demand.

3.4 Design of Port Expansion

In the design of port expansion, three levels can be distinguished: strategic, tactical and operational design. The different design levels and associated main design variables are presented in Table 3.2. With a view on the availability of data for the application case, this study focuses on the strategic level[22].

TABLE 3.2 Design levels and main design variables for port expansion

Design levels	Main design variables
strategic	size, investment recovery period, location, timing
tactical	layout, berth lengths, cargo-handling technology
operational	structural strength, material selection

At the strategic level, decisions are made on the size, the investment recovery period, the location (landwards expansion by using existing areas or seawards expansion by land reclamation) and the timing of port expansion works. Design variables at the tactical level include layout, berth lengths and cargo-handling technology. At the operational level, the structural strength and the construction materials of, for instance, quay walls are determined in detail. With a view on preliminary port expansion plans, cargo-handling technology is more strategic than purely tactical because the associated efficiency in terms of handling time determines the demand for space (see further).

[22] With the exception of interdependency between expansion size (strategic level) and cargo-handling efficiency (tactical level), interdependencies between the three design levels are not accounted for in the present study.

The terminals constitute the heart of each cargo port: they provide the actual handling capability (e.g., Ligteringen, 2003). Terminals are mostly privately owned and may be specialized in the handling of certain cargo types such as container terminals, fruit terminals and coal terminals; the handling equipment differs accordingly. Furthermore, multi-user and dedicated (‘single user’) terminals may be distinguished.

Seawards expansion by land reclamation, the focus of the application case, may have undesirable impacts: unique landscapes (coastal areas) may disappear and morphological processes along the coast may be disturbed leading to erosion and sedimentation. Alternative port development concepts can be used to overcome these impacts and to reduce the need for land reclamation works. Hayuth (1981), for instance, pointed at the rise of port networks making the potential for redirection of cargo flows more realistic.

The process of strategic design for port expansion plans can be represented by a two-step procedure, involving a conditional forecast of the demand, followed by determination of the port expansion strategy to satisfy this demand. A major characteristic is then the expansion size, which depends on the efficiency in the use of space that can be obtained by the terminals. A container handling productivity[23] of 60,000 TEU/hectare/year is reported for the port of Hong Kong (De Hartog *et al*., 2001). For Rotterdam, a productivity of 24,000 TEU/hectare/year is considered to be likely in the near future (CPB, 2001a).

Concepts to support strategic design of port expansion are discussed in the next sections.

3.5 Congestion-Based Design

The premise that port expansion should be designed to accommodate the full demand at all times is unrealistic. Most transportation system designs are based on the acceptance of a certain level of congestion (e.g., Bovy, 2001); this is here referred to as congestion-based design.

Below, different approaches for congestion-based design are introduced. These approaches can be used to deal not only with design, evaluation and financing of expansion works but also with management and operation of port systems.

Port expansion works serve to improve 1) the connection between maritime and land transportation modes, and 2) the buffer (storage) capability within logistic chains. In the past, after the original design proved to be insufficient, capacity was upgraded according to the highest (time-averaged) demand expected within the planning period. This design approach should be expanded to capture the full complexity of the port expansion problem.

[23] Container handling productivity indicates the efficiency in the use of space. The accuracy of the term ‘productivity’ can therefore be questioned. Ideally, deciding upon port expansion would include a comparison of the investment cost with the opportunity cost of productivity improvement.

Definitions

Design capacity can be defined as a single value (possibly derived from a distribution[24]) representing the highest volume or flow a transportation system can handle at a certain minimum level of service quality. It is determined by the system's design features (sizes and numbers), service characteristics (e.g., productivity), demand conditions (e.g., demand patterns) and external factors (e.g., weather conditions).

The *actual capacity* may be higher than the design capacity, since 1) the actual level of service and design level of service may differ, and 2) process improvements may have occurred before reaching the design year. The *design year* is some future year when available capacity meets expected demand.

Congestion is defined as the accumulation of transported items at a certain point in time and space (queuing). A transportation system can be defined as congested if the (time-averaged) flow of transported items approaches design capacity, which leads to higher service times than ideally can be performed by the system. The relationship between design capacity, flow and (ideal) service time is used in Figure 3.5 to illustrate the concept of congestion. This relationship refers only to stationary conditions and specific distributions of service times and arrival times. Service times decrease for increasing design capacity.

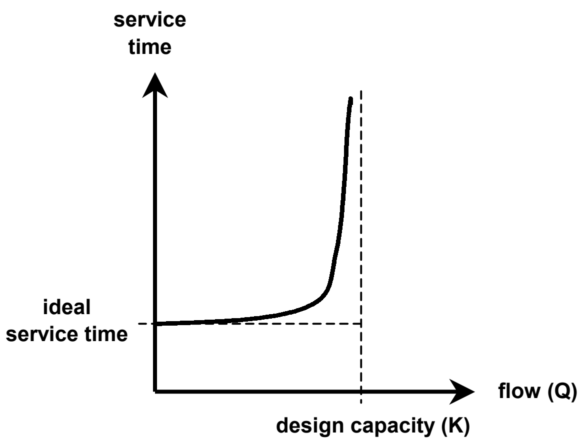

FIGURE 3.5 Concept of congestion.

Design and improvement of transportation system capacity depends on the system's response to usage of the system and the resulting congestion behavior. Two factors, namely 'flow' and 'design capacity' are to be considered in the decision on expansion incorporating a tolerable level of congestion. For ports, the flow is the cargo throughput, while the 'design capacity' is a function of its design features (e.g., surface area, number of cranes, storage capability) and productivity representing the efficiency of the handling services. Evidently, the

[24] Transportation system capacity depends on random variables such as weather conditions and labor productivity. The resulting capacity distribution can be used to choose a specific design capacity value such as the average of the distribution. In the Netherlands, the design capacity for freeways has been chosen on economic grounds so that a maximum of 2% (for hinterland freeways) or 5% (for other freeways) of the drivers will be confronted with congestion (e.g., Bovy, 2001).

characteristics of flow and design capacity are required for further study on the effects of congestion.

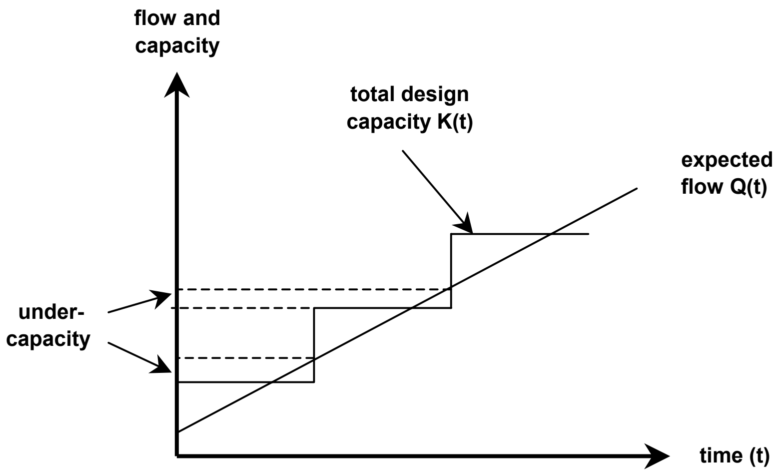

FIGURE 3.6 Under-capacity as time-varying phenomenon.

If the sum of all flows through a transportation system is defined as a generalized 'flow' Q, and the combination of all system characteristics leads to a generalized 'design capacity' K, then under-capacity occurs if '$Q > K$'. If the flow is expected to grow and design capacity is expanded over time then the occurrence of under-capacity is a time-varying phenomenon (see Figure 3.6).

Experience in transportation system operation under stationary conditions has shown that congestion starts to build up quickly when the flow exceeds about three quarters of the system's design capacity (see, e.g., Manheim, 1984). The resulting average service time increases exponentially as the ratio of flow to design capacity approaches 1 representing the level of saturation (see Figure 3.4). The service or supply function of a transportation system can therefore be written as a function of 'Q/K' (the utilization rate). May *et al*. (2000) discuss supply curves for urban road networks. Discussions on design capacity and utilization for other transportation systems such as highways, railways, and inland navigation systems can be found in Kreutzberger and Vleugel (1992).

Inspired by the different levels that can be distinguished in probabilistic design (see, e.g., Zhou, 1995; Kuijper, 1997), Dekker and Verhaeghe (2004) postulated five design approaches in determining the optimal design capacity of transportation systems:

- Approach 1: empirically based design standard for structural measures;
- Approach 2: explicit consideration of supply-demand and congestion effects;
- Approach 3: inclusion of investment cost;
- Approach 4: consideration of non-structural measures and welfare effects; and
- Approach 5: integration of public and commercial interests, and competition.

The common feature of the approaches is that the design variable, the design capacity K, is chosen in such a manner that the system satisfies the design flow Q at a minimum level of service quality. The main differences lie in the type of capacity measure (structural, non-structural or a combination) and the level of elaboration of costs and benefits. The different design approaches are discussed below and lead towards the aim of this study: integrated planning of port capacity incorporating competition and self-financing of port expansion.

Approach 1: empirically based design standard for structural measures
Approach 1 is based on an empirically based design standard for structural measures. The US Highway Capacity Committee, for instance, translated numerical traffic density results (expressed in vehicles/lane/mile) into a classification of different Levels Of Service (LOS) provided by the facility for the prevailing demand conditions (TRB, 2000). The LOS represents then the design standard, in which 'A' stands for the highest LOS and 'F' for the lowest. Hence, important is the choice of the demand conditions, related to the function of the road, and the associated LOS from which the principal dimensions of the road can be deduced. Approach 1 provides a method for routine (everyday) design practice.

In general, application of a design standard can be criticized for several reasons (see Zhou, 1995). First, the economic and environmental effects of meeting (some percentage of) a particular standard may not be incorporated (this is not true for the Dutch KWAST-approach for road design; see Botma, 1998 and Bovy, 2001). Second, design standards may have been set without rational procedures and data. As a consequence, a standard may lead to over- or under-design for a specific situation. Third, standards may not incorporate new knowledge or the latest technology or data. Fourth, design standards hide information about utilization rates, and costs and benefits of alternative options and, consequently, bypass discussions about acceptable congestion and willingness-to-pay for a specific situation.

Approach 2: explicit consideration of supply-demand and congestion effects
Approach 2 is based on finding a balance between supply and demand, incorporating congestion effects. The arrival rates of ocean vessels can be described adequately with the laws of probability (see, e.g., Jagerman and Altiok, 2003). Many decisions on seaside port investment (e.g., quay extension) are therefore based on queuing analysis. The port is then schematized as a queuing system represented by random vessel arrivals, random service times and a service system (queue discipline and number of berths). The aim is to find a balance between the average waiting time of the vessels (demand), the number of berths (supply) and the average berth occupancy rate and service time (congestion effect). Simulation techniques have been developed to deal with more complex queuing problems (see, e.g., Frankel, 1987).

Transportation modeling considering congestion effects can be regarded as a more elaborated type and can be used for network optimization. An application can, for instance, be found in Carey and Subrahmanian (2000). Lamar and Lee (1999) applied this concept to a strategic investment model for manufacturing systems.

Approach 2 is characterized by application of a criterion for acceptable congestion and does not include a relationship between design capacity and investment cost.

Approach 3: inclusion of investment cost

Approach 3 is an extension of Approach 2 by including the investment cost. For example, the investment cost can be optimized by using the equations of queuing analysis or transportation flow modeling as constraints. An application to optimal design of container ports can be found in Paelinck and Paelinck (1998).

Because capacity design with Approaches 2 and 3 is based on solving congestion problems with system optimization, it can be characterized as 'transportation system optimization' (see Jansson, 1984). It is important to note that the calculation process in Approaches 2 and 3 starts with given supply and demand characteristics. Consequently, these approaches accept a certain level of congestion.

In port design, over-design implying unnecessary high investment costs may occur due to demand drops making a sound commercial exploitation less likely. On the other hand, under-design leads to a level of congestion that deters potential users causing a poor economic performance and leading to congestion costs. The design approaches 1 to 3 are not applicable for the evaluation of welfare effects or efficiency improvement by non-structural measures. Therefore, in addition to these approaches, further extension is required.

Approach 4: consideration of non-structural measures and welfare effects

Approach 4 considers explicitly the application of non-structural measures and welfare effects such as the external cost of traffic congestion. The design capacity is found by optimizing an objective function such as maximizing some welfare function. For an expansion project, the welfare function in a more restrictive sense can be interpreted as the increase of consumers' surplus (due to cost savings for the users by, for instance, reduced congestion).

Based on Approach 4, further refinement can be made to account for improvement towards the ultimate goal: determining the optimal design capacity by integrating public and commercial interests to obtain overall viability of port expansion projects. This is only feasible if the potentials of structural and non-structural measures are combined in determining design capacity. With a view on the port-planning problem at hand, competition among ports should also be incorporated.

Approach 5: integration of public and commercial interests, and competition

Approach 5 integrates public and commercial interests to obtain overall viability of port expansion projects by combining the full potential of structural and non-structural measures 1) to increase consumers' surplus and to expand and use transportation systems economic efficient[25] (public interests), and 2) to recover the investment cost of facility expansion (port-commercial interest). Furthermore, this approach considers the effect of competition among ports on supply-demand interaction.

[25] Expansion and utilization of transportation systems are economic efficient if at least one individual becomes better off without making any other individual worse off (Pareto efficiency).

The concept of 'economic capacity' as noted by, for instance, Meersman *et al*. (1997) can be considered as a first step towards Approach 5.

The above-discussed capacity design approaches are summarized in Figure 3.7.

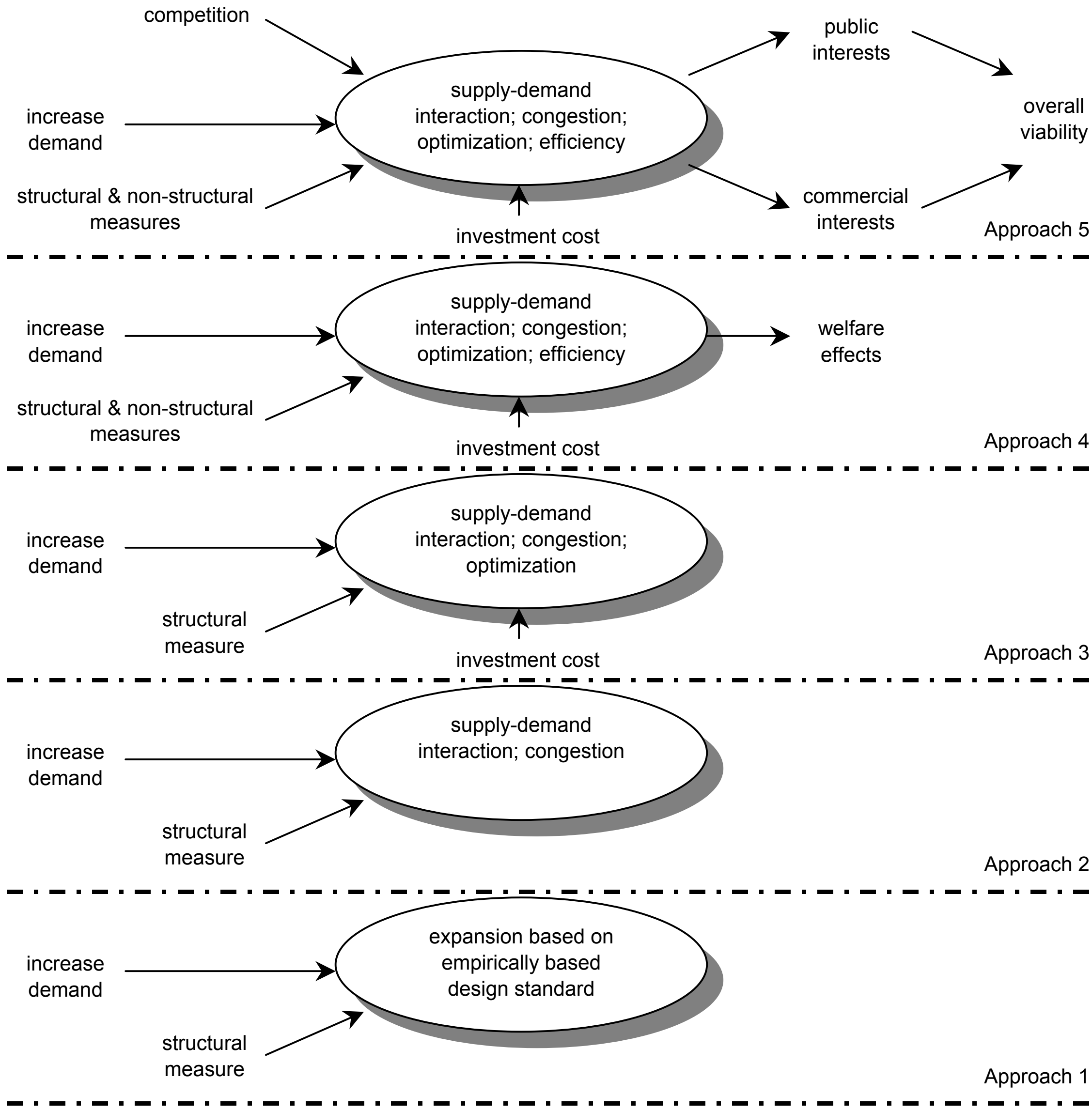

FIGURE 3.7 Summary of capacity design approaches (adapted from Dekker and Verhaeghe, 2004).

The port expansion problem at hand is a most complicated planning problem due to the combination of public and port-commercial interests. It should further incorporate the aspect of competition, because port expansion is here considered to be a strategy to deal with competition. This requires planning of port capacity based on Approach 5, which is here referred to as integrated planning of port capacity: port planning that integrates port-commercial and public interests, and incorporates route competition. Such approach applies to infrastructure objects that 1) need to combine their public function with a strong commercial perspective in order to obtain a viable setup, and 2) operate as nodes in transportation networks, which are characterized by competition between alternative routes.

The next section discusses the last step towards integrated planning of port capacity.

3.6 Towards Integrated Planning of Port Capacity

The port planner's task is to determine the optimal port capacity to deal with route competition and to facilitate further growth of demand. His aim is overall viability of the port expansion project by integrating public interests (increase of consumers' surplus and economic efficiency) and the port-commercial interest (investment recovery). Effects on national-welfare should only be integrated if contributions from public funds are involved. If self-financing of port expansion (i.e. only the users pay for the expansion cost) can be established, the use of scarce public funds is not necessary and difficult issues in determining national-welfare effects can be by-passed.

3.6.1 Public Interest: Economic Efficiency

A main public interest of port expansion is economic efficiency[26], which requires economic evaluation by cost-benefit analysis. In such evaluation, the present value of the costs of expansion works must be less than the discounted stream of economic benefits[27]: the difference between the welfare effects with and without expansion. The welfare effects include first of all direct effects, which comprise the increase of consumers' surplus (due to cost savings for port users) and producers' surplus (increased financial revenues for the port). Since the issues of external and indirect effects received more attention, the estimation of welfare effects became more complicated. Alternative approaches and methods were developed to include these effects.

External effects (of the use of port facilities) include social costs due to port congestion and environmental pollution. Social costs due to port congestion are internalized by congestion pricing, which is based on the marginal external cost of port congestion (see, e.g., Jansson and Shneerson, 1982; Button and Verhoef, 1998). Elaborate discussions on the application of marginal cost pricing in freight transportation and ports can be found in TRB (1996) and Goss and Stevens (2001), respectively. Environmental pollution can be internalized with, for instance, the so-called indirect (shadow) pricing method (see, e.g., Rothengatter, 2003).

It is generally recommended that the indirect effects should be examined in a separate analysis. For example, Eijgenraam *et al*. (2000) recommended starting with a so-called partial cost-benefit analysis to assess the direct effects and then to examine the indirect effects if, for instance, the national-competitive position is expected to be affected. If no indirect effects are

[26] The equity issue, another public interest (see Chapter 1), is not worked out in the application case but is an interesting issue for further study.

[27] The difference between economic benefits and costs (net economic benefit) is maximal if the marginal economic benefit is equal to the marginal investment cost. This principle is used in this study as criterion for economic efficiency (see Chapter 4).

to be expected, the welfare effects of a port expansion project can be determined with a partial cost-benefit analysis. A further distinction can be made between welfare effects for the national economy and welfare effects for the international economy (see, e.g., Blauwens, 1996).

Several attempts have been made to model indirect effects. The model types include regional-economic models, production function models and input-output models (see, e.g., Villaverde-Castro and Cota Millán, 1998; Banister and Berechman, 2000; Van de Vooren, 2004). When input-output modeling is applied, the difference between net and gross multiplier should be accounted for to prevent double counting (Stelder *et al.*, 1999).

3.6.2 Port-Commercial Interest: Investment Recovery

The main port-commercial interest associated with port expansion is recovery of the investment cost. A purely commercial (financial) evaluation is required to determine the financial viability of the project and to estimate the investment recovery period.

Government subsidies contribute to port investment financing, but may influence an efficient match of port demand and supply; it involves an investment cost (to the port) that does not reflect the ‘real’ investment cost, which may result in over-capacity. The combination of over-capacity and port competition gives cause to price wars between ports as can be observed in the North Sea region (Chlomoudis and Pallis, 2002). This spirals into collapsing port prices making investment recovery difficult.

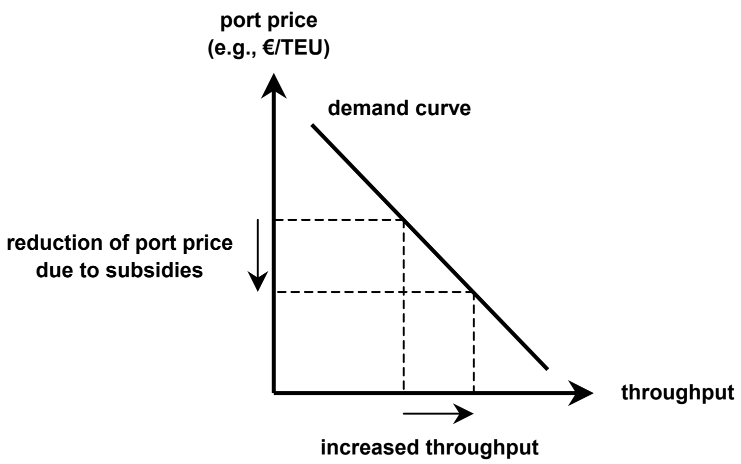

FIGURE 3.8 Effect of government subsidy on port price and throughput.

On the other hand, government subsidies may be desired with a view on promoting national welfare because subsidies lead, via port-price reduction, to a higher throughput but not necessarily to higher revenues (see Figure 3.8). A major justification for subsidies can then be found in the contribution of port expansion to national welfare. The government may contribute a portion to the investment (cost), which balances the discounted environmental and indirect effects (benefit) over the project’s lifetime. The proportions of direct effects, and external and indirect effects, respectively, in the total benefit increase will then determine the appropriate ratio of private to public investment (Dekker *et al*., 2003).

3.6.3 Self-Financing of Port Expansion

The above-discussed issues of government subsidies are by-passed if port expansion can be self-financing, which means that the investment cost can be paid only by the revenues from port pricing. Mohring and Harwitz (1962) established an interesting balance between congestion pricing and capacity expansion to achieve self-financing of infrastructure expansion. They showed that under certain conditions the revenues from congestion pricing are sufficient for financing expansion works, provided that the welfare surplus is maximized (see Appendix 7E for a numerical example).

The 'conditions' include (see, e.g., TRB, 1996; Verhoef, 2001):
- investment levels are optimal (no under or over-design);
- there are no economies of scale in investment cost;
- there are no economies of scale in infrastructure operation; and
- there are no other external effects than external congestion cost.

These conditions are violated when the Mohring and Harwitz-result is applied to the port expansion problem. First, over-design is common in port expansion. This is, in addition to other factors[28], caused by the fact that expansion plans should also account for potential future growth of port demand due to autonomous growth of trade flows. At the same time, future growth of port demand leads - given a certain level of capacity - to a growing level of port congestion, and, on its turn, to a higher congestion price and more revenues to recover the investment cost. Second, port development appears to be characterized by economies of scale, which lead to efficiency gains (due to lower unit costs) for the port owner and, if passed on, for port users, which affects welfare surplus and, as a result, the balance between congestion pricing and expansion. Third, other external effects due to the use of port facilities such as environmental pollution are likely and affect welfare surplus.

Using the basic principle of Mohring and Harwitz - financing based on congestion pricing - is however interesting with a view on analyzing the potential of a self-financing port expansion strategy (provided that port congestion exists). If it works, it contributes to the financial viability of port investments in basic infrastructure that may otherwise be funded with scarce public funds (see Chapter 2). Referring to transport-economists such as Verhoef and Rouwendal (2003), other advantages include: 1) achievement of an efficient port system in terms of optimal utilization and economic efficiency, and 2) improvement of the acceptability of port expansion projects by society, because self-financing may be perceived as fair - only the users of the port pay for the expansion - and transparent - there are no 'hidden' transfers surrounding investment financing.

[28] Other factors that may cause over-design in port expansion include 1) indivisibilities in port expansion, 2) economies of scale in investment cost making a larger capacity increment more attractive than a smaller one, and 3) the presence of strong competition, which requires less port congestion and thus a larger capacity increment.

The principle as established by Mohring and Harwitz (1962) is widely applied in transportation planning as well as in other fields. For example, it has been used in highway network design (Yang and Meng, 2000), applied to dynamic congestion models (Arnott and Kraus, 1998) and to airport expansion (Oum and Zhang, 1990).

3.7 Observations

Concepts for planning of port capacity, applied to port expansion, have been reviewed in this chapter. The findings are to be used for the development of a methodology for planning of port capacity.

Port capacity problems can be solved by (a combination of) 'structural' measures leading to facility expansion, and 'non-structural' measures leading to a more efficient utilization of existing facilities. Port expansion by means of land reclamation can be considered as a structural measure.

Ports combine their public role with a strong commercial perspective. Therefore, a viable set-up of port expansion projects requires integration of public interests (particularly economic efficiency) and the port-commercial interest (investment recovery) in the planning problem. On a scale of increasing complexity of planning, the highest level should then be applied: integrated planning of port capacity.

Integrated planning of port capacity is possible if congestion effects are incorporated in the design of port expansion. Reduction of congestion costs contributes to economic efficiency (a national public interest), and the revenues (if any!) from congestion pricing can be used to recover the investment cost of port expansion (a port-commercial interest). The fact that ports operate under competition in addition to autonomous demand growth and economies of scale, poses a particular challenge for such planning.

Given the potential of port expansion in dealing with competition and facilitating autonomous demand growth, a methodology for integrated planning of port capacity incorporating competition and autonomous demand growth will be developed in the next chapter. Also economies of scale in investment cost will be incorporated.

II. Methodology

4. Integrated Planning of Port Capacity

4.1 Introduction

In this chapter, a modeling approach for planning of a port's capacity is developed. This is applied to port expansion. The combination of port-commercial and public interests, the presence of competition, growth of demand, economies of scale and technological development strongly characterize the planning problem.

Conceptually, planning of a port's capacity can be based on a confrontation of the local demand for services with the local supply of service quality[29]. The port constitutes a node in an elaborate network of multimodal transportation routes connecting origins and destinations for freight flows. Determination of local demand entails then determination of freight transportation demand in a network characterized by competing routes and (assumed) growth of freight flows. The supply is characterized by tariffs for service provision and economies of scale.

As discussed in previous chapters, port expansion can be characterized as a structural measure, which aims at physical increase of the supply of capacity. It can further be considered as one of the possible strategies for a port to deal with competition. An interesting question is whether such strategy can be self-financing.

Hinterland connections are an important issue in port planning. With a view on this, a practical approach for the total port-planning problem – comprising port expansion and improvement of hinterland connections - is proposed in this chapter, which comprises two subsequent parts, namely:

1) optimization of the port expansion size assuming that hinterland capacities automatically follow port capacity; and
2) refinement of the optimization strategy by accounting for improvement of the hinterland connections.

The application case in this study focuses on the first step.

The remainder of this chapter is divided into four sections. Section 4.2 identifies the scope of the proposed methodology by briefly describing the port-planning problem and its relevant components. In Section 4.3, an operational framework for planning, applied to port expansion, is discussed emphasizing the concepts required for solving the port expansion

[29] This will be established in this study with an equilibrium analysis. Equilibrium means here that supply and demand match, also if demand grows over time.

problem. A practical solution comprising a modeling approach is discussed in Section 4.4. Section 4.5 summarizes the findings.

4.2 Scope of the Methodology

A port's competitiveness depends on many factors but the capacity of the port can be considered as an important factor in its total competitiveness. Expansion of a port's capacity reduces the costs for the users of the port, which reduces on its turn the total generalized transportation costs of the routes of which the port is part of. This affects the route selection decision of freight carriers in favor of the particular port if everything else remains unchanged.

The above-described relationship between capacity and competitiveness is used as basis for the present study, which addresses the determination of the optimal expansion of a port's capacity in response to a change in the transportation network. A scenario for such change, which will be worked out in this study, is the entry of new transportation routes via a competing port comprising, for instance, a maritime section and several land sections as illustrated in Figure 4.1.

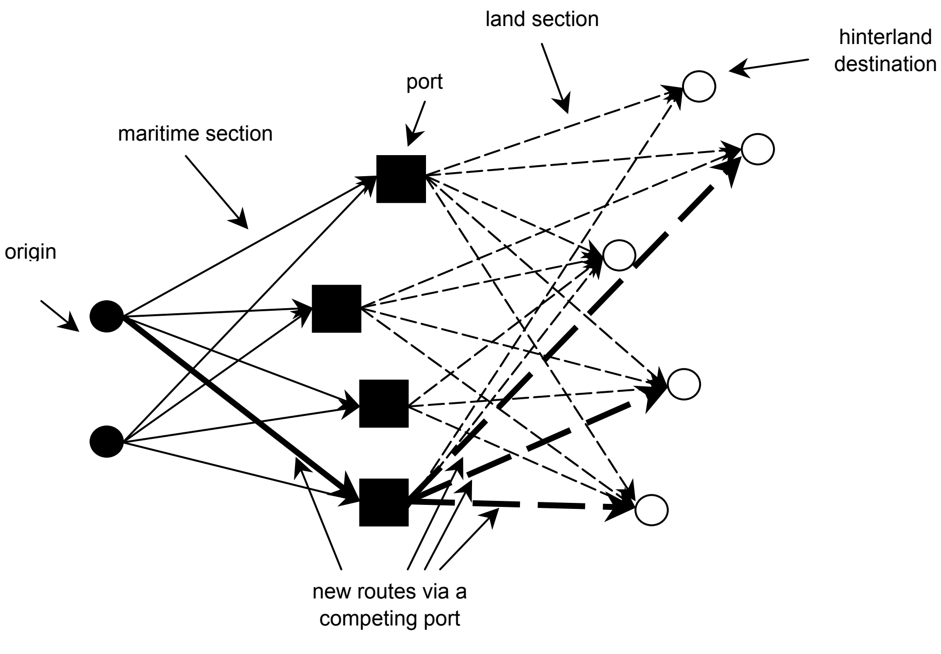

FIGURE 4.1 Entry of new transportation routes via a competing port.

Ports combine their public role with a strong commercial perspective. Therefore, a viable set-up of port expansion projects requires integration of public interests (increase of consumers' surplus and economic efficiency) and the port-commercial interest (investment recovery) in the planning problem.

A review of planning concepts in the previous chapter indicated that such integration is possible if congestion effects are incorporated in the design of port expansion. Economic efficiency (a public interest) requires that the marginal investment cost is equal to the marginal benefit (here: marginal decrease of total congestion costs) and the revenues from pricing of congestion earned in the port can be used to recover the investment cost of port expansion (a port-commercial interest). The fact that ports operate under competition in addition to the presence of economies of scale (on the increment), poses a particular challenge for capacity planning.

The present study focuses on the development and application of a methodology for integrated planning of port capacity. Particularly expansion as strategy for a single port to deal with competition and to facilitate further growth of demand is addressed. The central questions are: 1) what is the optimal expansion strategy for a single port to deal with route competition and to facilitate further growth of the port's demand? and: 2) can the port expansion strategy be self-financing?

To establish self-financing, expansion (enlarging the port's surface area by land reclamation, which is characterized by economies of scale) is combined with congestion pricing. Assuming that the size of the port's surface area is relevant for a port's competitiveness, local port demand that is lost due to competition can be recovered (to some extent) by expansion. The revenues from congestion pricing (which may lead, via the pricing mechanism, to loss of demand) are used to recover the investment cost.

Economic evaluation of a port expansion strategy includes assessing 1) investment cost, 2) increase of consumers' surplus, 3) increase of producers' surplus, 4) indirect effects, and 5) environmental effects. Commercial evaluation includes assessing the investment recovery period.

4.3 Operational Framework for Planning of Port Capacity

4.3.1 Supply-Demand Planning

Decision-making on port expansion to deal with competition - based on supply-demand planning[30] - can be schematized by a number of steps as presented in Figure 4.2. It considers 1) the entry of new routes via a competing port, and 2) the reaction of the port under consideration with an expansion alternative.

The method uses the classical comparison between a reference supply-demand equilibrium (here: 'do-nothing' after the entry of new routes via a competing port) and the incremental effect from an alternative option. Consumers' surplus is estimated both for the reference and the new (expected) equilibrium. Consideration of autonomous and induced changes to demand plays an essential role in the supply-demand planning.

[30] Similar concepts for port supply and demand, as will be worked out in the present study, have been used by Holguín-Veras and Jara-Díaz (1998) as basis for analysis of container terminal operation.

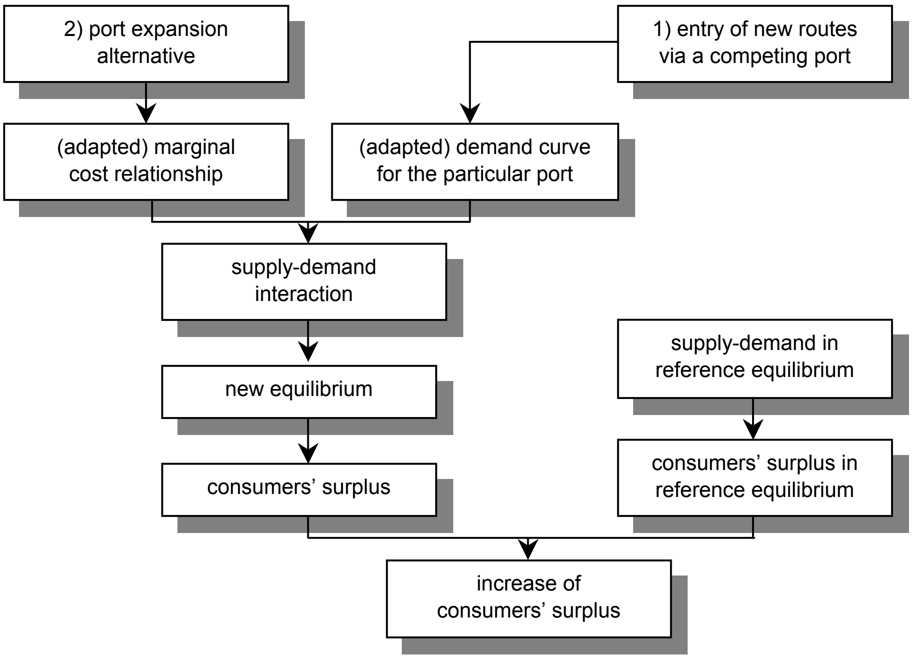

FIGURE 4.2 Supply-demand planning for port expansion.

The method uses the classical comparison between a reference supply-demand equilibrium (here: 'do-nothing' after the entry of new routes via a competing port) and the incremental effect from an alternative option. Consumers' surplus is estimated both for the reference and the new (expected) equilibrium. Consideration of induced (and autonomous; see further) changes to demand plays an essential role in the supply-demand planning.

The entry of new routes via a competing port leads to an adapted demand curve for the port under consideration. Any port expansion alternative improves service quality and changes therefore the existing marginal cost to the users. For each port expansion alternative, the supply-demand interaction[31] should be estimated, and equilibrium and consumers' surplus should be recalculated accordingly. An alternative in this sense can be defined as a set of (inter-related) capacity measures such as physical expansion with congestion pricing. Comparison of the consumers' surplus before and after expansion (assuming an increase of consumers' surplus for the port under consideration) indicates the reduction of port-congestion costs, which indicates, in turn, improvement of port competitiveness. It provides further a main input to economic evaluation.

4.3.2 Efficiency Concepts for Solving the Planning Problem

Integration of the public perspective, with increase of consumers' surplus and economic efficiency as main interests, and the port-commercial perspective, with investment recovery as main interest, is used here as basis for planning of a port's capacity. It serves as input to

[31] Feedback between price and market share is essential in competition analysis. In the proposed modeling approach, the market share is determined by tracing the prevailing demand curve with a number of port expansion alternatives, which is here referred to as supply-demand interaction. This interaction represents in fact feedback between price and market share of the particular port. A more complex feedback mechanism is required if potential reactions of other ports is also accounted for.

the simultaneous solution of determining 1) the optimal expansion size, and 2) the investment recovery period, incorporating an optimal utilization and pricing (see Section 4.4). The main concepts for solving this efficiency problem, intended to lead to self-financing of port expansion, are discussed below.

Supply-demand interaction

In this study, the basis for solving the planning problem comprises the interaction between the local port demand curve and the local port supply curve in a partial equilibrium model. A matching supply and demand is assumed also if the port demand curve changes autonomously over time. With such a (theoretical) model, a single port's response on a change in the network and an (expected) autonomous demand growth can be simulated. In practice, continuous shifts of freight flows and associated changes in port congestion may preclude equilibrium analysis. The assumption of equilibrium supports however the development of clear benchmarks to analyze the impact of competition and expansion.

Both the local supply and demand curves can be expressed in terms of generalized cost per unit service (e.g., in €/TEU). Port expansion will change the match of supply and demand of port services. A description of this change in terms of generalized cost can be used to evaluate the impact of the expansion. A typical (theoretical) form of this change is presented in Figure 4.3.

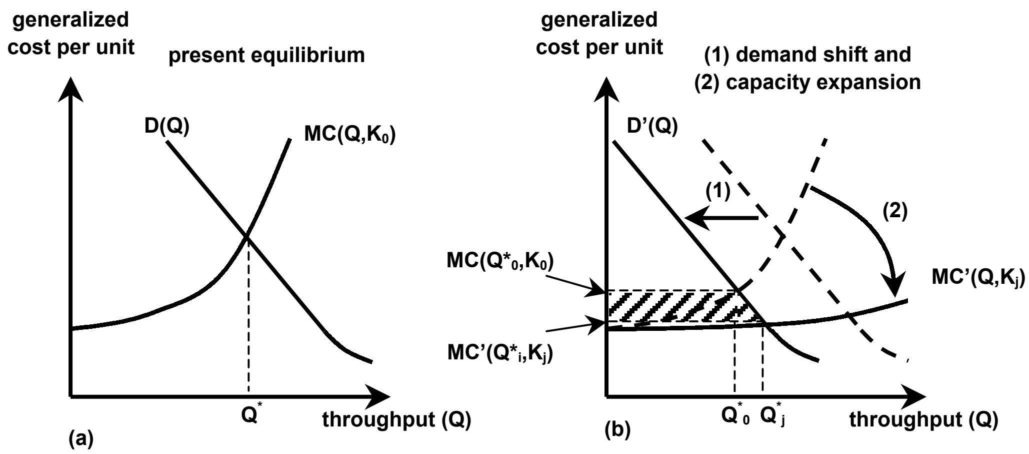

FIGURE 4.3 Supply-demand interaction of a single port.

For the present equilibrium with a given capacity K_0, the supply curve *MC* (here: the marginal social cost curve; see further for the difference between marginal social and marginal private cost) rises with increasing throughput due to higher port-congestion costs. Equilibrium between the supply curve $MC(Q,K_0)$ and the demand curve $D(Q)$ exists at equilibrium demand Q^* (see Figure 4.3a).

If new routes via a competing port enter the network, the demand of the port considered decreases due to a redistribution of freight flows over the network. Because it is assumed that this is valid for each potential port price (generalized port-related cost), the demand curve shifts from $D(Q)$ to $D'(Q)$. Consequently, equilibrium demand decreases to Q^*_0 (see Figure 4.3b). If the particular port is confronted with such a scenario, it can react with expansion, which is in fact capacity expansion. The lost demand may then be recovered to some extent, as explained below (see further for incorporating autonomous demand growth in the port expansion problem).

Consider a capacity expansion from the given capacity K_0 to K_j representing the expanded port capacity. This causes a reduction of the congestion cost for the port users leading to an increase of consumers' surplus. Lower port-congestion costs contribute to a reduction of the total generalized costs of the routes of which the particular port is part of, which leads to an increased attractiveness of these routes for freight carriers. This results in turn in an increased equilibrium demand for the port (Q^*_j) as demonstrated in Figure 4.3b. In practice, this increase in demand may be larger than the anticipated loss because the higher capacity affects many routes.

The situation directly after the demand shift is considered to represent the reference ('do-nothing') equilibrium for evaluation of the effects of the expansion strategy. If $D'(Q)$ represents the demand curve, and if $MC'(Q_j^*,K_j)$ and $MC(Q_0^*,K_0)$ represent the generalized cost for the new equilibrium with expanded capacity and the reference equilibrium, respectively, then the increase of consumers' surplus due to port expansion ($B(K_j,K_0)$) can be represented by the shaded area in Figure 4.3b. In mathematical terms, this can be expressed as:

$$B(K_j,K_0)=\int_0^{Q_j^*}\left(D'(Q)-MC'(Q_j^*,K_j)\right)dQ-\int_0^{Q_0^*}\left(D'(Q)-MC(Q_0^*,K_0)\right)dQ \qquad (4.1)$$

The above represents an approach that incorporates route competition in the capacity-planning problem. As discussed in Section 4.2, integrated planning of port capacity is further based on congestion pricing, determination of the optimal expansion size and investment recovery to capture the full complexity of the planning problem. Simultaneous application of these concepts is essential to establish the self-financing principle (see Section 4.4).

Congestion pricing
Optimal utilization of port facilities requires that the marginal benefit for the port of more intensive use is equal to the marginal cost for the users (e.g., Jansson, 2000b). The marginal benefit can be expressed in terms of marginal financial revenue for the port. The marginal cost can be interpreted as the price that an extra port user has to pay for causing the congestion he imposes on other port users, which is represented by the marginal external cost.

If the marginal financial revenue for the port is set equal to the marginal external cost - the congestion price - then the external congestion cost is internalized in the generalized cost per unit at the port user level. This is interesting from the public (welfare) perspective, because it reflects the utilization rate of scarce resources (port capacity) in monetary terms (this can, e.g., be used to limit port users' demands in order to reduce unnecessary port expansion). In the present study, the financial revenues from congestion pricing are used for investment recovery (see further), which is interesting from the port-commercial perspective.

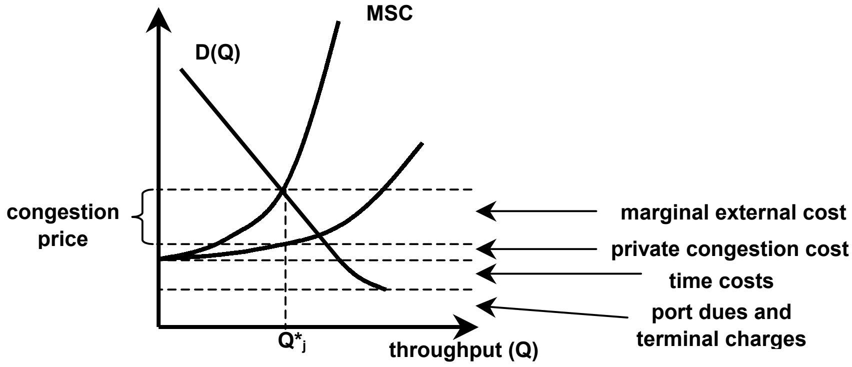

FIGURE 4.4 Concept of congestion pricing.

In the elaboration on supply-demand interaction, the difference between marginal *social* and marginal *private* cost has not yet been considered. It is however necessary to differentiate the two if congestion pricing is incorporated in the planning problem. The congestion price is determined by the difference between the marginal social cost (*MSC*) and the marginal private cost (*MPC*) for the equilibrium demand (Q^{*}_{j}), which is by definition the marginal external cost. The marginal private cost curve can be set equal to the average social cost curve (*ASC*) (see Verhoef, 2001) and includes port dues, terminal charges, time costs due to vessel discharge time and dwell time, and the private congestion cost. Figure 4.4 illustrates the concept of congestion pricing.

Other external cost components such as environmental costs can be added to the here-described concept of congestion pricing. Another extension can be made if the marginal private benefit (represented by the demand curve) is not equal to the marginal social benefit due to the presence of external benefits.

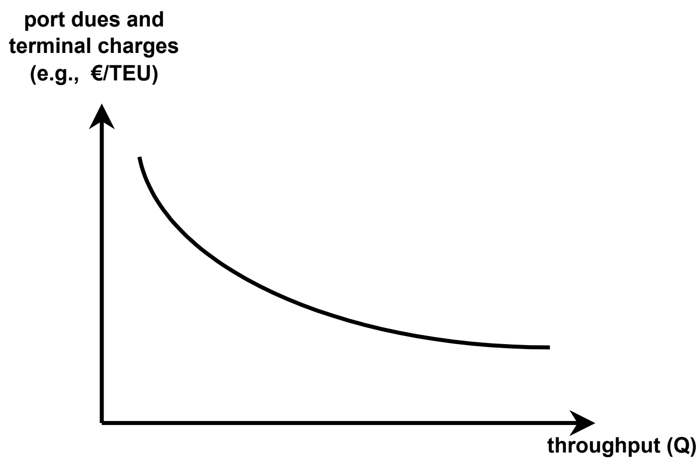

FIGURE 4.5 Concept of economies of scale in port operation.

It is assumed for the application case that expansion affects only congestion costs. Increased local demand due to expansion may however also affect port dues and terminal charges via economies of scale in port operation, because due to increased demand the investment cost can be distributed over a larger number of handled items resulting in lower port dues and terminal charges for higher throughputs (see Figure 4.5). Furthermore, different cargo types use certain port facilities jointly, which may lead to economies of scope (see Jara-Díaz *et al.*, 2002). For example, for container flows it can be cheaper to go through an existing port that has already been equipped with sufficiently deep entrance channels for crude-oil vessels than using a newly-build 'dedicated' port.

Optimal expansion size

Optimal port expansion requires that the expansion size is such that the marginal investment cost, which is here passed-on to the users, is equal to the marginal benefit for the users (e.g., Verhoef, 2001; Dekker *et al.*, 2003). The marginal benefit of port expansion is based on the decrease of port-congestion costs, which can be expressed by the reduction of the average social cost (*ASC*; see Figure 4.4) as experienced by the port users.

Typical patterns of the marginal investment cost (C^k_K) and the marginal benefit, represented by the product of the equilibrium demand (Q^*_j) and the derivative of the average social cost reduction for the port users ($-ASC^q_K$), are presented in Figure 4.6.

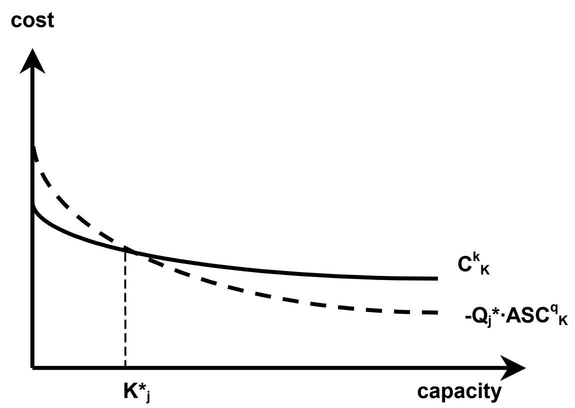

FIGURE 4.6 Optimal expanded capacity given the equilibrium demand.

The effect of a capacity expansion (increment) on the reduction of individual congestion costs (at the equilibrium demand) diminishes with increasing capacity. It is further assumed that the investment cost function is characterized by economies of scale. Therefore, the marginal benefit curve as well as the marginal investment cost curve show in Figure 4.6 diminishing returns (costs) to scale for expanding port capacity. The optimal port expansion size for an increment can be observed corresponding to the expanded port capacity K^*_j.

The economic benefit can be expressed as the present value of a future stream of annual benefits (increase of consumers' surplus) $B(K_j,K_0)$ for a particular capacity K_j. Other benefit components such as the increase of producers' surplus, indirect effects and environmental effects can be added to the future stream of annual benefits. This affects however the optimal port expansion size.

Investment recovery
The concept of congestion pricing and its contribution to investment recovery is introduced above. In the present study, the main factor determining investment recovery however is future growth of freight flows through the port leading to growth of port (equilibrium) demand (Q^*_j)[32]. In the present study, this is implemented by an annual shift of the demand curve according to an exogenously determined growth rate of port demand, which is illustrated in Figure 4.7.

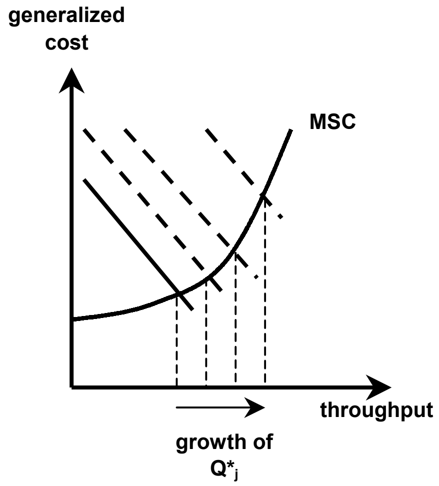

FIGURE 4.7 Growth of port equilibrium demand.

A growing demand leads here to a growing level of port congestion and, on its turn, to a higher congestion price. The period (in years) over which the sum of the annual revenues from congestion pricing is (at least) equal to the investment cost of port expansion is referred to as the investment recovery period.

In the above elaborations on supply-demand interaction, congestion pricing, optimum expansion size and investment recovery, a matching supply and demand ('equilibrium') is assumed also if the port demand curve changes autonomously over time. Such match is however less likely due to network effects representing transport-efficiency gains due to the combined occurrence of economies of traffic density, product scope and network structure (e.g., Berechman, 1993).

Carriers may concentrate their cargo flows on the expanded port or bundle different cargo types in one load leading to lower transportation costs (economies of traffic density and product scope, respectively). Carriers can further decide to shift certain (less voluminous) cargo flows to the routes of which the particular port is part of, which also leads to lower transportation costs (economies of network structure). Similar but opposite shifts of cargo flows may appear due to increasing levels of port congestion during the investment recovery

[32] Investment recovery becomes more complex if freight flows do not grow in future. In the application case, however, container flows are analyzed that also grow due to containerization (i.e. substitution from general cargo to containers).

period, which makes the port less attractive for freight carriers. Such shifts of cargo flows are particularly expected for transshipment flows.

4.3.3 Uncertainty in Port Planning

Uncertainty is an important aspect of (port) planning[33] (see Frankel, 1989; Grigalunas *et al.*, 2002). Several authors attempted to categorize uncertainty into different classes. A distinction can be made between inherent (or intrinsic), model and parameter uncertainty (Zhou, 1995, referring to Mays, 1979).

Inherent uncertainty is associated with unpredictable characteristics of (parts of) the system and cannot be explained by any model. *Model uncertainty* refers to the simplifications in modeling the system, while *parameter uncertainty* is involved due to less effectiveness of model calibration.

All types of uncertainty can be found in the above-discussed planning of port capacity. These uncertainties can briefly be described as follows:

- Inherent uncertainty on network demand: there will always be uncertainty on the development and thus prediction of transport flows, particularly over longer periods of time.
- Several model uncertainties are involved in the capacity planning. For example, the generalized cost concept is but one factor that determines port demand, and for modeling port congestion is assumed that the so-called BPR-formula (see further) can be used.
- Simulation of local port demand highly depends on assumptions (e.g., on time costs and the spreading parameter in traffic assignment modeling) leading to less effective model calibration.
- Planning of a port's capacity requires reliable data. Less reliable data (e.g., on port productivity) bring parameter uncertainty into the planning.
- There is uncertainty in the costs and benefits of port expansion. Information on costs is diffused in an early stage of planning and mostly site-dependent. Particularly the scale factor in the investment cost function is expected to have substantial influence on the outcome of the planning. Furthermore, the definition and valuation of indirect effects are still under debate and contribute therefore substantially to uncertainty on the benefits.

The various uncertainties propagate through the many relationships of the planning model and have the effect of diffusing the outcome of the planning by diffusing the differences between design alternatives (Zhou, 1995). In the present study, the design variables 'proposed capacity' and 'investment recovery period' will be determined by optimizing a function and not by comparing a number of design alternatives. Uncertainty about the influence of input parameters will therefore be analyzed with sensitivity analysis (see Section 4.4.3).

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[33] Uncertainty in port planning can be dealt with in many ways; for instance, by incorporating flexibility in port expansion plans by phasing of the implementation. Because uncertainty is not the emphasis of this study, it limits itself to analyzing uncertainty by sensitivity analysis (see Section 4.4.3).

4.4 Modeling Approach for the Planning Problem

The practical aim of integrated planning of port capacity is to implement the above-discussed efficiency concepts in order to integrate port-commercial and public interests. This process can be supported by modeling, which is discussed below.

The approach in this modeling represents the competitive position of a single port. The set-up of this analysis is presented in Figure 4.8. In the application, this analysis will be used to address trade offs in port investment planning.

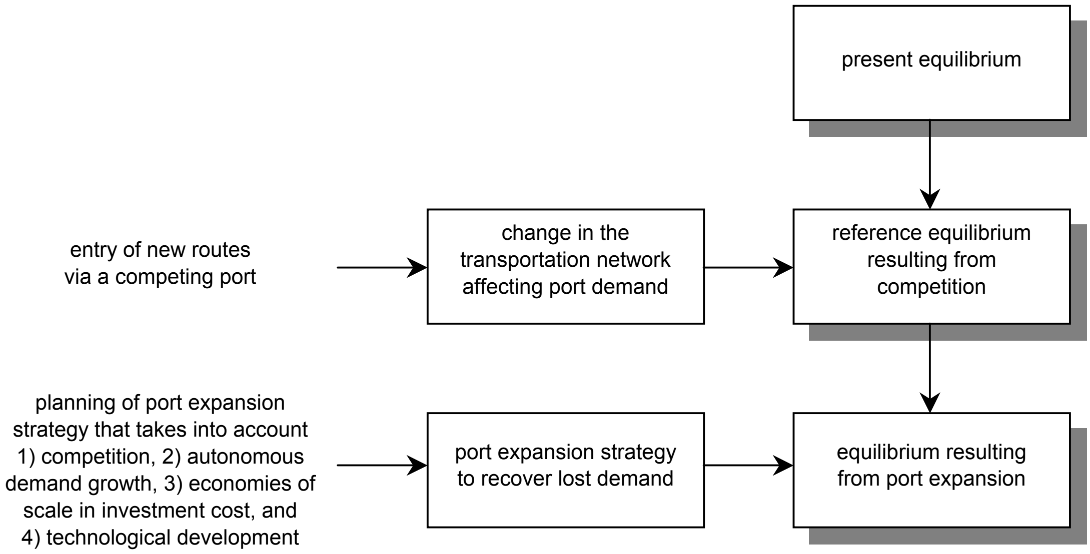

FIGURE 4.8 Analysis of the competitive position of a single port.

The entry of new routes via a competing port causes a change in the transportation network, which affects local port demand. This competition results in a reference equilibrium for the port considered characterized by lost demand. The port can react by an expansion strategy to recover this loss. Planning of such strategy takes here into account 1) competition, 2) autonomous growth of port demand, 3) economies of scale in investment cost, and 4) technological development. Establishing this planning leads to an equilibrium resulting from port expansion.

The solution procedure for the above-described analysis contains the following three steps:

1) determination of the reference equilibrium resulting from the entry of new routes via a competing port;
2) determination of the equilibrium resulting from port expansion; and
3) sensitivity analysis.

Step 1 generates the basic information for the capacity planning, which is required for establishing step 2: determination of the optimal port expansion strategy. Step 3 analyzes the sensitivity of the selected optimal strategy. These steps are elaborated below.

4.4.1 Determination of the Reference Equilibrium

Considering the port as a node in a transportation network, a common freight transportation model using a network equilibrium concept can be used to simulate port demand for the reference equilibrium. The input data describing the network are then adapted to include the relevant port characteristics. The demand curve can be established from a set of simulations with varying route characteristics (here: port dues). The supply curve can be represented by the marginal (social) cost.

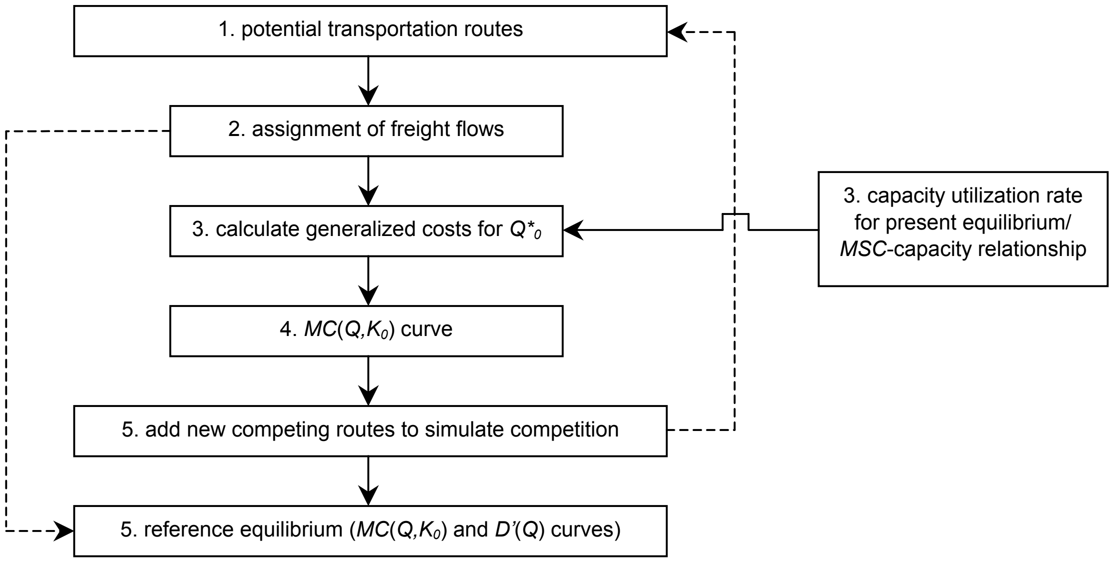

FIGURE 4.9 Procedure for determination of the reference equilibrium.

As presented in Figure 4.9, the procedure for simulation to determine the reference equilibrium directly after the entry of the new routes can be summarized into five steps (Dekker and Verhaeghe, 2005):

1) Establish a set of routes representing the most likely routes (e.g., the shortest distances).
2) Implement the assignment of freight flows with a traffic assignment model.
3) Calculate the generalized costs for equilibrium demand in the present equilibrium (Q^*_0) using a given capacity utilization rate for the present equilibrium and an *MSC*-capacity relationship (see further).
4) Construct the marginal cost curve for the reference equilibrium ($MC(Q,K_0)$ in Figure 4.3a).
5) Add the new routes via the competing port to the set of routes to simulate route competition: repeat step 1) and 2) to obtain the local demand curve for the reference equilibrium ($D'(Q)$ in Figure 4.3b).

For this study, an adapted version of the model by Luo and Grigalunas (2003) is used to estimate local port demand. While this model uses an all-or-nothing assignment modeling, in the present modeling approach a pure stochastic assignment modeling will be used instead. This is meant to incorporate uncertainty in route choice because the generalized cost (here based on the sum of out-of-pocket and time costs) is but one factor in the selection of a particular route; other factors, including strategic behavior, reliability of the port (e.g., chance of strikes), the risk of accidents and losses by container-handling activities, and the quality of auxiliary services in the port also play a role.

The *MSC*-curve, representing port supply, has been derived from an expression for the marginal private cost (*MPC*) using a typical expression of congestion in transportation planning (the so-called 'Bureau of Public Roads' (BPR) formula), which is often used in research on passenger transport (Ortúzar and Willumsen, 2000). Although application of this curve can be criticized (see Chapter 5), the assumption is that a curve with similar characteristics can be used to represent the effects of port congestion. The annual autonomous growth of port demand is used to calculate the congestion price.

More detailed elaborations on modeling port demand and supply, and port-congestion pricing are provided in Chapter 5. An approach to incorporate technological development, particularly in container transportation, is discussed in Chapter 6.

4.4.2 Determination of the Equilibrium resulting from Port Expansion

The port expansion problem is characterized as a network design problem. The aim is to determine the optimal design capacity of one of the ports in the network given the demand pattern or demand function. This problem is considered from the viewpoint of the port planner whose aim is overall viability of the port investment project by integrating port-commercial and public interests.

Determination of the optimal capacity to establish the equilibrium resulting from port expansion can be formulated as an optimization problem that is characterized by non-linear relationships involving interdependencies between expansion size, investment cost, congestion price and investment recovery period. The objective function of the port planner represents the reduction of congestion costs (increase of consumers' surplus) by which the port becomes more attractive for freight carriers. The constraints include port-commercial and public interests comprising investment recovery and economic efficiency, respectively, and pre-financing and the ability to meet peak demand.

The number of design alternatives for the port planner that has to be analyzed and the associated number of simulations that has to be carried out to generate the necessary information for optimization is considerable. Application of a formal mathematical optimization technique to handle the large number of possibilities is complex due to strong non-linearities in the problem (see, e.g., Hillier and Lieberman, 2001).

Solving this optimization problem by brute-force computation requires a substantial amount of simulations. An example may illustrate this. For an adequate coverage of the decision space, a set of 50 alternative expansion sizes and 30 alternative investment recovery periods are considered for the application case. The port system comprises 7 alternative hinterland connections that should be improved to accommodate 1) additional demand activated by port expansion, and 2) additional future demand due to autonomous growth of trade flows. This leads to a total of 50 x 30 x 7 = 10,500 simulations.

An optimization strategy should therefore be found to reduce the number of alternatives, for instance, by dividing into subsets. For the application case, the following optimization strategy is supposed:

- Step 1: optimization of the port expansion size assuming that hinterland capacities automatically follow port capacity. This reduces the total number of strategies to 50 x 30 = 1,500.
- Step 2: refinement of the optimization strategy by accounting for improvement of the hinterland connections.

Step 2 is not further elaborated, because it is assumed for the application case that the capacities of the hinterland connections are sufficient to deal with (time-averaged) additional demand. Formulation of step 1 and the concept in the selection of the optimal expansion strategy is presented below.

Objective Function

The port expansion problem considers determination of the optimal proposed capacity by maximization of the increase of consumers' surplus. It is assumed here that within the transportation network only the port's capacity is relevant for its competitiveness. A useful formulation to represent port capacity is the product of the port's surface area and its spatial productivity[34], which catches the service characteristics of the port. The objective function, a function of the continuous design variable 'proposed capacity', can be written as follows:

$$\max_{K_j} \{ B(K_j,K_0) \} \tag{4.2}$$

with:

K_0	:	the capacity of the port in the reference equilibrium;
K_j	:	the proposed capacity of the port after expansion alternative j;
$B(K_j,K_0)$	:	present value of a stream of future economic benefits (increase of consumers' surplus) of port expansion from K_0 to K_j.

In the application case, the objective function is also a function of the (endogenous) variable 'investment recovery period' (see further). Furthermore, the planning horizon is set equal to the investment recovery period and is thus also an endogenous variable. This may lead to under-estimated economic benefits, but it helps to improve analytic tractability of the modeling approach.

Constraints

<u>Port-Commercial Interest: Investment Recovery</u>

The investment cost is to be recovered with the revenues from congestion pricing. The total revenues are equal to the cumulative revenues collected during the investment recovery period. This can be expressed as:

[34] The spatial productivity is here considered to be independent from the spatial size of the port.

$$\{ C(K_j,K_0), r \} <= f(\textit{congestion price, demand growth}, T_j, K_j, K_0) \quad (4.3)$$

in which: $C(K_j,K_0)$ is the present value of the investment cost for port capacity expansion from K_0 to K_j; r is the interest that has to be paid; *demand growth* represents the annual additional demand for the port based on autonomous growth of trade flows; T_j is the investment recovery period (endogenous variable).

Public Interest: Economic Efficiency

Port expansion is economic efficient if the marginal investment cost, which is here passed-on to the users, is equal (or close to) to the marginal economic benefit for the users. The relationship between marginal investment cost and marginal economic benefit is in this optimization a function of *O-D flows*, *network configuration*, *transportation technology*, *demand growth*, reference capacity K_0, and proposed capacity K_j. This can be expressed as:

$$\{ C^k_K, -Q^*_j \cdot ASC^q_K \} = f(\textit{O-D flows, network configuration, transportation technology, demand growth}, K_j, K_0) \quad (4.4)$$

in which: C^k_K denotes the marginal investment cost; and $-Q^*_j \cdot ASC^q_K$ represents the present value of a stream of future marginal benefits of port expansion.

Pre-Financing

The investment cost, and thus the expansion size, is restricted by a budget constraint. This is determined by the maximum amount of money that can be borrowed from the capital market for pre-financing. This can be expressed as:

$$\{ C(K_j,K_0), r \} = f(\textit{available budget, capital market}) \quad (4.5)$$

in which: r is the interest that has to be paid. The amount of money that can be borrowed from the capital market should in fact be determined by the expected financial return on investment of the project.

Ability to Meet Peak Demand

During the investment recovery period, the average capacity utilization rate grows due to the exogenous growth of port demand. At the end of the investment recovery period, the port should still be able to meet peak demand at a certain service quality level. This can be expressed as:

$$U_{max} >= f(\textit{demand growth}, T_j, K_j, K_0) \quad (4.6)$$

in which: U_{max} is the maximum allowed capacity utilization rate.

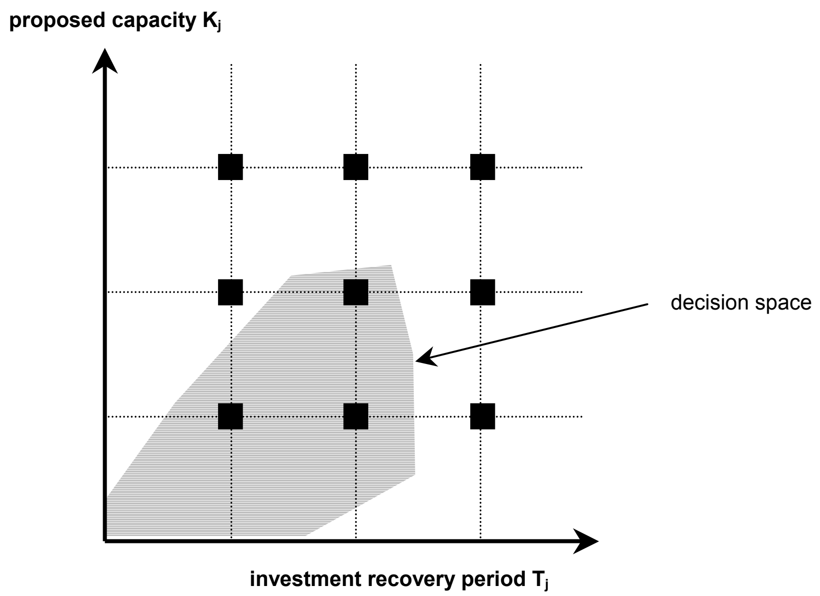

FIGURE 4.10 Decision space for the selection of the optimal expansion strategy.

The concept in the selection of the optimal expansion strategy is to follow an approach by which the response surface (economic benefit in terms of increase of consumers' surplus) for the port expansion problem is traced for a set of possible values for the decision variables, namely, alternative sets of proposed port capacity and investment recovery period $\{ K_j, T_j \}$. Tracing the decision space, as determined by the constraints (see Figure 4.10), in terms of maximum economic benefit for a selected number of alternative sets, allows selecting the optimal set.

Although there are more elegant optimization techniques, major advantages of this approach are that it can 1) relative simply be implemented in a spreadsheet and, thus, efficiently linked with sensitivity analysis (see further), and 2) be used to visualize the effect of changes in the optimal set of proposed capacity and investment recovery period on the increase of consumers' surplus (see Chapter 7).

The above-described approach to trace the decision space is applied in various studies on planning and optimization. For example, it has been used by Zhou (1995) to determine the economic-optimal design height for river dikes. De Palma *et al.* (2003) report about application in urban transport analysis to determine the optimal implementation path of marginal cost pricing.

4.4.3 Sensitivity Analysis

Due to uncertainty about the influence of input parameters on the outcome of the modeling approach (see Section 4.3.3), it is important to analyze how the optimal set of proposed port capacity and investment recovery period would change if the values assigned to the input parameters were changed within a range of plausible values. This analysis is referred to as sensitivity analysis (see Hillier and Lieberman, 2001).

If the changes in the input parameters can be expressed with numerical probability distributions, *Monte Carlo simulation* is an effective technique for sensitivity analysis. By comparing the effects of the changes of different input parameters, one can establish the relative contribution of each pre-selected input parameter to the optimal solution. In this way, the input parameters that have the largest contributions to the variance of the optimal solution can be traced. The results can further be used instead of intensive model calibrations. Present add-ins for spreadsheet software offer the possibility to carry out Monte Carlo simulations efficiently (e.g., Dekker, 2001).

In our application, Monte Carlo simulation will be used to analyze the sensitivity of the optimal set of expansion size and investment recovery period for 1) the scale factor in the investment cost function, 2) port productivity, 3) volumes of the O-D flows, 4) growth rate of port demand, and 5) developments in transportation technology.

4.5 Summary

In this chapter, a modeling approach has been developed for planning of port capacity. The approach integrates port-commercial and public interests. It further incorporates competition, autonomous demand growth and economies of scale. The modeling approach can therefore be characterized as *integrated* planning of port capacity incorporating *route competition*, *autonomous demand growth* and *economies of scale*.

The modeling approach is applied to port expansion, which can be considered as a strategy for a single port to deal with route competition. Important questions are: 1) what is the optimal expansion strategy for a single port to deal with route competition and to facilitate possibly further growth of the port's demand? and: 2) can the expansion strategy be self-financing?

The basis for solving this planning problem comprises an analysis of port demand and supply in a partial equilibrium model. With such an approach, the reaction of a single port on a change in the network can be simulated.

To establish the optimal expansion strategy, port expansion is combined with congestion pricing. This is used for the simultaneous determination of 1) optimal expansion size, and 2) investment recovery period.

More detailed elaborations on modeling freight flow demand and supply, and congestion pricing are provided in Chapter 5. An approach to incorporate technological development, particularly in container transportation technology, is discussed in Chapter 6.

In Chapter 7, an application will be worked out to determine the optimal expansion strategy for the Port of Rotterdam in the Netherlands. In this application, the optimal expansion size and investment recovery period will be sought. Improvement of the hinterland connections will not be included in the application.

5. Modeling Port Demand and Supply

5.1 Introduction

In the previous chapter, we developed an approach for planning of port capacity applied to port expansion. This modeling approach is based on a partial equilibrium model to simulate the reaction of a single port (here: port expansion) on a change elsewhere in the transportation network. An important input to this approach is determination of the demand for services and the supply of capacity for the particular port.

Supply of port capacity is considered here as a function of a port's surface area and its spatial productivity, which indicates the efficiency of the port. The supply-curve can be represented by the marginal cost-curve. Given the O-D flows and a transportation network, the demand curve for services at a particular port node can be simulated by freight transportation modeling. Other approaches include simulation of port selection (not route selection) by ocean carriers such as reported in Malchow (2001) and Malchow and Kanafani (2001).

The intent of this chapter is to formulate specifications for the simulation of port demand and supply and to incorporate pricing in the planning problem. The focus is on demand estimation for container transit flows using a network equilibrium model.

The remainder of this chapter is divided into five sections. Section 5.2 presents the schematization of ports in a transportation network. In Section 5.3, a brief review of state-of-the-art demand modeling approaches in transportation planning is given. Section 5.4 presents the requirements for port demand modeling, while Section 5.5 provides the schematization for port supply modeling. Section 5.6 summarizes the findings.

5.2 Ports in a Transportation Network

In this study, ports constitute nodes in an elaborate network connecting origins and hinterland destinations for freight flows as conceptually shown in Figure 5.1. Determination of demand for port services is essentially based on competition between routes.

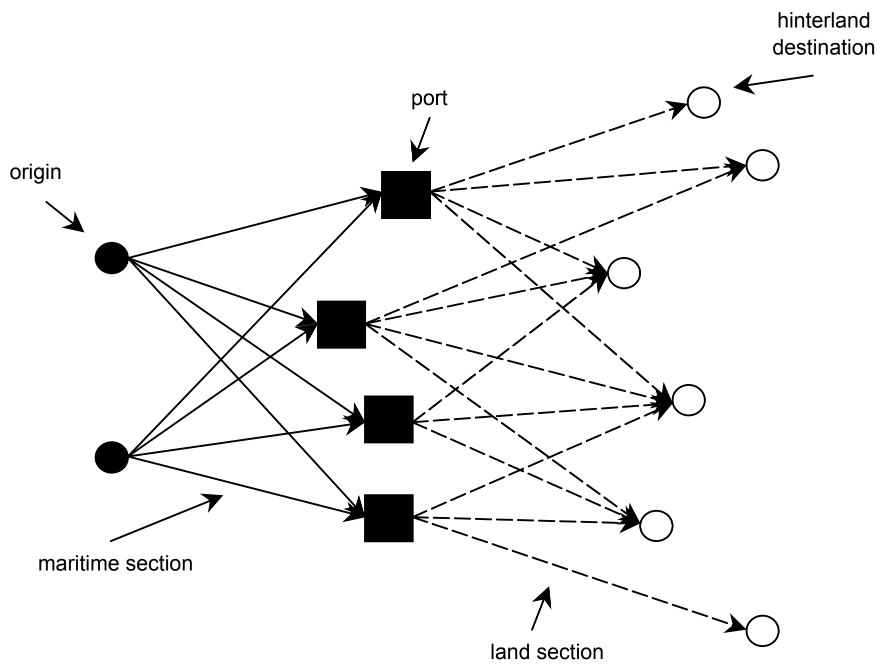

FIGURE 5.1 Schematization of ports in a network.

Many routes could be used for transporting containers between, for instance, origins in Asia and destinations in Europe. Some routes may use more maritime transportation but less land transportation, so the transportation cost is low, but may take a longer time to the destination. Other routes use a shorter maritime section but a longer land section. These cost and time patterns become more complicated by adding the costs and service times experienced in the ports.

Various trade-offs have to be made for a route selection decision. It is assumed that a container carrier selects the route that minimizes the sum of time and transportation costs in the transportation process from origin to destination. The time and transportation costs include the service time as experienced in the port and the price paid to the port owner.

In the model, each route is assumed to use only one port. To incorporate uncertainty about the factors that determine route choice by the carriers (see further), a logit-type traffic assignment will be used. The aggregation of all containers going through a particular port in the network gives the simulated container transportation demand of that port.

5.3 Brief Review of Demand Modeling Approaches

Simulation of port demand involves calculation of traffic assignment with a freight transportation model. There are basically two types of models to simulate freight transportation, namely spatial price equilibrium models and network equilibrium models.

Spatial price equilibrium models are used to determine simultaneously O-D (origin-destination) flows between producing and consuming regions as well as the selling and buying prices. These models are based on the equilibrium condition that the commodity demand price is equal to the supply price plus the transportation costs. The main advantage of these models is that the impact of port investment on the entire economic and logistic system can be evaluated. An important drawback is that these models are rather complicated and difficult to calibrate because they include producer and consumer behavior. Applications of spatial price equilibrium models can be found in Friesz *et al*. (1998) and Gabriel *et al*. (2000).

In *network equilibrium models*, in contrast, the volumes of the O-D flows (network demand) are determined exogenously or follow from a demand function and may be based on observations or input-output modeling. These models are based on the equilibrium condition that (generalized) transportation costs are minimal and equal for homogeneous routes. Application of such models is attractive due to their relative simplicity. Examples of network equilibrium model applications can be found in Tavasszy (1996) and Luo and Grigalunas (2003). With a view on the availability of O-D data for the application case, a network equilibrium model is used in the present study.

Another distinction should be made between ‘demand estimation’ and ‘demand prediction’. *Demand estimation* is basically determination of the curve for local demand of the port considered with, for instance, a network equilibrium model. *Demand prediction* represents the development of (equilibrium) local port demand in time, which is relevant to judge on long-term developments (e.g., the cargo flow model ‘GSM’ for the Port of Rotterdam). For this study, a combination of demand estimation and demand prediction is used to simulate the effect of route competition and to incorporate autonomous growth of network demand as well.

There is further a need to differentiate ‘transhipment flows’ and ‘transit flows’. *Transhipment flows* usually have lower storage requirements than *transit flows* due to less rehandling and shorter dwell times, and the port selection decision for transhipment flows is determined by the ocean carrier and not by the shipper/receiver (Veldman and Bückman, 2003). For the application case, which focuses on transit flows, it is assumed that it is possible to split transshipment flows and transit flows in a port context.

5.4 Requirements for Port Demand Modeling

Various studies (e.g., Huybrechts *et al*., 2002; Luo and Grigalunas, 2003) make clear that analysis of port demand is a difficult task. This is caused by uncertain global-economic developments, the dynamics of port competition, strategic behavior of ports, commercial decisions of freight carriers, and traditional relationships between ports and carriers. Estimating container port demand using historic statistics (e.g., extrapolation or regression analysis) may therefore be problematic. Methodologically, it represents a challenge to address the major data requirements and the computationally intensive nature of the problem.

In this study, an adapted version of the network equilibrium model by Luo and Grigalunas (2003) is used to estimate port demand. The heart of this simulation model is a traffic assignment model to simulate route choice. The theoretical background of traffic assignment can be found in various textbooks such as Ortúzar and Willumsen (2000) and Cascetta (2001). A brief summary is given in the next section.

5.4.1 Traffic Assignment

The basic premise in traffic assignment is the choice of a route, which offers the least perceived (anticipated) costs (i.e. the premise of a rational choice). The costs associated with a particular route in a network can be expressed in ‘generalized cost’, which is analogue with the concept of ‘generalized travel times’ in passenger transport where variables measured in time units are transformed into variables measured in monetary units (Tavasszy, 1996, referring to Goss, 1991). The generalized cost-concept usually involves a weighted sum of different cost components including transportation costs and travel time giving them economic (thus behavioral) significance (Tavasszy, 1996).

The generalized cost is but one factor in the selection of a particular route; other factors, including reliability of the port (e.g., chance of strikes), the risk of accidents and losses by container-handling activities, and the quality of auxiliary services in the port, should also be incorporated. A generalized cost expression incorporating all of these factors is a difficult task; an approximation has to be used.

The most common approximation is to consider only two factors in route choice, namely transportation cost and transit time. The transportation cost is often considered to be proportional to travel distance. In passenger transport, according to Ortúzar and Willumsen (2000), a generalized cost expression containing only transportation costs and transit time explains about 60-80% of the route choices actually observed in practice. The fact that different travelers choose different routes when traveling between the same two points may mainly be due to two reasons (Ortúzar and Willumsen, 2000):

1) differences in individual perceptions of what is the ‘best route’ (stochastic effects); and
2) congestion effects affecting shorter routes first and making their generalized costs comparable to initially less attractive routes (capacity constraint).

Further on the above distinction, a distinction can be made between assignment models that include stochastic effects or not, and between assignment models that include capacity constraints or not. The assignment modeling is characterized by the selected features. The possibilities are represented in Table 5.1.

Table 5.1 Possibilities for traffic assignment modeling (adapted from Ortúzar and Willumsen, 2000)

		Stochastic effects	
		No	**Yes**
Capacity constraints	**No**	all-or-nothing	pure stochastic
	Yes	Wardrop's equilibrium	stochastic user equilibrium

The simplest assignment modeling is the '*all-or-nothing*' assignment, which assumes that there are no stochastic effects and no capacity constraints. *Pure stochastic* modeling includes stochastic effects representing the variability in travelers' perceptions of generalized costs affecting the route choice.

If it is assumed that all travelers perceive generalized costs in the same way (no stochastic effects), then traffic arranges itself in congested networks such that all routes between an O-D pair have equal and minimum generalized costs while all unused routes have greater or equal costs. This is usually referred to as *Wardrop's equilibrium*. *Stochastic user equilibrium* represents in fact Wardrop's equilibrium incorporating uncertainty on route choice.

Uncertainties about the factors that determine route choice by carriers can be incorporated in traffic assignment using a logit-type assignment modeling. Inclusion of capacity constraints is less simple because this requires detailed knowledge about the capacities of each link and node of the network. Furthermore, containers and container carriers, the focus of this study, are not the only users of the network. Other users (e.g., passenger vehicles) make use of the network as well, which requires an extended analysis of the combined effect of all transport flows (see Bliemer, 2001). Considering the scope of this study (strategic rather than operational), a pure stochastic modeling is used as a first approximation. Further study on traffic assignment modeling should incorporate ports as links with limited capacities.

5.4.2 Specifications for Demand Simulation

Assume there are Q^i_{am} containers (in TEU's) of commodity type i ($i \in [1,I]$) that are to be imported from region a (continent) to a destination m in Europe. The unit cost for maritime transportation is α euros per kilometer per TEU. There are N coastal ports to choose from; the maritime distance to the n^{th} port ($n \in [1,N]$) is l_{an}. The port dues and terminal charges at the n^{th} port are pd_n and tc_n, respectively, per TEU. The costs for maritime transportation and port usage, C_{an}, are then:

$$C_{an} = \alpha \cdot l_{an} + pd_n + tc_n \tag{5.1}$$

Observe that pd_n and tc_n are independent from the throughput and capacity of the n^{th} port, suggesting there are no economies of scale in port operation. In practice, such economies may exist due to distribution of investment costs over a larger number of handled containers and result, if passed on to port users, in decreasing port tariffs for increasing throughputs.

For hinterland transportation, various route and mode combinations are possible. The hinterland transportation cost from the n^{th} port to destination m via route r is the sum of the costs over all modes used for that route. Assume for mode j ($j \in$ [truck, train, barge]) that the unit cost is β_j euros per TEU per kilometer, with transportation distance l_{rj}. The transfer between two modes is performed at an inland terminal with a charge p_t per TEU. The costs for hinterland transportation via route r, C_{nmr}, can then be expressed with:

$$C_{nmr} = \sum_{j-1} p_t + \sum_j \beta_j \cdot l_{rj} \tag{5.2}$$

The maritime transportation speed is S_s kilometers per hour; the time spend on the maritime leg is then $\frac{l_{an}}{24 \cdot S_s}$ days. If the average time for container discharge in port n is H_n days, then the total number of days spent in maritime transit is $D_{an} = \frac{l_{an}}{24 \cdot S_s} + H_n$.

It is assumed that the dwell time in the port, H_{ndr}, depends on hinterland transportation modes (see ARCADIS *et al.*, 2001).

Observe that the average time for container discharge H_n and the dwell time H_{ndr} are here assumed to be independent from the throughput and capacity, suggesting there is no port congestion. This is connected with the pure stochastic modeling-approach as applied in the present study. Accounting for such dependency would incorporate congestion in traffic assignment modeling and requires, for instance, a stochastic user equilibrium-approach.

Hinterland transportation speed is S_j kilometers per hour; the time spend per hinterland transportation mode is then $\frac{l_{rj}}{24 \cdot S_j}$ days. The dwell time at an inland terminal, H_{tdj}, is also mode-dependent. The total number of days spent in hinterland transit for route r is $D_{nmr} = H_{ndr} + \sum_j \frac{l_{rj}}{24 \cdot S_j} + \sum_{j-1} H_{tdj}$.

Further assume the value per TEU is V_i, and the daily unit cost of capital is ρ. For commodity group i, the time cost of transportation is approximated by the opportunity cost of time, OC^i. This represents the loss on capital for the receiver of the container in transit. The opportunity cost of time can be expressed with:

$$OC^i(D) = V_i \cdot \left[(1+\rho)^D - 1 \right] \tag{5.3}$$

The generalized cost for commodity group i using hinterland transportation route r, GC^i_{nmr}, can be expressed with:

$$GC^i_{nmr} = C_{nmr} + OC^i(D_{nmr}) \tag{5.4}$$

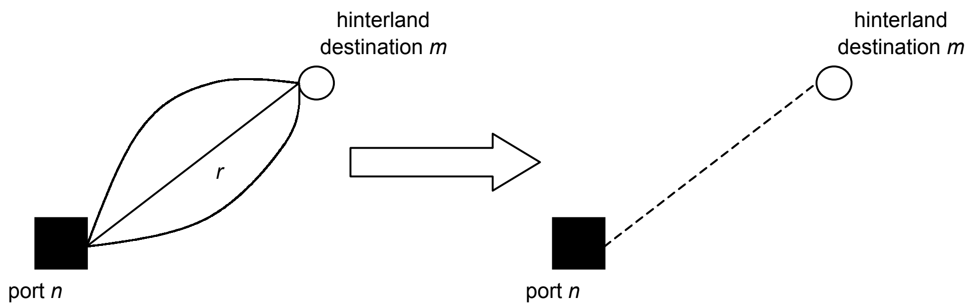

FIGURE 5.2 Clustering of hinterland transportation routes.

To avoid biased results due to differences in the number of hinterland transportation routes per port (a port with less hinterland transportation routes would receive then less containers; see, e.g., Ortúzar and Willumsen, 2000), the hinterland transportation routes are aggregated into a single link according to the approach as followed by, for instance, Fernández *et al.* (undated) (see Figure 5.2). A logit-type assignment modeling is used to incorporate uncertainty on the route choice, because route choice is only partly explained by transportation cost and duration. A practical formulation of the generalized hinterland transportation cost for port n is then:

$$GC^i_{nm} = \sum_r \frac{GC^i_{nmr} \cdot \exp(-\mu \cdot GC^i_{nmr})}{\sum_r \exp(-\mu \cdot GC^i_{nmr})} \tag{5.5}$$

in which μ represents the spreading parameter. For the application case, μ is set arbitrarily to 0.001 [1/(€/TEU)]. Calibration of this parameter would be required if the aim of the application was to choose the most effective strategy to deal with competition instead of to address trade offs in a port's investment planning.

The total generalized cost for transporting commodity group i by using the n^{th} port is:

$$GC^i_{anm} = C_{an} + OC^i(D_{an}) + GC^i_{nm} \tag{5.6}$$

Let Q^i_{amn} be the number of containers for commodity group i move from a to m that use port n. Local demand for port n, Q_n, is then:

$$Q_n = \sum_a \sum_m \sum_i Q^i_{anm} \tag{5.7}$$

in which Q^i_{anm} can be calculated with the following formulation:

$$Q^i_{anm} = \frac{Q^i_{am} \cdot \exp(-\mu \cdot GC^i_{anm})}{\sum_n \exp(-\mu \cdot GC^i_{anm})} \tag{5.8}$$

As can be observed from the above discussion and equations, changes in transportation speed, costs and durations will affect the demand for port services. This model can be used to examine the effect of changes in these factors due to, for instance, technological development (see Chapter 6). Observe further that throughput and capacity are not included in the equations because a pure stochastic modeling is used as a first approximation to simulate local port demand (see Section 5.4.1). The demand curve for port *n* can be established from a set of traffic assignment simulations with varying port dues pd_n.

5.5 Schematization for Port Supply Modeling

The supply of capacity for port *n* can be schematized by the marginal social cost, MSC_n. The marginal social cost is a function of the port's throughput, Q_n, and capacity, K_n. The MSC_n is derived from the expression for the marginal private cost, MPC_n. The format of the supply curve is established below.

The marginal private cost, *MPC*, is equal to the average social cost for port capacity usage, *ASC*, (see Verhoef, 2001) and is determined by the sum of port dues, terminal charges, and the product of the *VOT* (Value-Of-Time; the monetary cost of one unit of travel time delay) and the travel time t_n for using port *n*. The travel time t_n depends on the port throughput/capacity ratio (i.e. the capacity utilization ratio). The following relationship is adopted to represent congestion in the port:

$$t_n = t_{ff,n} \cdot \left(1 + c \cdot \left(\frac{Q_n}{K_n} \right)^k \right) \tag{5.9}$$

The factor $t_{ff,n}$ expresses the 'free-flow-travel-time' – here: the 'ideal' service time without port congestion – which is set equal to the sum of the vessel discharge time and the (average) dwell time on the yard. The yard is here assumed to be part of the port and not of the hinterland section, and port access time (e.g., to sail through the access channel) is assumed to be negligible. The vessel discharge time depends on the vessel size; the larger the vessel, the more cargo it transports, thus the longer it takes to discharge the vessel.

Different values for the parameters *c* and *k* can be used for different circumstances; for instance, these parameters can be modified to include the approximate effect of intersection delay associated with a transportation link. In the present study, *c* and *k* are set arbitrarily[35] to 0.15 and 4, respectively, representing the so-called 'Bureau of Public Roads' (BPR) formula that is often used for research on passenger transport (see, e.g., Ortúzar and Willumsen, 2000). The assumption is that a curve with similar characteristics can be used to simulate port congestion. Further research on simulation of port congestion is indicated.

[35] The sensitivity of the results of the application case for the choice of the parameters *c* and *k* has been analyzed by varying the chosen values within a range of ±10%. The outcome was that the results are particularly sensitive for the choice of *c*. This indicates the relevance of the choice of these parameters.

The expression for the marginal private cost is then:

$$MPC_n = ASC_n = pd_n + tc_n + VOT \cdot t_{ff,n} \cdot \left(1 + c \cdot \left(\frac{Q_n}{K_n}\right)^k\right) \qquad (5.10)$$

For the sake of simplicity, port dues pd_n and terminal charges tc_n are assumed to be independent from vessel size and dwell time. Observe further that MPC_n increases unlimited for increasing flows, suggesting that the throughput (Q_n) can become higher than capacity (K_n) and that travel time (t_n) can grow endless; in other words, capacity does not restrict throughput increase. Therefore, alternative expressions (e.g., Davidson, 1966; Tisato, 1991) have been proposed to overcome this problem[36]. Using Eq. 5.10 is nevertheless attractive because it helps to improve analytic tractability. In the present modeling approach, this is completed with a constraint (the maximum allowed capacity utilization rate) to restrict throughput increase.

The marginal social cost, MSC_n, can be expressed as:

$$MSC_n = \frac{\partial Q_n \cdot ASC_n}{\partial Q_n} = ASC_n + Q_n \cdot \frac{\partial ASC_n}{\partial Q_n}$$

$$= MPC_n + VOT \cdot t_{ff,n} \cdot c \cdot k \cdot \left(\frac{Q_n}{K_n}\right)^k \qquad (5.11)$$

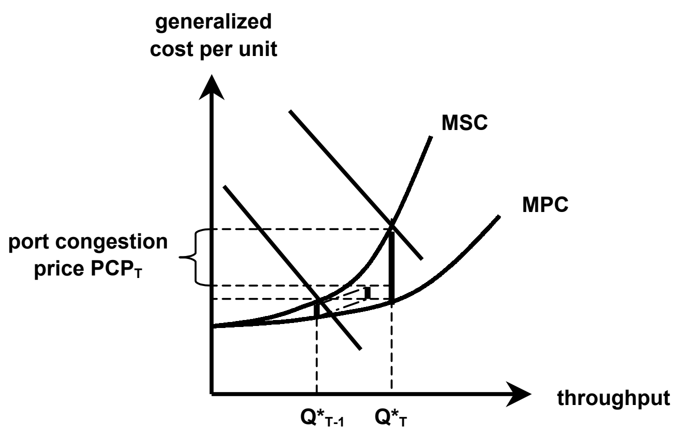

FIGURE 5.3 Determination of port congestion price.

The port congestion price for port *n* – assumed to be paid by all users of port *n* - for year *T*, $PCPn,_T$, is in this study based on the annual change of the marginal external cost due to the autonomous growth of port demand, $Q_{n,T}$* - $Q_{n,T-1}$* (see Figure 5.3). The port congestion price for port *n* in year *T*, $PCP_{n,T}$, is then approximated by:

[36] The interested reader is referred to Bliemer (2001) for an extended overview of travel time functions.

$$PCP_{n,T} = VOT \cdot t_{n,ff} \cdot c \cdot k \cdot \left(\left(\frac{Q^*_{n,T}}{K_n} \right)^k - \left(\frac{Q^*_{n,T-1}}{K_n} \right)^k \right) \quad (5.12)$$

The financial revenues for the owner of port n in year T obtained from congestion pricing, $R_{n,T}$, can be calculated with the product of equilibrium demand in year T, $Q_{n,T}$*, and the port congestion price in year T, $PCP_{n,T}$. This can be expressed as:

$$R_{n,T} = Q_{n,T}^{\ *} \cdot PCP_{n,T} = Q_{n,T}^{\ *} \cdot VOT \cdot t_{n,ff} \cdot c \cdot k \cdot \left(\left(\frac{Q^*_{n,T}}{K_n} \right)^k - \left(\frac{Q^*_{n,T-1}}{K_n} \right)^k \right) \quad (5.13)$$

Special attention should be paid to the *VOT*, which expresses the willingness to pay of a port user for a unit reduction of service time. According to, for instance, Tavasszy (1996), the *VOT* varies among different goods, not only due to differences in physical characteristics, but also due to different logistical circumstances of the sending and receiving companies. The *VOT* varies also among different transport modes being used. Many studies have been established to determine the *VOT* for freight transportation (see, e.g., Tavasszy *et al.*, 2002). An overview of some studies that estimated the *VOT* for containers can be found in (CPB, 2004). The latter study indicates a *VOT* of about € 156-192/TEU/day.

For the application case, the *VOT* is approximated by the daily loss on capital for the receiver of the container in transit. This is established by determining the steepness of the linear approximation of the curve (opportunity cost of time) that can be constructed with the help of Equation 5.3 as function of the duration (in days). This is conceptually shown in Figure 5.4.

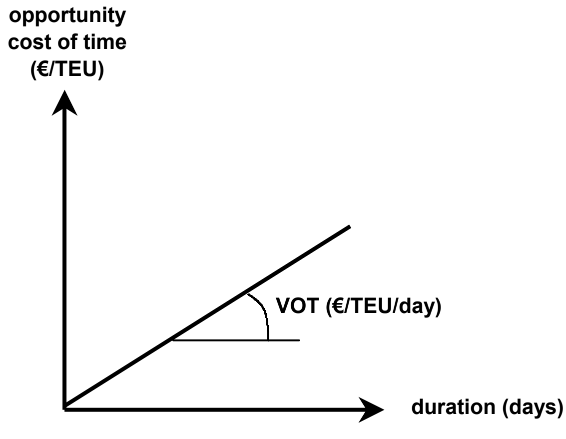

FIGURE 5.4 Concept of determination of the VOT for the application case.

The linear approximation of the opportunity cost of time is here based on a Taylor series approximation for $(1 + \rho)^D$, which can be set equal to $1 + \rho \cdot D$ because $\rho << 1$. The approximated opportunity cost of time, $OC^i(D)_{app}$, is then expressed by:

$$OC^{i}(D)_{app} = V_i \cdot \rho \cdot D \tag{5.14}$$

The value of the slope of this function, $V_i{\cdot}\rho$, represents the approximated *VOT* for commodity group i. For the sake of simplicity, the average value per TEU for the present equilibrium for port n, $V_{n,av}$, is used instead of V_i.

For the application case, $V_{n,av}$ is about € 17.566/TEU and ρ about $3.8{\cdot}10^{-4}$/day (based on 15% interest per year). This results in a *VOT* of about € 6.75/TEU/day. Comparing to the results as found in literature (see above), this represents a substantial underestimation (at least a factor 23) that may lead to underestimated port congesting costs.

The sensitivity of the financial and economic results of the application case for the choice of the *VOT* has been analyzed. This has been established by varying the *VOT*-value within a range of 6.75-192 €/TEU/day. The outcome was that the financial revenues from pricing of port congestion vary accordingly within a range of 18.69-118.52 million euros and the increase of consumers' surplus within a range of 45.69-175.20 million euros. This indicates that the above-described approximation of the *VOT* leads to an under-limit approach for the financial and economic results of the application case.

5.6 Observations

We will use a network equilibrium model to simulate freight transportation to estimate local port demand. The model structure and schematization have been described in this chapter. The supply curve, represented by the marginal social cost curve, makes use of the so-called 'Bureau of Public Roads' (BPR) formula that is often used for research on passenger transport. The assumption is that a curve with similar characteristics can be used to simulate port congestion.

The specifications and procedures as formulated in this chapter will be applied in Chapter 7 to the Port of Rotterdam in the Netherlands.

Up to now, our methodology for planning of port capacity does not yet incorporate technological development. This will be established in the next chapter, which discusses developments in container transportation technology and provides a practical approach to incorporate these developments in the planning methodology.

6. Incorporating Developments in Container Transportation Technology

6.1 Introduction

Our methodology for planning of port capacity, as developed so far, integrates port-commercial and public interests, and incorporates competition, autonomous growth of demand and economies of scale. As announced in Chapter 1, our methodology will also incorporate technological development. This will be established in this chapter.

Ports are perceived in this study as nodes embedded in networks of alternative transportation routes making their competitiveness highly dependent on the attractiveness of the routes. Technological development in freight transportation may affect the attractiveness of certain routes and therefore port development due to decreased transportation costs. Particularly developments in container transportation continue to have drastic influence on port development.

With a view on the application case, developments in container transportation technology are reviewed in this chapter. This review results in establishing a practical approach to incorporate these developments in our modeling approach for planning of port capacity. A change in types of goods that are containerized, types of containers and advances in container-handling equipment in ports are not discussed; the present chapter focuses on technological development of access/egress modes (ocean vessel, truck, train and barge).

The remainder of this chapter is divided into five sections. Section 6.2 briefly discusses the background of containerization and associated transport-technological developments, namely, by discussing the relationship between developments in economy, logistics and freight transportation. Section 6.3 presents advances in maritime transportation; cost savings as well as other consequences of larger ocean vessels are discussed. In Section 6.4, technological advances in land transportation are described. A practical approach to incorporate these developments in the planning of port capacity is discussed in Section 6.5. Section 6.6 summarizes the findings.

6.2 Background: Economy, Logistics and Freight Transportation

The general purpose of freight transportation is to connect different locations for production and consumption of goods. Its main function is therefore facilitating the economic system. Logistic services interact between freight transportation and economy by providing efficient concepts to organize the transportation of goods from the origin to the required destination (e.g., Van Binsbergen and Visser, 2001). Advances in freight transportation such as technological development are therefore to a large extent determined by developments in the economic system and logistics[37], as illustrated in Figure 6.1.

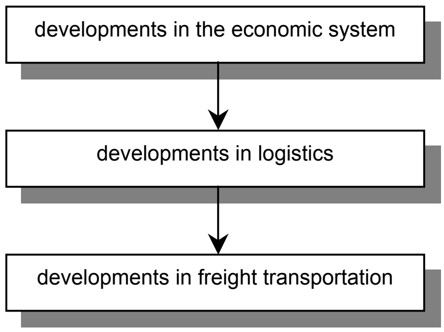

FIGURE 6.1 Developments in freight transportation determined by developments in the economic system and logistics.

Until the 1970's, the global economic system was essentially supply-driven and based on mass production. Since then, this system has fundamentally been changed. According to Van Klink and De Langen (1999), this was induced by an increasing individualization of the consumer, attention for environmental issues, liberalization of global trade and the rise of information technology. Responding to this, new production models emerged, which are essentially demand-driven and based on tailored production volumes (e.g., Reeve, 2002). This requires fast-responding (efficient) supply chains.

With the increasing pressure on firms to minimize inefficiencies in their supply chains, more complex transportation concepts were developed: integrated transportation systems, in which the transportation process is organized in its totality. Such systems include also distribution, storage and information associated with cargo flows. This has led to intermodal freight transportation, in which seamless connections between the different transportation modes are essential.

The obstacles for efficient functioning of intermodal transportation were to be found at each cargo handling activity. Furthermore, each cargo handling activity entails the risk of damage. The solution was found in the unitization of cargo. Particularly the container facilitates efficient and safe freight transportation. More than half of all general cargo (measured by volume) in international liner trade is currently being moved in containers. By 2010, it is predicted that 90% of all liner freight will be containerized (U.S. DOT, 1998).

[37] It is assumed here that developments in freight transportation do not have impact on logistics and the economic system.

The various developments in freight transportation initiated by containerization (see further) have lead to a restructuring of carrier operations. Major trade flows were consolidated at a relatively small number of ports, which have been transformed into load centers or hubs where container flows are concentrated, and where carriers focus their operations (hub-and-spoke networks; Hayuth, 1987; Notteboom, 1997; Notteboom and Winkelmans, 1998). The attractiveness of hubs lays in the fact that economies of scale in port operation can be obtained due to the handling of large numbers of containers, which further enhances the competitive position of hubs in international transportation networks.

6.3 Advances in Maritime Transportation

6.3.1 Cost Savings due to Larger Vessels

During the last decades, vessel sizes have increased dramatically. In Table 6.1, a summary is given of the development of transportation capacity and vessel dimensions for different container vessel generations. Blue prints exist for 15,000 TEU vessels (McLellan, 1997) and even for 18,000 TEU vessels (Wijnolst *et al.*, 1999).

TABLE 6.1 Development of container vessel capacity and dimensions

Generation	Year of introduction	Maximum transport capacity (TEU)	Maximum length (m)	Maximum beam (m)	Maximum draught (m)
1st	1964	1100	200	27	9
2nd	1967	1800	240	30	11.5
3rd	1974	3000	300	32	12.5
4th	1984	4500	310	32.3	12.5
5th	1995	6000	350	38	12.5
6th	2003	8000	323	43	14.0

Sources: Cullinane and Khanna (2000) and various issues of Containerisation International

Transportation cost reductions due to increasing vessel sizes seem to be significant. Empirical studies indicate reductions approaching 40% on the break-even freight rates for a 6000 TEU vessels compared to a 4000 TEU vessels (Phillips, 1996). Lim (1998) estimates the reduction in operational costs of increasing vessel size from 4000 to 6000 TEU at about 21%. Assuming that the marine transportation component accounts for about 30% of total intermodal costs, this represents a 6.3% reduction of total transportation costs (Lim, 1998).

6.3.2 Other Consequences of Larger Vessels

The trend of designing larger vessels is limited by various factors (e.g., Wijnolst, 1999; De Hartog *et al.*, 2001): high investments in vessel engines, the dimensions of the Panama Canal locks (length 294 m and width 32.3 m); profile developments of the Suez Canal (expected depth up to 21 meters in 2009); the depth of the Strait of Malacca (21 m); and port accessibility limitations. Furthermore, the construction of large ocean vessels represent formidable investments; about $100 million for a 6700 TEU ship according to Lago *et al.* (2001).

Responding to the high investment cost, ocean carriers try to rationalize their service networks. For a forth generation container vessel, Talley (1990) estimated for Trans-Atlantic routes an optimal number of calls between three and five, and for around-the-world services eight to thirteen. He showed further that the optimal size of container vessels diminishes when the number of ports of call increases.

It became clear to ocean carriers that further individual efficiency measures would not lead to a further increase of market shares and profits (Shashikumar, 1999). This has lead to an increasing number of strategic alliances in liner shipping (see, e.g., Robinson, 1998; Heaver *et al*., 2000; Slack *et al*., 2002). When the structure of a new alliance has not been perceived as sufficiently adequate due to, for instance, complex management structures, mergers have sometimes been an alternative (see, e.g., Heaver *et al*., 2000).

As a result of alliances and mergers, volume and capital available for developing carrier-owned terminals (so-called dedicated terminals) is increasing. Only when the transported volumes are big enough, carriers will be able to exploit dedicated facilities. Some carriers achieve this by inviting other carriers to call at their terminals. The advantages of running a dedicated terminal are a guaranteed availability of berths and the ability to control planning and operation, which leads to cost reductions (De Hartog *et al*., 2001).

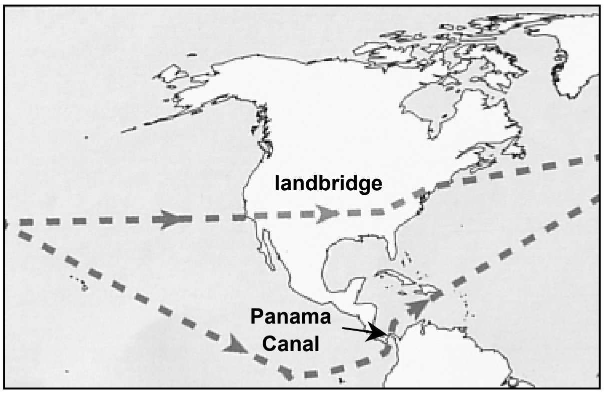

FIGURE 6.2 The landbridge instead of the Panama Canal.

Vertical integration of maritime transportation with land transportation appeared as a competitive alternative to all-water services. Therefore, ocean carriers began offering intermodal services - aiming at shorter transit times - at competitive rates (Foggin and Dicer, 1985; Brooks, 1992). For example, container shipments between East Asia and Europe can partly be moved by train via the so-called landbridge in the U.S. instead of via the Panama Canal (see Figure 6.2).

6.4 Advances in Land Transportation

Land container transportation comprises transportation by 1) truck, 2) train, and 3) barge. The most important technological developments that support efficient transportation by these modes are discussed below. The focus is on the size in terms of the transported volume of the modes.

6.4.1 Truck

In Europe, container transportation by truck holds a strong position. The relatively short distances and the high density of road networks in Europe matches with the flexibility of trucks[38] (Hayuth, 1987). Technological innovations in truck transportation include more efficient fuels and engines, self-loading semi-trailers, and longer trucks (4 TEU) (De Hartog *et al*., 2001). Further development of intelligent transportation systems contributes to further improvement of highway usage (Stough, 2001).

Major disadvantages of road transportation are environmental pollution and the fact that a large number of trucks is needed to transport the shipment of one ocean vessel.

6.4.2 Train

An example of technological innovation in rail freight transportation is the introduction of the double-stack railcar (see Figure 6.3), particularly used in the U.S.. This system allows to carry more containers per train, which – given the high cost of rail equipment – means a more efficient use of railroads. Cost savings (in the U.S.) per container unit carried have been estimated at 30-40% (Fleming, 1989).

FIGURE 6.3 Double-stack railcars.

There are however some negative aspects of using the double-stack railcar. It requires large handling yards, and the cranes and loaders that are needed to handle the stacking are expensive to purchase and maintain. Using the double-stack railcar is therefore only suitable for very productive non-stop freight routes. Moreover, the stacking height of two containers

[38] Another cause is that in European railways priority is given to passenger trains instead of to freight trains. This factor in addition to a lack of harmonization between European railway companies contributes to a higher attractiveness of truck transportation.

(about 5.2 m) prevents using double-stack railcars in combination with electric propulsion; the clearance under the wires is simply too small to accommodate such trains, particularly in Europe. In addition, the clearance in tunnels and under crossovers can be too small. In the Netherlands, for instance, the maximum clearance is 4.8 m, while the maximum double-stack train height is 6.5 m (Roscam Abbing, 1999).

6.4.3 Barge

Inland (container) shipping is a more energy-efficient and cost-effective alternative for road and rail freight transport. An important innovation is the development of the large self-propelling inland container barge. An example is the Jowi (see Figure 6.4) with a transport capacity of 408 TEU, a length of 135 m and a speed of 23 km/h (with no current). A reduction of transport costs of 15-20% per container unit, compared with smaller inland container barges, can be reached (Roscam Abbing, 1999).

FIGURE 6.4 The inland container barge Jowi.

A special feature of barge transportation is short sea shipping. Short sea container vessels act as feeders for the major hub ports, operate under the schedule of the deep-sea vessels and have a transport capacity between 150 and 500 TEU (Paixão and Marlow, 2002).

In Europe, the river-sea vessel appeared in the 1990's, which has the following (average) dimensions (Rissoan, 1994): 1) length: maximum of 82 m to be able to access Scandinavian waterways, 2) beam: 11.4 m to go through the locks of continental waterways which are generally 12 m wide, 3) draught: 3 m, 4) air draft: less than 7 m. An important advantage of this vessel is that it can sail directly to an inland port or terminal without calling at a seaport.

The drawbacks of larger container barges include increased container handling times due to the larger transported volume of one ship, and less accessibility due to increased vessel sizes. Responding to this, 32 TEU barges have been developed. Such small barges can sail in small inland waterways and reach individual clients as an alternative to road transport (De Hartog *et al.*, 2001).

6.5 Incorporating Transportation Technology in Capacity Planning

The above-discussed developments in container transportation technology lead to reduced transportation costs and therefore to reduced generalized transportation costs. Some transportation routes may become more attractive due to such reductions; they will receive then a larger portion of total transportation demand. Other routes may become less attractive causing decreased demands. Because ports are considered to be part of transportation routes, this will have consequences for local port demand and, thus, for the size of port expansion plans.

A number of developments in container transportation have been identified in this chapter. Not all of these developments are equally important for deciding upon port expansion and their influence on the outcome of capacity planning vary due to the availability of data and the degree of accurateness in the estimation of transportation cost functions. Incorporating certain developments in transportation technology in planning of port capacity is nevertheless attractive with a view on their potential impact on local port demand and the size of port expansion plans (see above); some judgment can then be made on the relative importance of transport-technological developments on planning of port capacity.

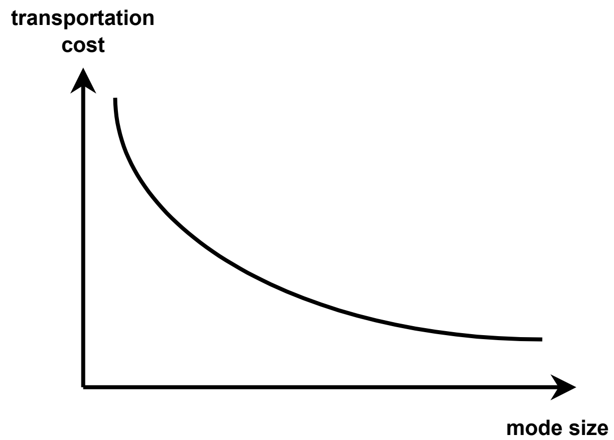

FIGURE 6.5 Relationship between mode size and transportation cost.

In our application, four developments in container transportation technology have been studied: 1) larger ocean vessels, 2) larger (longer) trucks, 3) larger (double-stack) trains, and 4) bigger barges. These developments can easily be incorporated in the traffic assignment modeling as discussed in Chapter 5. A practical approach is the inclusion of relationships between mode size (in terms of transport capacity) and transportation cost reflecting economies of scale as conceptually shown in Figure 6.5. The influence of mode sizes on the outcome of deciding upon port expansion can then be analyzed with, for instance, the help of Monte Carlo simulation.

6.6 Observations

Various developments in container transportation technology have been identified in this chapter. The main developments include the introduction of larger ocean vessels, longer trucks, double-stack trains and bigger barges, and the introduction of alternative fuels. The introduction of larger ocean vessels has further induced horizontal integration of ocean carrier operations and vertical integration of maritime and land transportation. These developments affect transportation costs and may therefore influence port demand. Being aware of this influence, any decision on port expansion should incorporate the influence of developments in transportation technology.

With the above results, the intended challenge of this study is now complete: the development of a methodology for planning of port capacity that integrates port-commercial and public interests, and incorporates competition, autonomous demand growth, economies of scale and technological development.

In the next part, this methodology will be applied to the Port of Rotterdam in the Netherlands. With a view on incorporating developments in container transportation technology, only the influence of larger access/egress modes will be examined in the application. The influence of a change in types of goods that are containerized, types of containers and advances alternative fuels and horizontal and vertical integration might also be important, but will not be included in our application due to a lack of data. Advances in container-handling equipment in ports will be catched by changes in spatial productivity.

III. Application

7. Trade Offs in the Investment Planning for the Port of Rotterdam

7.1 Introduction

To demonstrate the methodology for planning of port capacity, it has been applied to the Port of Rotterdam in the Netherlands. This study focuses on a hypothetical port expansion for non-domestic container flows by means of expansion of the port surface area by land reclamation. It is assumed that only the port's surface area is relevant for capacity expansion; the capacities of the hinterland connections are assumed to automatically follow port capacity.

The character of this chapter[39] is explorative: tracing the decision space for the Port of Rotterdam. The scenario of the entry of new competing routes via the Italian port Gioia Tauro is used to illustrate the impact of route competition. The emphasis is on the trade offs in investment planning of a single port rather than the choice of the most effective strategy to deal with competition.

The remainder of this chapter is divided into six sections. Section 7.2 presents the description of the case. In Section 7.3, the data sources and data estimation process are described. Section 7.4 discusses the modeling approach for the application case and includes an overview of the most relevant equations. Section 7.5 discusses some implications for port planning. A comparison with other studies is discussed in Section 7.6. Section 7.7 summarizes the findings and gives some observations.

[39] This chapter is largely based on Dekker and Verhaeghe (2005).

7.2 Case Description

The Port of Rotterdam serves a hinterland that includes the industrial heart of Europe (the Ruhr basin area, Southern Germany and the area of the Alps). Its main competitors for this hinterland are the North Sea ports Hamburg and Bremen in North-Germany, and Antwerp in Belgium. The ongoing competition between these ports triggered a spiral of investment decisions. The investment plans involved mainly structural capacity measures, which increased their container-handling capability with 50% by the year 2000 (see Chapter 2).

The further development of South-European ports, such as those in Italy, is considered to be a serious threat for Rotterdam and the other North Sea ports, particularly if the hinterland connections of the South-European ports are developed as well. For example, the German rail freight carrier *Railion* and the Italian terminal operator *Contship Italia* recently started a joint venture (*Hannibal*) for transport services between the Italian port Gioia Tauro and the Alp area. Daily rail services for container transportation are planned to be offered (Elliot, 2002; Beddow, 2004b). Reduced market shares for the North Sea ports are suspected.

For the purpose of this study, the assumption is that competition between the North Sea ports is not affected[40]. The above-described scenario is then analyzed as the entry of new transportation routes via a competing port (Gioia Tauro). This change in the European network leads to a loss of market share (local demand) for the Port of Rotterdam and, consequently, causes fewer benefits for Rotterdam port (less financial revenues) and for the Dutch economy (less value-added and employment). At the same time, a further growth of container trade between Europe and Asia, particularly China, is to be expected.

The question then is: what should be the optimal expansion strategy for Rotterdam to allow for the expected demand growth and to deal with route competition from Gioia Tauro? And: can the expansion strategy be self-financing? Furthermore, the issue of 'leakage' of Rotterdam port investment benefits to the European (non-domestic) hinterland is addressed and related with economies of scale in port operation.

The network for the application comprises the North Sea ports Hamburg, Bremen, Rotterdam and Antwerp and the Mediterranean ports La Spezia and Gioia Tauro in Italy. Their common hinterland or 'competition area' is located around the area of the Alps (see Figure 7.1). It consists of the regions 'Basel' (comprising Switzerland and the western part of Austria), 'Stuttgart' (representing the south-west of Germany), 'Munich' (south-east of Germany), and 'Milan' (northern Italy).

[40] In reality, it is likely that competition between the North Sea ports is also affected by the entry of Gioia Tauro. Such entry leads to a decrease of market shares of all North Sea ports considered, which intensifies the existing spiral of investment decisions (see above).

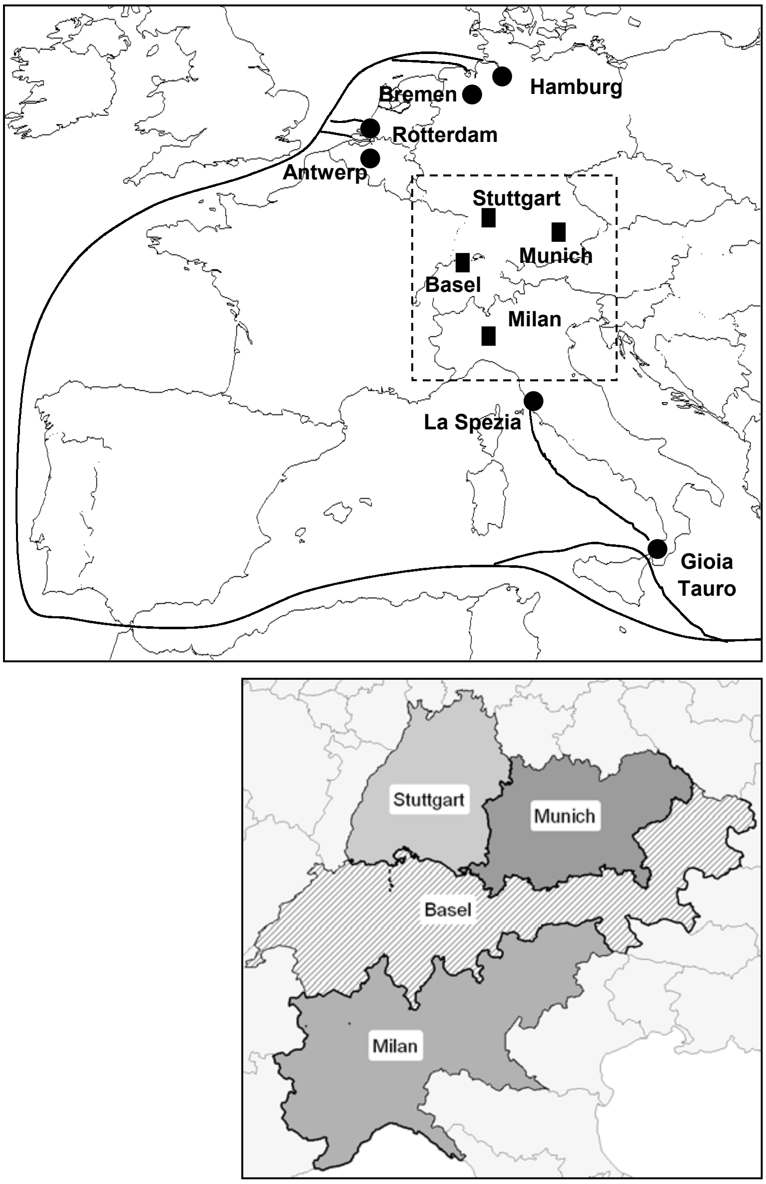

FIGURE 7.1 Ports and their common hinterland in the application.

For this network, a substantial amount of data is available, including:

- service characteristics of the ports including port dues, terminal charges and productivity figures; and
- trade data (import and export flows) of the hinterland regions.

The modeling approach outlined in previous chapters has been applied to the case. It has been implemented in a spreadsheet and contains a partial equilibrium model to simulate container demand for the Port of Rotterdam, based on scenarios for route competition, demand growth and transportation technology that have been formulated as input.

The scenario to illustrate trade offs in the investment planning for the Port of Rotterdam comprises 1) route competition due to the entry of new routes via Gioia Tauro, 2) demand growth of 64,000 TEU/year, 3) and transportation technology expressed by an ocean vessel size of 5000 TEU, short sea vessel size of 500 TEU, truck size of 2 TEU, train size of 90 TEU and barge size of 200 TEU.

The data requirements to apply the modeling approach to the application case are discussed in the next section.

7.3 Data Requirements

To apply the modeling approach, there is a need for data on 1) container flows to and from the hinterland regions considered, 2) the intermodal transportation network including port service characteristics, 3) transportation parameters characterizing transportation technology, 4) economic parameters characterizing the capital market and the exogenous growth of international trade, and 5) investment characteristics. The data sources and the data estimation process are described below.

7.3.1 Container Flows

Data is needed on containerized cargo imports and exports, measured in TEU's, and on the value per TEU. These origin-destination (O-D) data are used to simulate the assignment of the container flows over the transportation network.

The O-D data source used for this study is derived from the SCENES database, which has recently been used by RAND Europe to simulate transport flows in the European Union (EU) (see De Jong *et al*., 2004). This database includes trade information from 1995 between European zones and foreign continents in weight (tons per day), but not in TEU's and value. The trade information represents equilibrium flows, which reflect capacities and congestion conditions of 1995. Furthermore, the data is given for commodity groups following the NSTR classification. Apart from the flows to and from the EU, the database includes also intra-EU flows, which are not used for this study.

The flowchart in Figure 7.2 presents the process to convert this comprehensive database in a container flow O-D matrix for the application network. This process consists of four steps. First, the commodity flows that would reasonably be containerized were separated from the other commodity flows[41]. Second, the O-D zones that make up the competition area and the continents (East Africa, Asia, Australasia, Egypt and the Middle East) considered were taken apart, and the intra-EU flows were excluded. Third, the remaining flows (expressed in tons per day) were converted into number of TEU's, using the research result on estimating the mass of containers by Hancock and Sreekanth (2001), and value per TEU[42], using the results from the US commodity flow survey from 1997 (U.S. DOT, 1999). Finally, the daily

[41] Due to containerization, an increasing number of commodities is containerized. This is however not accounted for in this study.

[42] In this study, *average* numbers for TEU's/commodity flow, mass/TEU and value/TEU are used. In reality, these numbers may strongly differ due to, for instance, regional differences and differences between import and export flow.

numbers were converted into annual numbers of TEU's for container imports and exports per region.

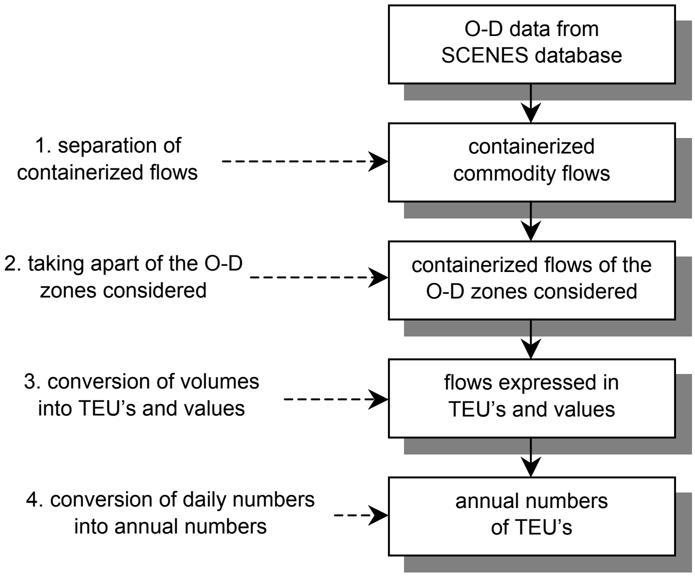

FIGURE 7.2 Conversion of the SCENES database in a container flow O-D matrix.

The final result of this conversion process is presented in Appendix 7A.

7.3.2 Intermodal Transportation Network

The intermodal transportation network in the model comprises seaports, and maritime and land transportation sub-networks. The service characteristics of the selected seaports are represented by tariffs and durations. The tariffs comprise port dues and terminal charges, and are estimated on basis of information from experts in the field of port operation. The durations (i.e. the time interval between entering and leaving the port by a container) are built up from the vessel discharge time at the quay, which depends on the vessel size, the number and productivity of the cranes (see CPB/Port of Rotterdam, 1999), and the dwell time at the stack (see ARCADIS *et al*., 2001). It is assumed that an ocean vessel 1) calls at three ports of which one in Europe, and 2) discharges in each port one third of its total transport capacity.

The service characteristics of the selected ports can be found in Appendix 7B.

The maritime transportation sub-network is simplified by using the shortest direct path between Gioia Tauro and the other ports, and includes also a short sea shipping line between Gioia Tauro and La Spezia. The inland transportation sub-network consists of (intermodal) truck, barge and train transportation. Two inland terminals in the west of Germany (Duisburg and Mannheim) connect the different inland transportation modes within the chains between the North Sea ports and the hinterland regions.

The distances by mode (in kilometers) are presented in Appendix 7C.

7.3.3 Transportation Parameters

To simulate container port demand, several transportation parameters must be specified. These include the speed of movement (e.g., CPB/Port of Rotterdam, 1999; Cullinane and Khanna, 2000), the cost per ton-kilometer[43] (AVV, 2003), and unit costs and delays in inland terminals (Kuipers *et al*., 2001). Relationships between mode size (in TEU's) and transportation cost per ton-kilometer, indicating economies of scale (see Figure 7.3), are used to incorporate the impact of transport-technological developments (i.e. larger vehicle sizes; see Chapter 6). Based on the study by Cullinane and Khanna (2000), a similar relationship is assumed between ocean vessel size and maritime transportation speed due to, for instance, developments in propulsion technology. The estimated relationships for the different transportation modes, derived from the findings in Chapter 6, are shown in Figure 7.3.

The values of the transportation parameters as used in the application are presented in Appendix 7D.

7.3.4 Economic Parameters

The growth rate of the total container flows through Rotterdam is related to projections used by the Port of Rotterdam, which are based on a fixed market share for the port[44], and has been set to 64,000 TEU/year. The interest rate to determine the time costs of transportation (15% per year in this study; see Luo and Grigalunas, 2003) should in fact be the opportunity cost of capital in business operation. A social discount rate of 4% is used in this study (see Eijgenraam *et al*., 2000). Furthermore, pre-financing is needed for the construction cost. It is assumed that the required funds can be borrowed from the national capital market; a maximum fund of € 25 million and an interest rate of 3% are used for illustration. The maximum amount that can be borrowed from the capital market should in fact be a function of the expected financial return on investment.

[43] The transportation costs are expressed in cost per *ton*-kilometer and not in cost per *TEU*-kilometer to account for differences in mass/TEU for different commodity groups.

[44] Particularly shifts in transshipment flows give cause for doubts on this assumption of a fixed market share. An empirical study by Meersman *et al*. (1997) indicated that although Rotterdam's container throughput increased between 1975 and 1996, its market share in the Hamburg-Le Havre range decreased in the same period.

Transportation costs in monetary values of 2003

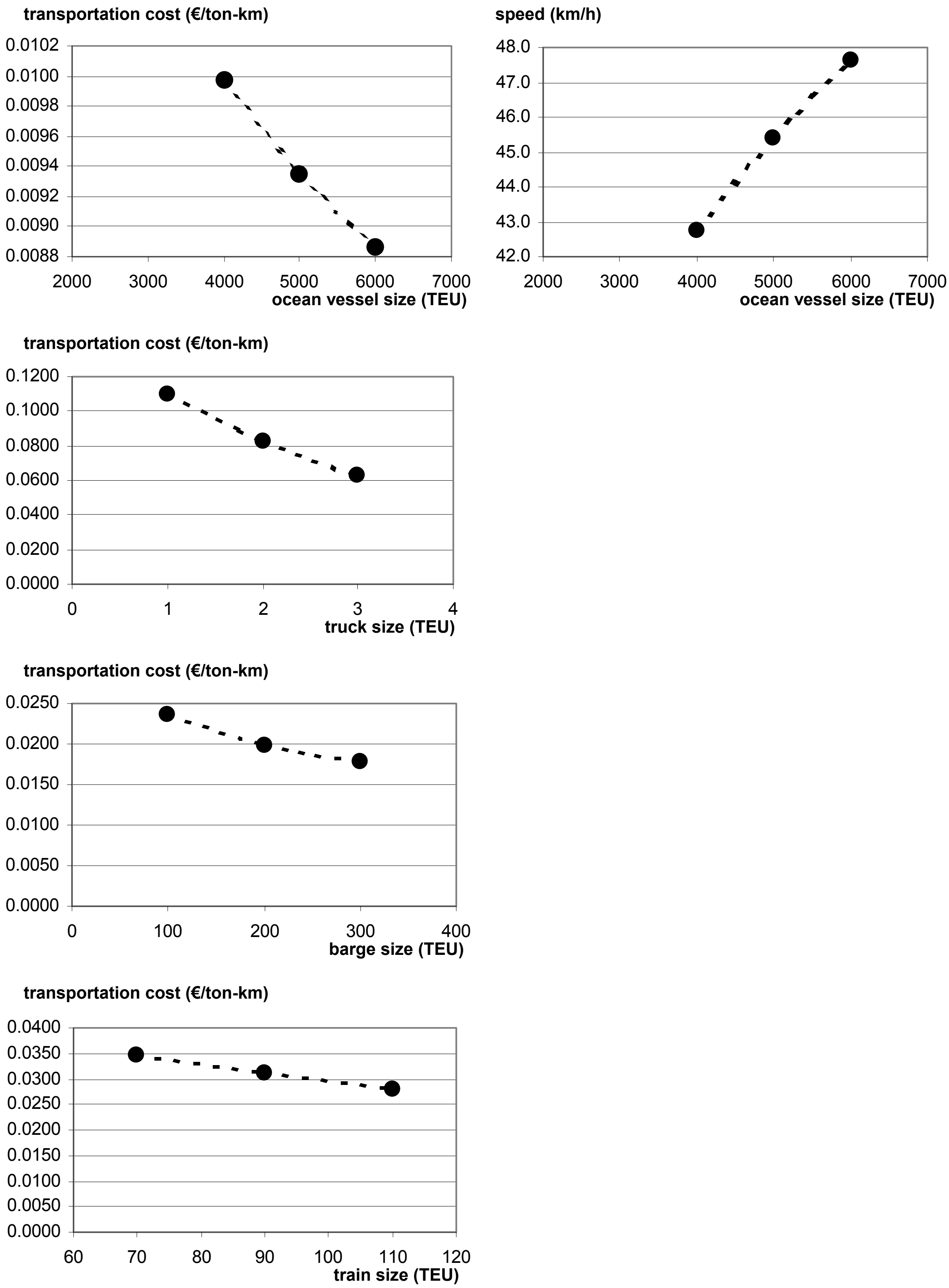

FIGURE 7.3 Mode-size dependent relationships.

7.3.5 Investment Characteristics

Port expansion by land reclamation involves cost of construction and maintenance. The maintenance cost is relatively low in comparison with the construction cost. Investments in sea defense structures are usually funded *a fonds perdu* by the Dutch national government[45]. Therefore, only the construction cost for surface area expansion is considered in this application.

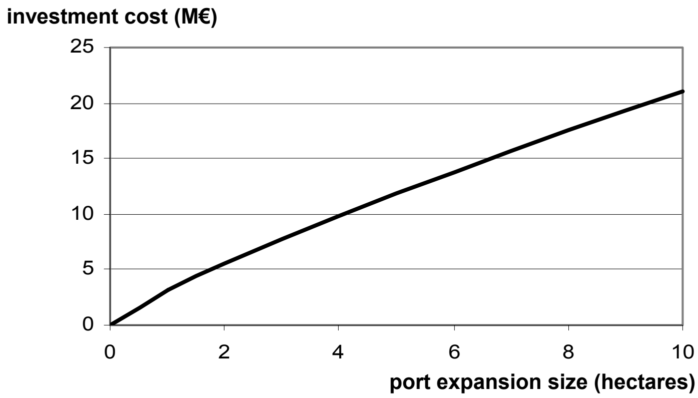

FIGURE 7.4 Investment cost function for port expansion.

The investment cost function for land reclamation is based on information in (CPB, 2001a) for the Maasvlakte 2 project. In this source, the investment cost for land reclamation, C, varies exponentially with the surface area, x, of the land reclamation. It can be represented by the function $C(x) = ax^b$ (in million euros) with a = 3.125 and scale factor b = 0.829, which is presented in Figure 7.4.

The need for surface area highly depends on the efficiency in the use of space that can be realized in the future. A port efficiency (here referred to as 'port productivity') of about 24,000 TEU/hectare/year is considered likely for Rotterdam port (CPB, 2001a).

[45] This contradicts with EU-guidelines for port investment financing as formulated in the so-called Green Paper and Port Package (see Chapter 2 of this thesis).

7.4 Modeling Approach for the Application Case

7.4.1 Set Up of the Analysis

The entry of new routes via Gioia Tauro causes a change in the European network, which affects the present assignment of container flows over the routes through Hamburg, Bremen, Rotterdam and Antwerp. This route competition results in a lost demand for each of these ports due to a redirection of parts of their freight flows (here: between the competition area and East Africa, Asia, Australasia, Egypt and the Middle East) via Gioia Tauro. Each port can react with its own particular strategy to recover its lost demand. In practice, ports will operate more pro-actively to prevent potential losses of market shares (see Appendix 7H). Analysis of a reaction by a particular port is nevertheless interesting in order to illustrate trade offs in port investment planning.

Rotterdam is assumed here to select an expansion strategy to recover its lost demand. Planning of such strategy takes into account 1) competition, 2) autonomous growth of port demand, 3) economies of scale in investment cost, and 4) technological development. Establishing this planning leads here to an equilibrium resulting from port expansion.

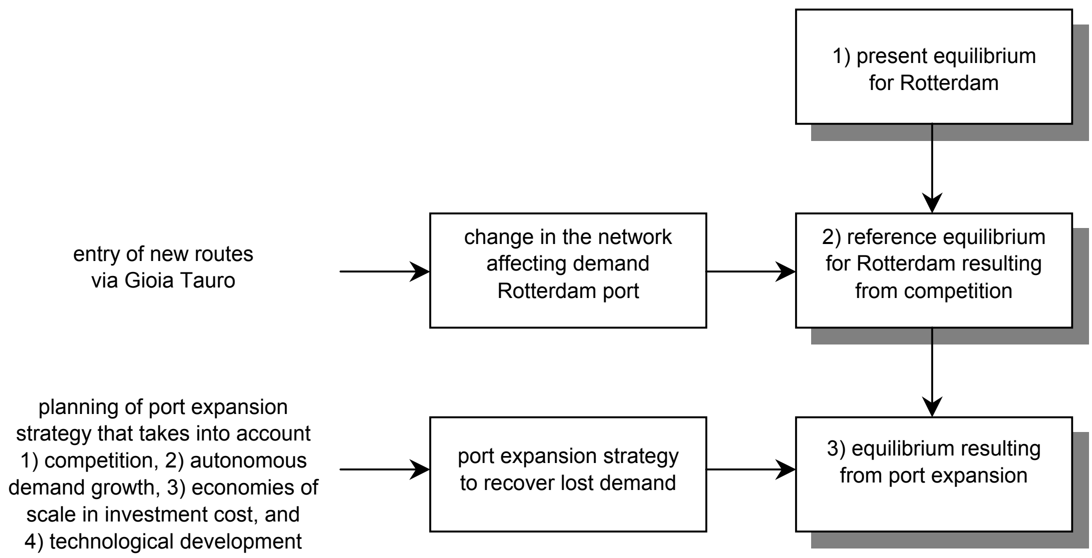

FIGURE 7.5 Analysis of the competitive position of Rotterdam.

The set up of the analysis of the competitive position of Rotterdam is presented in Figure 7.5. The modeling approach for planning of port capacity comprises establishing of 1) the present (1995) equilibrium for Rotterdam, 2) the reference equilibrium for Rotterdam resulting from competition due the entry of new routes via Gioia Tauro, and 3) equilibrium for Rotterdam resulting from port expansion to recover (a part of) the loss of demand and to allow for demand growth. Monte Carlo simulation will be used to investigate the sensitivity of the outcome of this analysis.

Extensive model calibration would be required if the aim of the present study was to choose the most effective strategy to deal with competition instead of to address trade offs in port investment planning. Such calibration is however complicated by the presence of various non-linear relationships in the modeling approach and the availability of data.

7.4.2 Determination of the Reference Equilibrium for Rotterdam

Considering the Port of Rotterdam as a node in the European transportation network, the freight transportation model as discussed in Chapter 5 is used to simulate demand. The procedure for simulation to determine the reference equilibrium for Rotterdam directly after the entry of the new routes via Gioia Tauro is summarized in Figure 7.6. The different steps, applied to the Rotterdam situation, are discussed below.

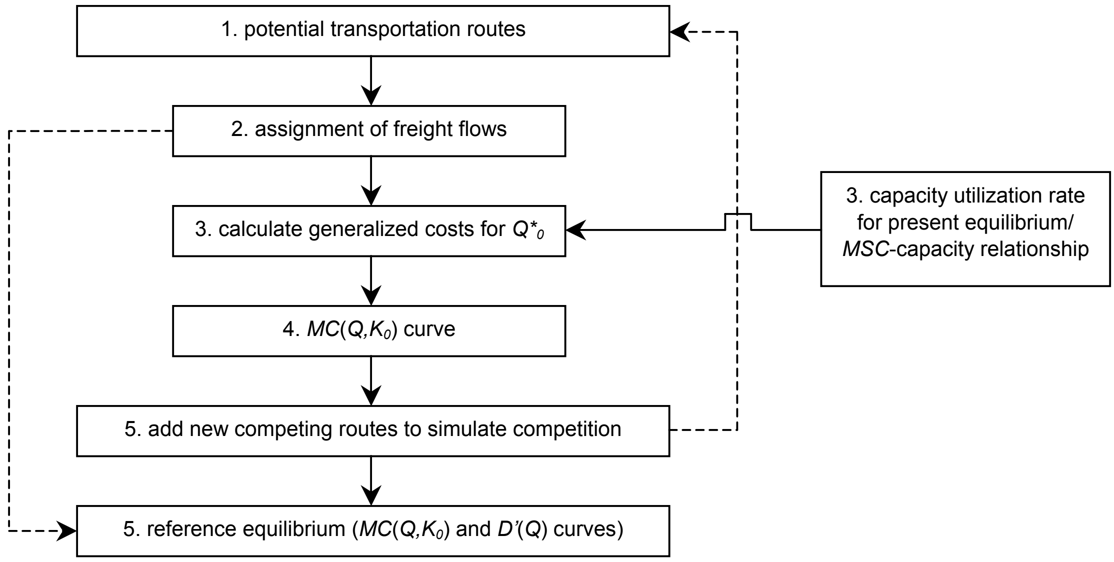

FIGURE 7.6 Procedure for determination of the reference equilibrium.

1) Establish a set of routes representing the most likely routes

Section 7.3.2 provides a description of the case being used for this application. To establish the present equilibrium, only the routes through the ports of Hamburg, Bremen, Rotterdam and Antwerp are used. These routes are based on shortest paths in terms of distances.

2) Implement the assignment of freight flows with a traffic assignment model

To implement the assignment of freight flows over the routes, the logit-assignment model as discussed in Chapter 5 has been used to determine Rotterdam's demand for its present equilibrium (Q^* = 1,071,794 TEU/year). This represents about 57% of the actual non-domestic container flows through Rotterdam in 1995 (estimation based on NHR, 2001, and Port of Rotterdam, 2004). In the present modeling approach, the total generalized costs associated with the routes are the main factor determining traffic assignment.

3) Calculate the generalized costs for equilibrium demand in the present equilibrium (Q*$_0$) using a given capacity utilization rate for the present equilibrium and a* MSC*-capacity relationship

Referring to an empirical study by Drewry Shipping Consultants (DSC, 1999), a capacity utilization rate of 70% is used as given capacity utilization rate for the Port of Rotterdam. The resulting present capacity (K_0), which can be calculated with present equilibrium demand and utilization rate (Q^* divided by 0.70), is then 1,531,135 TEU/year. In more detailed studies, the simulation would be the other way around: given the present capacity, equilibrium demand can be estimated from which the utilization rate follows.

In Chapter 5, a function for the marginal private cost (*MPC*) for ports has been discussed. This includes port dues, terminal charges, time cost and private congestion cost:

$$MPC = pd + tc + VOT \cdot t_{ff} \cdot \left(1 + 0.15 \cdot \left(\frac{Q}{K}\right)^4\right) \tag{7.1}$$

The marginal social cost (*MSC*) was expressed as the sum of marginal private cost and external congestion cost:

$$MSC = MPC + VOT \cdot t_{ff} \cdot 0.6 \cdot \left(\frac{Q}{K}\right)^4 \tag{7.2}$$

The parameter values for the Rotterdam situation are:

pd	:	port dues (€ 30/TEU)
tc	:	terminal charges (€ 130/TEU)
VOT	:	Value-Of-Time (€ 6.75/TEU/day; see Chapter 5)
t_{ff}	:	average 'ideal' service time without port congestion (5.34 days)

The 'ideal' service time, t_{ff}, consists of the average discharge time (0.24 days, assuming that an ocean vessel discharges one third of its total transport capacity[46], crane productivity is 30 moves/hour and about 3.5 gantry cranes serve one vessel) and the average dwell time (5.1 days).

Filling in the above values in Eq. 7.1 and Eq. 7.2 gives:

$$MPC = ASC = 194.44 + 5.14 \cdot \left(\frac{Q}{K}\right)^4 \tag{7.3}$$

and:

$$MSC = 194.44 + 5.14 \cdot \left(\frac{Q}{K}\right)^4 + 20.67 \cdot \left(\frac{Q}{K}\right)^4 \tag{7.4}$$

The resulting generalized (port-related) cost for Rotterdam, based on filling in equilibrium demand (Q^*) and capacity (K_0) in Eq. 7.4, is about € 200.87/TEU. This cost consists of port dues (€ 30/TEU), terminal charges (€ 130/TEU), time costs due to vessel discharge time and dwell time (= $VOT \cdot t_{ff}$ = € 34.44/TEU), private congestion cost (= $VOT \cdot t_{ff} \cdot 0.15 \cdot (Q/K)^4$ = €

[46] The vessel discharge time depends therefore on the vessel size: the larger the vessel, the more cargo it transports, thus the longer it takes to discharge the vessel.

1.24/TEU), and external congestion cost (= $VOT \cdot t_{ff} \cdot 0.6 \cdot (Q/K)^4$ = € 5.19/TEU). The sum of private and external congestion cost (i.e. the total congestion cost at the user level) is € 6.43/TEU.

4) Construct the marginal cost curve for the reference equilibrium

The marginal (social) cost curve (i.e. supply curve) for the reference equilibrium can now be constructed with help of Eq. 7.4 for varying throughputs (Q) and K_0 = 1,531,135 TEU/year.

5) Add new competing routes via Gioia Tauro to the set of routes to simulate route competition: repeat step 1) and 2) to obtain the local demand curve for the reference equilibrium

Repeating step 1) and step 2), taking into account the new route via Gioia Tauro, leads to the reference equilibrium for Rotterdam resulting from competition (Q^*_0 = 806,645 TEU/year). The port-related cost for this equilibrium, obtained by filling in K_0 and Q^*_0 in Eq. 7.4, is € 196.43/TEU. The expression for the demand curve $D'(Q)$, expressed in generalized cost and established from a set of traffic assignment simulations with varying Rotterdam port dues, is then:

$$D'(Q) = 1406.40 - 0.0015 \cdot Q \tag{7.5}$$

The port-related cost for Q^*_0 (€ 196.42/TEU) consists of port dues (€ 30/TEU), terminal charges (€ 130/TEU), time costs due to vessel discharge time and dwell time (= $VOT \cdot t_{ff}$ = € 34.44/TEU), private congestion cost (= $VOT \cdot t_{ff} \cdot 0.15 \cdot (Q/K)^4$ = € 0.40/TEU) and external congestion cost (= $VOT \cdot t_{ff} \cdot 0.6 \cdot (Q/K)^4$ = € 1.59/TEU). The total congestion cost at the user level (€ 1.99/TEU) is reduced with € 4.44/TEU compared to the present equilibrium and represents about 1% of the total port-related cost for Rotterdam (see further).

The total generalized costs of the routes through Rotterdam vary between € 762/TEU and € 2153/TEU. These costs depend on port-related costs, transportation distances, costs and speed, and commodity type (in terms of mass and value), and can be calculated with Eq. 5.6 in Chapter 5. The port-related cost varies then between 9% to 26% of the total generalized costs of the routes through Rotterdam. This indicates the potential of a competitive strategy aiming at reduction of the port-related cost.

The $MSC(Q,K_0)$ curve, which is here almost horizontally due to the relatively low level of congestion, and $D'(Q)$ curve[47] for the reference equilibrium are shown in Figure 7.7. This equilibrium serves as starting situation for the optimization to determine the new equilibrium resulting from port expansion.

[47] The (port-related cost) elasticity of port demand is relatively small: about -0.16. The (port-due) elasticity is even smaller: about -0.02 (based on the outcome of Appendix 7H). This highlights the question if port investment and tariff strategies are the most effective approaches to deal with competition. And the other way around: a relatively low price elasticity indicates that a port can increase its tariffs (e.g., with a congestion price) without substantial demand losses.

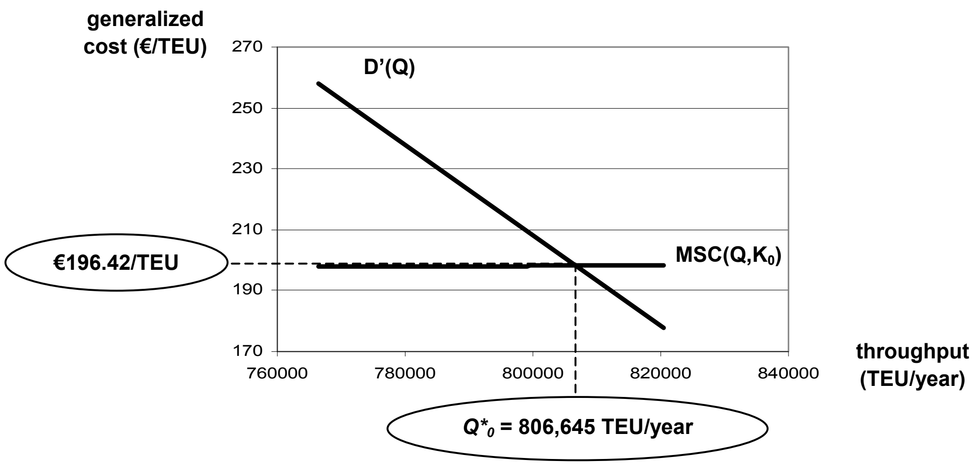

FIGURE 7.7 Supply-demand for the reference equilibrium.

It is assumed that Rotterdam's reference equilibrium demand grows further with 64,000 TEU/year (see Section 7.3.4). After 11 years (the investment recovery period; see further), reference equilibrium demand is then 1,510,645 TEU/year. The capacity utilization rate increases accordingly to about 99%, which indicates that measures to deal with peak demand are required for the reference development. Potential effects on market shares are not accounted for.

7.4.3 Determination of the Equilibrium resulting from Port Expansion

Determination of the optimal capacity to establish the new equilibrium for Rotterdam resulting from expansion of its surface area has been formulated as an optimization problem. The objective function for the port planner is represented by the increase of consumers' surplus due to adding a capacity increment[48] (in the year after the demand shift) by which the port becomes more attractive for freight carriers. The constraints include port-commercial and public interests comprising investment recovery and economic efficiency, respectively, and pre-financing and the ability to meet peak demand.

The approach in the selection of the optimal expansion strategy is tracing the response surface (in terms of increase of consumers' surplus) for a set of possible values for the decision variables, namely, alternative sets of proposed port capacity and investment recovery period $\{ K_j, T_j \}$. These are both endogenous variables in the modeling approach.

If $D'(Q)$ represents the demand curve, then the increase of consumers' surplus due to a reduction of the generalized cost per unit by port capacity expansion (from K_0 to K_j) can be represented by the shaded area in Figure 7.8. The increase of consumers' surplus can further be expressed as the present value of a future stream of annual benefits for the alternative sets of proposed port capacity and investment recovery period $\{ K_j, T_j \}$. With a view on the

[48] A phased implementation has not been studied in the present application but is an interesting alternative for adding a capacity increment. It would, for instance, lead to a different stream of costs and benefits in terms of magnitude and time-pattern.

analytic tractability of the modeling approach, the investment recovery period is here considered to be equal to the planning horizon (here 11 years).

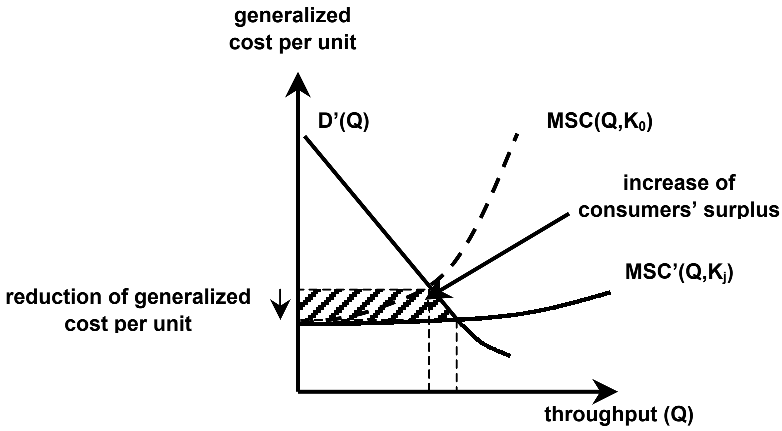

FIGURE 7.8 Increase of consumers' surplus due to capacity expansion.

For each proposed capacity K_j, the associated surface area expansion (x_j) has been determined by dividing the difference between proposed and present capacity ($K_j - K_0$) by the port productivity (24,000 TEU/ha/year, see Section 7.3.5). The resulting area expansion is used in the function $C(x) = ax_j^b$ to determine the investment cost. The investment cost, and thus the expansion size, is restricted by the maximum funds that can be borrowed for pre-financing (here: € 25 million; see Section 7.3.4). Because a sufficient expected return on investment would always lead to available funds, the maximum funds should in fact be a function of the expected financial return on investment instead of be restricted by a maximum fund[49]. The marginal investment cost, passed-on to the port users, should be equal to (or close to) the marginal benefit for the users (economic efficiency; a public interest).

For each set of proposed port capacity and investment recovery period, the sum of the annual revenues from congestion pricing has been determined. The period (in years) over which this sum is (at least) equal to the investment cost of the proposed port capacity is referred to as the investment recovery period for the particular proposed capacity.

During this period, average capacity utilization rate grows due to autonomous growth of port demand (here: 64,000 TEU/year; see Section 7.3.4). At the end of the investment recovery period, the proposed port capacity should still be able to meet peak demand. Therefore, the investment recovery period is restricted by a maximum allowed capacity utilization rate (90%; CPB, 2001a, referring to ECT, 2000).

[49] The sensitivity of the results for the magnitude of the maximum fund has been analyzed by varying it within a range of ±20% (i.e. ± € 5 million). The outcome was that the results of the application case are not sensitive for such a variation, which indicates that the pre-financing constraint does not determine the results of the application case.

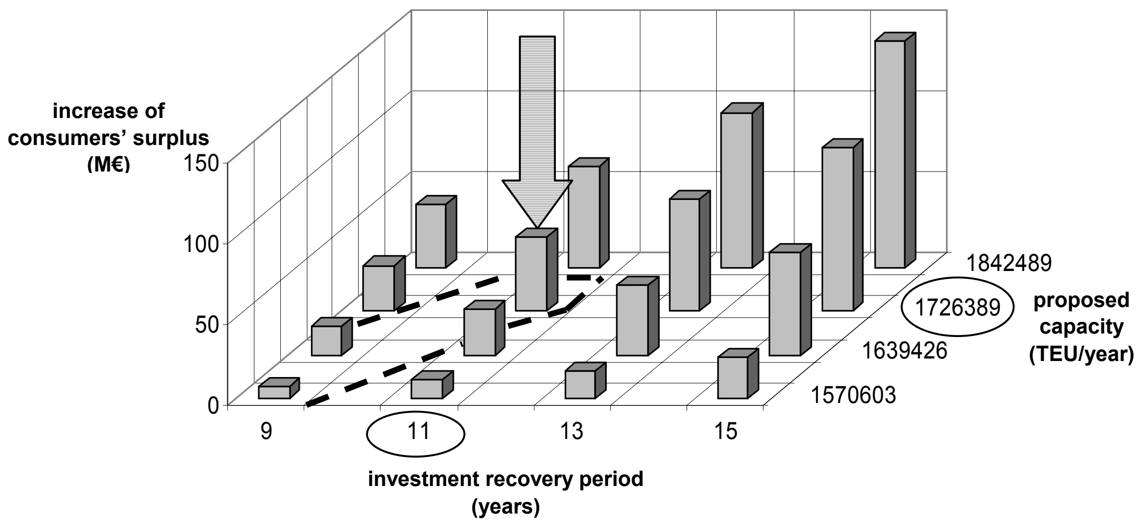

FIGURE 7.9 Response surface for the increase of consumers' surplus.

The response surface for the present (1995) value of the increase of consumers' surplus is presented in Figure 7.9 as a function of the variables proposed capacity and investment recovery period. It can be observed that an (unrestricted) increase of the proposed capacity as well as an increase of the investment recovery period would in this optimization lead to a further increase of the consumers' surplus. The reason is that a further increase of capacity leads to a further reduction of congestion costs and a further increase of the investment recovery period (here also equal to the planning horizon) leads to more future benefits.

The decision space is indicated by the dashed lines. For the optimal combination of proposed capacity K_j (1,726,389 TEU/year) and investment recovery period T_j (11 years), the present value of the sum of future economic benefits (increase of consumers' surplus) is € 45.69 million, which is indicated by the arrow in Figure 7.9.

The resulting optimal capacity expansion is 195,254 TEU/year (= $K_j - K_0$ = 1,726,389 – 1,531,135 TEU/year), representing an expansion size of about 7.9 hectares. This expansion strategy involves an investment cost of € 17.63 million and a financing cost of € 0.52 million. Rotterdam's equilibrium demand increases directly after the expansion strategy with 600 TEU/year (from 806,645 to 807,245 TEU/year).

Equilibrium demand at the end of the investment recovery period of 11 years, increased due to an assumed autonomous demand growth of 64,000 TEU/year, is about 1,5 million TEU/year; the capacity utilization rate is then 88% (the maximum allowed utilization rate was assumed to be 90%[50]).

[50] A maximum allowed utilization rate of 90%, based on figures from the ECT terminal in Rotterdam, is rather high. Particularly berth occupancy rates are generally considered to be bottlenecks in port capacity. Fourgeaud (2000) argues that if competition between ports exists (more in particular for liner shipping), the berth occupancy rate usually does not exceed 50-60%.

7.4.4 Sensitivity Analysis

The sensitivity of the optimal set of 'expansion size' and 'investment recovery period' has been analyzed with Monte Carlo simulation by varying the values of selected input parameters simultaneously 5,000 times within a range of ±10%. The selected input parameters are relevant with a view on the objective of this thesis (indicating autonomous growth of demand, economies of scale in investment cost and transportation technology) and the debate on Rotterdam port investments (indicating efficiency in the use of space and composition of trade flows; see Chapter 2).

The outcome of this simulation is presented in Table 7.1 and in the bar charts of Figure 7.10. It expresses the contributions of variances of input parameters (in percentages) to the total variance of the design variables 'expansion size' and 'investment recovery period'. The '+/-' expresses the direction of the causality; for instance, a higher scale factor leads to a decrease of the expansion size.

TABLE 7.1 Outcome of the sensitivity analysis (in % of total variance)

Input parameter	Indicates:	Influence on expansion size (%)	Influence on investment recovery period (%)
Scale factor 'b'	economies of scale in investment cost	-96.9	-50.9
Port productivity	efficiency in the use of space	+0.2	+6.8
Volumes of the O-D flows	composition of trade flows	2.6	42.0
Growth rate of the flows	autonomous growth of port demand	+0.2	-0.0
Ocean vessel size	transportation technology	+0.1	+0.3
Land vehicle size	transportation technology	+0.0	+0.0
Total		100.0	100.0

The influence of scale factor '*b*' indicates the influence of economies of scale in the investment cost. Given an expansion size, a higher scale factor leads to a higher investment cost and therefore to a longer period needed to recover the investment cost. In the present modeling approach, this period is however restricted because the increase of demand over time – and thus the total revenues from congestion pricing - is restricted by the maximum allowed capacity utilization rate. To balance the higher investment cost with the total revenues, a smaller expansion size is required. A smaller expansion size leads in turn to a higher congestion level and thus to more revenues from congestion pricing, which leads to a shorter investment recovery period. The described directions of the causalities support the observed directions of the causalities. The strong inter-relationship between investment cost and design variables supports the observation that the optimal solution is highly sensitive for the scale factor in comparison with the other varied input parameters.

The smaller expansion size and the shorter investment recovery period is in accordance with the result of the 'traditional' capacity expansion approach for an exponential investment cost function $C(x) = ax^b$, as discussed by Freidenfelds (1981, pp. 82-83; see Appendix 7G).

The port productivity indicates the efficiency in the use of space. A higher port productivity contributes in this optimization to a little increase of the expansion size. One would however expect a substantial and negative contribution, because the demand for space depends highly on the efficiency that can be reached in the use of space (e.g., Dekker *et al*., 2002). In the present modeling approach, a higher port productivity leads to a higher capacity and, given the throughput, to lower congestion costs and a lower congestion price. The latter requires a longer period to recover the investment. Because the investment recovery period is set equal to the planning horizon, a higher investment recovery period leads to more benefits that can be captured and, therefore, to a higher increase of the consumers' surplus by which the increase of the expansion size can be explained.

Changes in the volumes of the O-D flows considered in our application indicate changes in the composition of trade flows in terms of container-flow volumes. The direction of the causalities for the volumes of the O-D flows is not given because it differs per hinterland region considered. It can however be observed that varying volumes of the O-D flows contribute particularly to the variance of the investment recovery period due to its impact on port congestion and congestion price and, therefore, on the investment recovery period. It would further be expected that it contributes significantly to port capacity requirements (larger volumes means a larger expansion size to accommodate all flows); in this optimization, it accounts for only 2.6% of the total variance of the expansion size. Further research on the impact of changes in the composition of trade flows on port expansion strategies is indicated.

The growth rate of the flows indicates the autonomous growth of port demand. A relatively small influence of a higher growth rate of the flows on the expansion size is indicated. One would however expect a substantial contribution, because the demand for space highly depends on the expected growth of demand. The relatively low congestion costs in the reference equilibrium (see above) leads however to a relatively small increase of the congestion costs over time, which requires a relatively small increase of the expansion size to reduce additional congestion costs. The relatively small increase of the congestion costs leads also to a small increase of financial revenues from port congestion pricing and, therefore, to a small decrease of the investment recovery period. The direction of the causalities is in accordance with the Freidenfelds-result for the exponential investment cost function (see Appendix 7G).

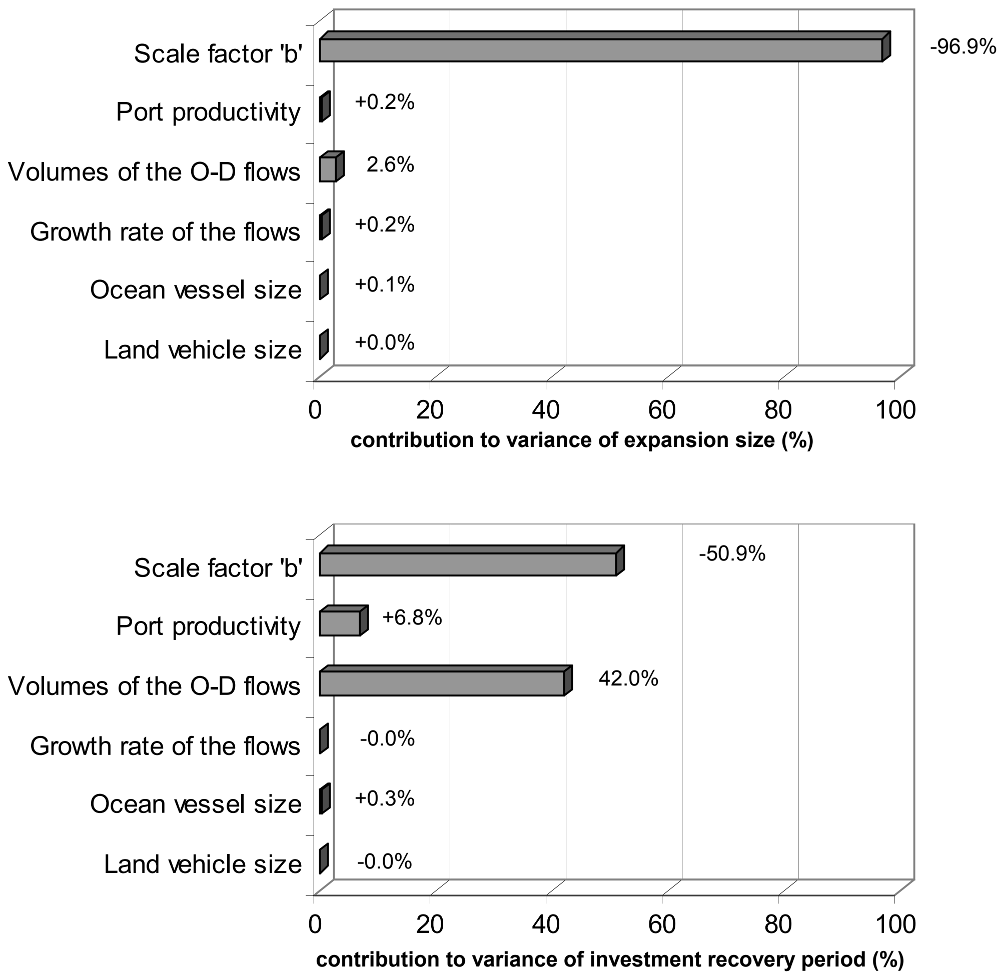

FIGURE 7.10 Bar charts representing the outcome of the sensitivity analysis.

Changes in vehicle sizes indicate the impact of transportation technology on the optimal solution due to changes in transportation costs. The results for the vehicle sizes indicate no or a relatively small influence of larger ocean vessels and land vehicles. The direction of the causality tends however towards an increase of the expansion size and the investment recovery period for larger ocean vessels. Larger ocean vessels contribute in this optimization to lower generalized transportation costs for the routes in the network. Apparently, this contributes positively to the attractiveness of the routes of which Rotterdam is part of in spite of the fact that the vessel discharge time increases. This tends towards a higher demand for Rotterdam resulting in larger expansion requirements and a longer investment recovery period.

More (detailed) research on the impact of larger vehicle sizes on port development is needed. Particularly interesting with a view on port competitiveness is the issue of increasing peak loads due to increasingly large vessels that have to be handled in the shortest possible time.

7.5 Implications for Port Planning

The above-exploration of the port expansion problem focused on determination of the optimal set of expansion size and investment recovery period for Rotterdam port in a strongly stylistic setting, because, for instance, the full dynamics of port competition and investments in access infrastructure and terminals have not been considered. It has nevertheless lead to some insights that fit into a wider scope for port planning. These insights are discussed below using the results for the different equilibriums as distinguished in the modeling approach.

7.5.1 Present Equilibrium

The assumed capacity utilization rate for Rotterdam (70%) indicates the presence of too much supply in the European port market. It is likely that the other North Sea ports also have over-capacity due to recent implemented expansions. This serves as a stimulus for serious competition between the ports to obtain sufficient market share in order to recover the associated investments. The assumption of equilibrium (supply-demand match) for Rotterdam in the present situation is therefore questionable from this point of view.

7.5.2 Reference Equilibrium

The addition of a new route via Gioia Tauro to the competition area results for Rotterdam in a loss of demand (reference equilibrium); Rotterdam's equilibrium demand decreases directly after the demand shift with 265,149 TEU/year to 806,645 TEU/year. The capacity utilization rate decreases accordingly to 53%.

Rotterdam looses demand due to redirection of a part of its container flows via Gioia Tauro. The assumption then is that container flows are not bounded to the port, for instance, by tradition or long-term agreements. To which degree this assumption is realistic, might be an interesting issue for further research. Furthermore, the assumption of equilibrium (supply-demand match) for Rotterdam port in the reference situation is questionable, because the lost demand for Rotterdam and the other North Sea ports serves as a stimulus for serious competition between these ports to obtain sufficient market share to recover previous investments.

As has already been mentioned in Chapter 1 of this thesis, port expansion aiming at demand increase by congestion reduction is not the only strategy available for dealing with competition. Alternative (less capital-intensive) strategies include:

- lower tariffs aiming at lower port dues and/or terminal charges;
- new (fast) cargo-handling facilities leading to lower vessel discharge times; and
- cooperation with other ports to develop competitive strategies together.

The decision to implement an expansion strategy for the Port of Rotterdam will only be made if it is considered to be the most effective strategy from the port-commercial perspective and also beneficial from the public perspective. This requires a comparison between costs and benefits of all potential strategies. With a view on the investment-scope of this thesis, only the expansion strategy has been discussed in more detail.

The (port-related cost) elasticity of Rotterdam port demand is relatively small: about -0.2. The (port-due) elasticity is even smaller: about -0.02 (based on the outcome of Appendix 7H). This highlights the question if port investment and tariff strategies are the most effective approaches to deal with competition. The other way around: a relatively low price elasticity indicates that a port can increase its tariffs (e.g., with a congestion price) without substantial demand losses.

7.5.3 Equilibrium resulting from Port Expansion

Port expansion is a common strategy to allow for demand growth. It is also an effective strategy to deal with competition - by reduction of congestion costs - if congestion is the dominant problem of Rotterdam's competitiveness in the reference situation. Particularly the relatively low proportion of the congestion costs in the reference equilibrium (1% of the port-related costs, see above) gives serious doubts to this dominance for the Rotterdam situation.

An expansion strategy would further lead to additional over-capacity in Rotterdam and competing ports. The combination of additional over-capacity and competition gives cause to price wars between ports. This spirals into collapsing port prices making investment recovery difficult to achieve. Additional over-capacity is also less desired from the European welfare perspective, because it indicates inefficient utilization of capital-intensive facilities in the European transportation system. From this point of view, a tariff strategy would be more obvious.

Dealing with port congestion requires extensive analyses of the cargo transfer process in order to trace the bottlenecks in a port's capacity (see Chapter 3). With a view on the availability of data, Rotterdam is here considered to be a point entity with an overall capacity. Extensive analyses of its bottlenecks are not provided in this chapter, but comprise an interesting issue for further study on port congestion.

The simulated reaction of Rotterdam comprises an optimum expansion size of 7.9 hectares representing a capacity expansion of 195,254 TEU/year. Rotterdam's equilibrium demand increases directly after the expansion strategy with 600 TEU/year to 807,245 TEU/year. This means that about 0.23% of the lost demand is recovered by the expansion strategy. This relatively small proportion supports the view that a congestion-reducing strategy is not the most obvious strategy to deal with competition for this situation. The capacity utilization rate directly after expansion is 47%.

The associated investment recovery period, here only based on the revenues from congestion pricing, is 11 years. Equilibrium demand at the end of this period, increased due to assumed market growth, is 1,517,077 TEU/year; the capacity utilization rate is then 88% (the maximum allowed utilization rate was assumed to be 90%). This expansion strategy involves an investment cost of € 17.63 million and a financing cost of € 0.52 million.

As has already been mentioned, the planning horizon is here considered to be equal to the investment recovery period. The lifetime of port investment projects is however much longer than 11 years. Blauwens (1996), for instance, argues that a lifetime of 30-50 years is a good approximation. However, future rounds of port expansion and reactions by competing ports, leading to new shifts of container flows within the planning horizon, complicate the estimation of future benefits.

A further distinction can be made between *technical* and *economic* lifetime. Technical lifetime expresses the lifetime, which is limited by physical and chemical processes such as corrosion and erosion. Economic lifetime expresses the lifetime, which is limited due to economic reasons such as strongly increasing maintenance costs. The technical lifetime of port facilities is usually longer than the economic lifetime.

It is obvious that other ports such as Antwerp will implement their own competitive strategies during Rotterdam's investment recovery period; the full dynamics of port competition should be accounted for. Furthermore, the assumption of equilibrium (supply-demand match) for Rotterdam is less likely due to potential network effects representing transport-efficiency gains due to the combined occurrence of economies of traffic density, product scope and network structure (see Chapter 4).

To address port-commercial and public issues of port investment, the financial and economic results of the supposed expansion strategy are presented in a number of overviews of costs and benefits. These overviews, with amounts in millions of euros in values of 1995, are discussed below. Furthermore, the issue of 'leakage' of port investment benefits to other countries is discussed.

TABLE 7.2 Costs and revenues from the *port-commercial* perspective (in M€)

Costs		Revenues	
Expansion cost	17.63	Congestion pricing	18.69
Financing cost	0.52	Port dues	pm
Maintenance cost	pm	Terminal charges	pm
Access infrastructure	pm		
Terminals	pm		
Total	18.15	Total	18.69

Table 7.2 gives an overview of costs and revenues from the *port-commercial* perspective. The costs comprise, in addition to the expansion cost, also the financing cost, because the Port of Rotterdam has to pay interest over the borrowed capital. The maintenance cost, which is neglected in this application (see Section 7.3.5), is usually also included in cost-benefit analysis for port investment (e.g., Blauwens, 1996).

The revenues comprise the sum of the annual financial revues (over 11 years) for the port. These revenues are based on congestion pricing (the congestion price increases over time due to assumed demand growth). The total financial revenues at the end of the investment recovery period are a little higher than the costs; the resulting financial return on investment after 11 years is 6 %.

With a view on the focus on port basic infrastructure, only the revenues from congestion pricing have been considered. A complete financial picture should however also include the revenues from port dues and terminal charges, which is important for further disentangling of public and private issues. The revenues from port dues are for the benefit of the port authority and can, for instance, be used to finance access infrastructure for the planned expansion. Terminal charges are for the benefit of (private) terminal operators. Expected returns on terminal investment are a decisive factor for terminal operators for their port selection.

The public role of ports requires a distinction between costs and benefits from the national-economic perspective, and from the international-economic perspective. The benefits comprise the welfare effects of port expansion.

TABLE 7.3 Costs and benefits from the *national-economic* perspective (in M€)

Costs			Benefits
Expansion cost	17.63	Increase of producers' surplus	13.57
Maintenance cost	pm	Less congestion in other Dutch ports	pm
Sea defense structures	pm	Increased congestion on hinterland connections	pm
		Efficiency gains for Dutch port users	pm
		Environmental effects for the nation	pm
		Indirect effects for the nation	pm
Total	17.63	Total	13.57

Table 7.3 gives an overview of costs and benefits from the *national-economic* perspective, which is interesting if the port expansion would be financed with national public funds. The increase of producers' surplus is equal to the present value of the stream of annual revenues from congestion pricing. The resulting present value of the net national-economic benefit is - € 4.06 million.

The costs comprise, in contrast to the overview from the port-commercial perspective, only the investment cost for port area expansion, because it is assumed that the capital is borrowed from the national capital market (see Section 7.3.4). This implies that the financing cost is at the same time a benefit for the nation and can therefore be neglected. Because it was assumed that the sea defense structures are funded by the national government (see Section 7.3.5), this investment cost, in addition to the maintenance cost, should also be included to get a complete picture of the costs for the government.

The benefits are the increase of the producers' surplus, which is equal to the present value of the stream of financial revenues. Normally, the benefits would also include the increase of the consumers' surplus for the Dutch users of the port (i.e. the containers to and from the Netherlands). The port users in this case study are assumed to comprise only non-domestic users. The increase of their consumers' surplus is therefore included in the overview of costs and benefits from the international-economic perspective (see further). This highlights the issue of 'leakage' of port investment benefits to other countries.

Such leakage supports the arguments of those opposing government subsidies for (large-scale) port investment projects, because the government should not invest for the benefit of other countries. This should however be traded off against efficiency gains for domestic users due to economies of scale (and scope) in port operation, which requires the presence of non-domestic users to obtain sufficiently large cargo volumes. These efficiency gains (represented by the shaded area in Figure 7.11) are obtained via a reduction of the port price due to economies of scale in port operation.

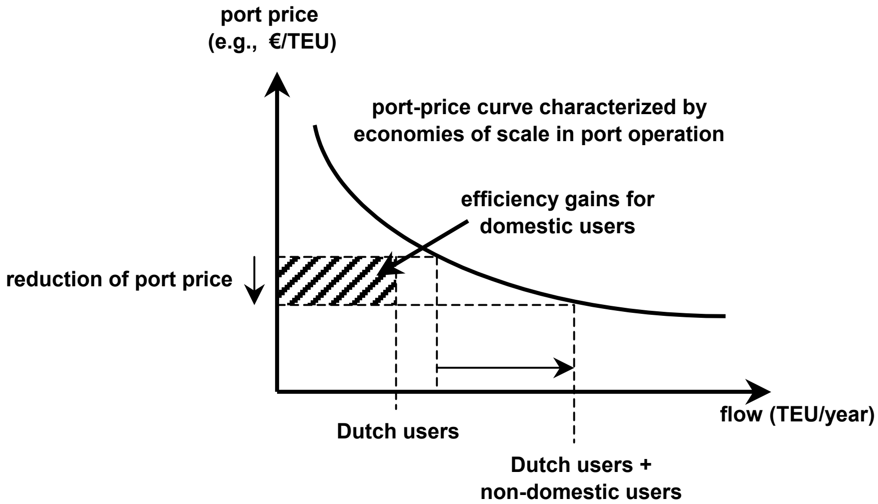

FIGURE 7.11 Efficiency gains for domestic users of the port.

A complete national-economic cost-benefit analysis should include (e.g., Blauwens, 1996): 1) costs due to investment in sea defense structures and maintenance, 2) benefits due to less congestion[51] (for Dutch users) in other Dutch ports (expansion of the Rotterdam port may also attract transport flows through other Dutch ports), 3) (negative) benefits due to congestion on the Dutch hinterland connections, 4) efficiency gains for port users due to economies of scale in port operation, 5) environmental effects, and 6) indirect effects in terms of value-added and employment.

Estimation of the environmental effects is most relevant, because container handling and transportation contribute negatively to a nation's environment (air pollution and noise). Because the container flows in this study only concern non-domestic container flows, the associated indirect effects comprise mainly value-added and employment for the Dutch transportation sector. Temporarily indirect effects include the investment effect in terms of value-added and employment for the construction sector and its supplying companies.

[51] The benefits for users of other ports due to less congestion may be temporarily, because demand in other ports will also grow due to autonomous growth of trade flows.

TABLE 7.4 Costs and benefits from the *international-economic* perspective (in M€)

Costs		Benefits	
Expansion cost	17.63	Increase of producers' surplus	13.57
Maintenance cost	pm	Increase of consumers' surplus	45.69
Sea defense structures	pm	Less congestion in other European ports	pm
		Increased congestion on hinterland connections	pm
		Efficiency gains for port users	pm
		Environmental effects	pm
		Indirect effects	pm
		Network effects	pm
Total	17.63	Total	59.26

Table 7.4 gives an overview of all costs and benefits from the *international-economic* perspective, which is interesting if the port expansion would be financed with international public funds. The resulting present value of the net international-economic benefit is € 41.63 million.

The costs comprise, like the overview of costs and benefits from the national-economic perspective, only the investment cost for port area expansion. Costs due to investments in access infrastructure and terminals are not included because they are paid for by the port authority and the terminals, respectively. The benefits comprise, in addition to the increase of the producers' surplus, also the increase of the consumers' surplus.

A more complete economic analysis from the international perspective should further include (e.g., Blauwens, 1996): 1) costs due to investment in sea defense structures and maintenance, 2) benefits due to less congestion in other European ports (expansion of the Rotterdam port attracts transport flows through other European ports), 3) (negative) benefits due to congestion on the hinterland connections, 4) environmental effects, 5) efficiency gains for port users, 6) efficiency gains in international transportation due to network effects, and 7) indirect effects.

7.6 Comparison with Other Studies

In order to obtain an indication on the optimal capacity utilization rate for the Port of Rotterdam in the reference situation, an example has been worked out based on the model as established by Mohring and Harwitz (see Appendix 7E). This model is meant to capture the self-financing of a capacity expansion (increment) in a simple setting; the aspect of autonomous demand growth is ignored and only congestion is taken into account. This resulted in an optimal capacity utilization rate of 52% and the associated optimal congestion price is about € 1.56/TEU. The results indicate further that port expansion, which deals with a relatively low level of congestion in the starting situation, leads to a rather small additional demand. This confirms the relevance of the question whether a port expansion strategy is the most obvious measure to deal with competition.

The influence of autonomous demand growth on the outcome of the modeling approach, as applied in this chapter, has been indicated by working out a scenario that is based on demand growth without competition (see Appendix 7F). The results of this exercise, taking the present equilibrium with no demand growth as reference situation, indicate that a substantial part of the expansion strategy to deal with autonomous demand growth and competition (about 96% of the total expansion size of 7.9 hectares) is based on only autonomous demand growth. This highlights (again) the question whether physical expansion is the most effective measure to deal also with competition.

The Freidenfelds-approach for determining the optimal phasing of an investment strategy - a non-integrated analysis ignoring congestion and competition - has been applied to the port expansion problem of this chapter (see Appendix 7G). The result was an optimal port expansion size of about 27.5 hectares and an optimal relief interval of 10.3 years. Particularly the expansion size differs from the result of the optimization as proposed in this thesis. This difference can be explained by the limited scope of the Freidenfelds-approach. First, it assumes the presence of an efficient utilization of existing capacity just before expansion, which leads to a larger physical expansion requirement. Second, it considers only expansion due to demand growth; the effect of competition and the associated feedback between price and market share is not accounted for.

As mentioned above, the Freidenfelds-approach is used to determine the *optimal phasing* of an expansion strategy. A most relevant inter-related issue is the *optimal timing* of implementing the first capacity increment. A first approximation has been found by setting the decrease - in time - of the discounted investment cost equal to the increase - in time - of the discounted flow of the increase of total congestion costs. This concept has been applied to the port expansion problem of this chapter (see Appendix 7G). Taking the reference equilibrium as starting situation, the solution indicates that if no (further) competition and only demand growth and congestion are taken into account, the planner should wait about 10 years before implementing a new capacity increment. Further research on incorporating competition and uncertainty, based on the theories of optimal control and real options, is indicated.

In the present study, a potential reaction of a single port on a change in the transportation network has been simulated. This approach ignores the full dynamics of port competition, which requires accounting for reactions of competing ports during the planning horizon. Furthermore, ports operate more pro-actively to prevent potential losses of market shares instead of reacting on developments. In order to address these issues, a scenario has been worked out for Rotterdam to obtain some indications on the decision space (see Appendix 7H). The results indicate also the potential of less capital-intensive strategies to deal with competition.

The profitability of port investments is a problem that has kept economists busy for a long time. The Rotterdam historian Van de Laar provided an overview of ex-post commercial evaluations of Rotterdam port investments during the period 1870-1940 (Van de Laar, 1999). One of his findings was that the Rotterdam Port Authority obtained a positive financial result based on an average financial return on investment requirement of 5.5%. This is not much different from the 6% after an investment recovery period of 11 years as found with the ex-ante approach in this thesis. The question if this financial result is typical for port investments in general may be an interesting topic for further research.

The Netherlands Bureau for Economic Policy Analysis has recently made an economic evaluation for the Maasvlakte 2 project (CPB, 2001a,b). An assessment of all welfare effects, including indirect effects for the nation, was part of this analysis. The effects were computed using a social discount rate of 4% and expressed in net present (2003) value with a planning horizon up to 2035. The total direct effects, representing the sum of producers' and consumers' surpluses, vary from 30 to 710 million euros depending on the economic scenario used. For container handling, the direct effects vary between 0 and 540 million euros, which accounts for non-domestic as well as for domestic and transshipment flows. The total expected indirect effects, including network effects, vary between 0 and 30 million euros.

The economic evaluation in the present application becomes more comparable to the above-mentioned economic evaluation for the Maasvlakte 2 project if more container flows, a longer planning horizon, environmental effects, indirect effects, and network effects are included in the application. Inclusion of indirect effects requires however detailed knowledge about *who* reveals these benefits in addition to the question *how* these benefits propagate through the economic system. If mainly foreign parties reap the benefits then the usefulness of expansion from a national-economic point of view can be questioned (see, e.g., Manshanden and Kuipers, 2003). This is particularly so for non-domestic and transshipment flows. From the national-economic perspective, these transport flows are expected to contribute negatively to the economy due to the associated environmental effects. This should however be traded off against efficiency gains due to economies of scale and scope in port operation, which requires the presence of non-domestic and transhipment flows.

7.7 Summary and Observations

To demonstrate the methodology as developed in this thesis, it has been applied to the Port of Rotterdam. The character of this application has been explorative: tracing the decision space for Rotterdam. The scenario of the entry of new competing routes via the Italian port Gioia Tauro was used to illustrate the impact of route competition. The emphasis was on the trade offs in investment planning rather than the choice of the most effective strategy to deal with competition.

It is demonstrated that 1) competition, 2) demand growth, 3) economies of scale, and 4) technological development can be incorporated in a modeling approach for planning of port capacity. The modeling approach as developed and applied in this thesis integrates further port pricing based on congestion pricing, which contributes to an economic-efficient utilization of port capacity (a public interest) and to investment recovery (a port-commercial interest) as well.

It can further be observed from the results that port investment in land reclamation can be self-financing. It should however be noted that the costs due to investment in sea defense structures and maintenance are not included in the self-financing principle as applied in this chapter. Furthermore, the effect of reactions by competing ports during the investment recovery period of Rotterdam is not accounted for. Inclusion of 1) all costs, and 2) the full dynamics of port competition is necessary to obtain a complete picture of the potential of self-financing of port investment in a competitive environment.

The outcome of the sensitivity analysis demonstrates that the results are highly sensitive for economies of scale in the investment cost. This highlights the need to account for economies of scale in planning of port capacity. In addition, more (detailed) research on the impact of larger vehicle sizes on port development, particularly of larger ocean vessels on port congestion, is indicated.

The results of the application indicate that port expansion contributes only to a partial recovery of a loss of demand due to competition. This is highly determined by the relatively low level of port congestion in the reference situation. A tariff strategy, for instance, would then be more obvious. On the other hand, port expansion allows also for future demand growth due to exogenous factors such as trade growth (which is however very uncertain).

The results of the economic evaluation in the application highlight the issue of ‘leakage’ of port investment benefits to other countries. Such leakage supports the arguments of those opposing government subsidies for (large-scale) port investment projects, because the government should not only invest for the benefit of other countries. This should however be traded off against efficiency gains for domestic users due to economies of scale and scope in port operation, which requires the presence of non-domestic users to obtain sufficiently large cargo volumes.

A more complete economic evaluation should further include: 1) benefits due to less congestion in other ports, 2) (negative) benefits due to congestion on the hinterland connections, 3) environmental effects, 4) efficiency gains for port users due to economies of scale and scope in port operation, 5) efficiency gains in international transportation due to network effects, and 6) indirect effects. This is confirmed by a comparison with the recent economic evaluation of the Maasvlakte 2 project by The Netherlands Bureau for Economic Policy Analysis.

Appendix 7A Container Imports and Exports per Region in 1995

Region Stuttgart:

Commodity group	Import (TEU/year)	Export (TEU/year)	Mass (ton/TEU)	Value (euro/TEU)
Consumer food	9988	221	14.55	22,292
Conditioned food	5876	1053	14.55	22,292
Cement/manufactured building materials	4597	0	14.65	765
Small machinery	5933	6928	10.85	198,508
Miscellaneous manufactures	49346	31007	7.37	22,979

Region Munich:

Commodity group	Import (TEU/year)	Export (TEU/year)	Mass (ton/TEU)	Value (euro/TEU)
Consumer food	9,260	308	14.55	22,292
Conditioned food	4,561	1,390	14.55	22,292
Cement/manufactured building materials	3,525	0	14.65	765
Small machinery	4,135	6,140	10.85	198,508
Miscellaneous manufactures	36,559	22,826	7.37	22,979

Region Basel:

Commodity group	Import (TEU/year)	Export (TEU/year)	Mass (ton/TEU)	Value (euro/TEU)
Consumer food	121,271	115,789	14.55	22,292
Conditioned food	99,577	96,925	14.55	22,292
Cement/manufactured building materials	455,098	460,102	14.65	765
Small machinery	14,007	14,089	10.85	198,508
Miscellaneous manufactures	836,794	820,854	7.37	22,979

Region Milan:

Commodity group	Import (TEU/year)	Export (TEU/year)	Mass (ton/TEU)	Value (euro/TEU)
Consumer food	106,185	100,256	14.55	22,292
Conditioned food	87,736	81,810	14.55	22,292
Cement/manufactured building materials	523,570	529,559	14.65	765
Small machinery	6,295	13,131	10.85	198,508
Miscellaneous manufactures	314,719	334,323	7.37	22,979

Values (euro/ton) in monetary values of 1997.

Appendix 7B Port Service Characteristics

Characteristic	Bremen	Hamburg	Rotterdam	Antwerp	La Spezia	Gioia Tauro
Port dues (€/TEU)	42	42	30	29	50	37
Terminal charges (€/TEU)	179	179	130	125	200	156
Port dues (€/TEU)	42	42	30	29	50	37
Crane productivity (moves/hour)	23	23	30	33	21	21
Cranes per vessel	3	3	3.5	4	3	3
Import dwell vessel to truck (days)	6.4	6.4	6.4	6.4	7.4	7.4
Export dwell truck to vessel (days)	4.6	4.6	4.6	4.6	5.6	5.6
Import dwell vessel to train (days)	6.5	6.5	6.5	6.5	7.5	7.5
Export dwell train to vessel (days)	4.7	4.7	4.7	4.7	5.7	5.7
Import dwell vessel to barge (days)	4.1	4.1	4.1	4.1	5.1	5.1
Export dwell barge to vessel (days)	4.3	4.3	4.3	4.3	5.3	5.3
Transshipment dwell (days)	-	-	-	-	-	5.3

Terminal charges and port dues based on estimations for a 5000 TEU vessel and expressed in monetary values of 2003.

Appendix 7C Distances by Mode

Maritime distances (in km):

	Bremen	Hamburg	Rotterdam	Antwerp	La Spezia
Gioia Tauro	3788	3865	3520	3512	426

Truck distances (in km):

	Duisburg	Mannheim	Stuttgart	Munich	Basel	Milan
Duisburg	-	290	400	600	520	860
Mannheim	290	-	117	328	257	570
Bremen	260	476	587	750	722	1043
Hamburg	373	557	648	713	803	1096
Rotterdam	200	464	582	791	650	978
Antwerp	175	414	532	742	566	894
La Spezia	-	-	698	600	551	224
Gioia Tauro	-	-	1657	1492	1511	1183

Train distances (in km):

	Duisburg	Mannheim	Stuttgart	Munich	Basel	Milan
Duisburg	-	318	448	690	573	974
Mannheim	318	-	130	372	255	656
Bremen	282	541	697	727	807	1011
Hamburg	400	607	753	783	863	1067
Rotterdam	217	518	648	890	773	1191
Antwerp	290	523	653	895	778	1264
La Spezia	1218	900	770	528	645	244
Gioia Tauro	2267	1949	1819	1577	1694	1293

Barge distances (in km):

	Duisburg	Mannheim	Stuttgart	Munich	Basel	Milan
Duisburg	-	345	545	-	562	-
Mannheim	345	0	200	-	217	-
Bremen	365	710	910	-	955	-
Hamburg	520	865	1065	-	1057	-
Rotterdam	200	545	745	-	762	-
Antwerp	373	718	918	-	852	-
La Spezia	-	-	-	-	-	-
Gioia Tauro	-	-	-	-	-	-

Appendix 7D Transportation Parameters

	Size (TEU)	Average speed (km/h)	Transportation cost (€/ton*km)
Ocean vessel	5000	45.4	0.0093
Short sea vessel	500	45.4	0.01
Truck	2	50.0	0.08
Train	90	17.0	0.03
Barge	200	14.0	0.02

Transportation costs in monetary values of 2003.

Appendix 7E Mohring-Harwitz Approach applied to Port Expansion

In order to obtain an indication on the optimal capacity utilization rate for the Port of Rotterdam in the reference situation, an example has been worked out based on the model as established by Mohring and Harwitz (1962). They showed that under certain conditions the revenues from congestion pricing are sufficient for financing expansion works, provided that the welfare surplus is maximized. This model is meant to capture the self-financing of an capacity expansion (increment) in a simple setting; the aspect of autonomous demand growth is ignored and only congestion is taken into account. The remainder of this appendix gives a brief summary of the most important results.

The reference equilibrium for Rotterdam is taken as starting situation. The demand curve *D'*(Q) is supposed to be linear and is represented by:

$$D'(Q) = d_i - d_s \cdot Q \qquad \text{(E.1)}$$

in which d_i (= 1406.40) is the intercept and d_s (= 0.0015) is the slope.

The marginal private cost curve $MPC(Q,K_e)$ is equal to the average social cost curve $ASC(Q,K_e)$ and is represented by:

$$MPC(Q,K_e) = ASC(Q,K_e) = 194.44 + 5.14 \cdot \left(\frac{Q}{K_0 + K_e} \right)^4 \qquad \text{(E.2)}$$

in which K_0 is the capacity in the starting situation and K_e is the capacity expansion.

The marginal social cost curve $MSC(Q,K_e)$ is represented by

$$MSC(Q,K_e) = 194.44 + 25.81 \cdot \left(\frac{Q}{K_0 + K_e} \right)^4 \qquad \text{(E.3)}$$

It is further assumed that the investment cost of additional units of capacity follows an exponential function, specified by $C(K_e) = 3{,}125{,}000 \cdot \left(\frac{K_e}{P} \right)^{0.829}$ (in euros) in which P is the port productivity (24,000 TEU/ha/year). This function represents the present value of providing K_e units of capacity (in TEU/year).

For the reference equilibrium, the traffic assignment resulted in an equilibrium demand of 806,645 TEU/year. The capacity for the reference equilibrium (K_0) is assumed to be 1,531,135 TEU/year; the resulting capacity utilization rate is 53%.

To determine the optimal capacity utilization rate (after expansion), the optimal combination of port usage Q and capacity expansion K_e needs to be found. This forms a bi-variate optimization problem. The objective function, the welfare surplus $W(Q,K_e)$, is composed of three welfare components, namely, 1) total benefit of port usage, 2) total social cost of port usage, and 3) the investment cost, and can be written as:

$$\max_{Q,K_e} W(Q,K_e) = \int_0^Q D'(q)dq - Q \cdot ASC(Q,K_e) - C(K_e) \qquad \text{(E.4)}$$

The first order conditions for an optimum are:

$$\frac{\partial W(Q,K_e)}{\partial Q} = 0 \rightarrow D'(Q) - Q \cdot \frac{\partial ASC}{\partial Q} - ASC = 0 \qquad \text{(E.5)}$$

$$\frac{\partial W(Q,K_e)}{\partial K_e} = 0 \rightarrow -Q \cdot \frac{\partial ASC}{\partial K_e} - \frac{\partial C}{\partial K_e} = 0 \qquad \text{(E.6)}$$

In words this means: the optimum is reached when a marginal change in Q and K_e does not change the welfare surplus.

Additional port users will participate up to the point where the marginal social cost $MSC(Q,K_e)$ for the users is equal to the marginal benefit $D'(Q)$ for the users. This can be expressed by:

$$D'(Q) - MSC(Q,K_e) = 0 \qquad \text{(E.7)}$$

The above-described optimization problem has been implemented and solved with an add-in to carry out mathematical optimization[52]. The optimal solution comprises a port usage Q of 806,675 TEU/year and an (relatively small) expansion size K_e of 8,009 TEU/year, which represents a surface area expansion of about 0.33 hectares. The associated investment cost is € 1.25 million. This is a little lower than the financial revenues from congestion pricing (= € 1.26 million). The optimal capacity utilization rate is then 52% and the associated optimal congestion price is about € 1.56/TEU.

The results indicate that port expansion that deals with a relatively low level of congestion in the starting situation – here expressed by a capacity utilization rate of 53% - leads to a rather small additional demand. This confirms the relevance of the question whether a port expansion strategy would be the most obvious measure to deal with competition.

[52] To improve analytic tractability, equation E.6 has been formulated as ‘<= 0’ instead of ‘= 0’ and an investment recovery constraint (‘investment cost <= total revenues from congestion pricing’) has been added.

Appendix 7F Modeling Approach without Competition

In order to obtain an indication on the influence of autonomous demand growth on the outcome of the modeling approach as developed in this thesis, a scenario has been worked out that is based on demand growth without competition. It considers a demand growth for the new equilibrium of 64,000 TEU/year.

The present (1995) equilibrium for Rotterdam is taken as reference situation. For this situation, equilibrium demand is 1,071,794 TEU/year and is assumed to remain constant (no growth). The reference capacity (K_0) is 1,531,135 TEU/year. The resulting capacity utilization rate is 70%.

Application of the modeling approach results for this scenario in an optimum expansion size of 7.6 hectares representing a capacity expansion of 189,876 TEU/year. Rotterdam's equilibrium demand increases directly after the expansion strategy with 2,100 TEU/year to 1,073,894 TEU/year. The capacity utilization rate directly after expansion is 62%.

The associated investment recovery period is 7 years. Equilibrium demand at the end of this period, increased due to the demand growth, is 1,521,894 TEU/year; the capacity utilization rate is then 88% (the maximum allowed utilization rate was assumed to be 90%). This expansion strategy involves an investment cost of € 16.79 million and a financing cost of € 0.43 million. The total financial revenues are € 19.19 million; the resulting return on investment is about 14%.

The results of the above-exercise indicate that a substantial part of the expansion strategy to deal with autonomous demand growth and competition (about 96% of the total expansion size of 7.9 hectares) is based on only autonomous demand growth. This highlights (again) the question whether physical expansion is the most effective measure to deal also with competition.

Appendix 7G Freidenfelds-Approach applied to Port Expansion

In the simplest engineering approach for dealing with expansion problems, it is assumed that demand for additional units of capacity will grow linearly at rate g over an unbounded horizon; the aspects of competition and congestion are ignored. Starting from time $t = 0$, $g\tau$ additional units will be required at time τ (i.e. the relief interval) in the future. Figure G.1 illustrates the demand and expansion pattern[53].

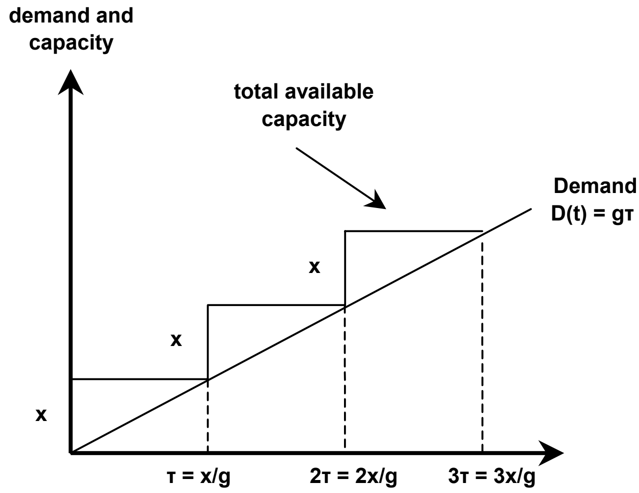

FIGURE G.1 Capacity expansions to meet growing demand (adapted from Freidenfelds, 1981).

It is further assumed that the investment cost of additional units comprises an exponential function, specified by $C(x) = ax^b$ with $0<b<1$. This function represents the present value of providing x units of capacity forever.

This model is meant to capture some important phenomena in capacity expansion problems in the simplest possible setting. For example, the interaction between demand and expansion strategy is not accounted for. A thorough discussion for the exponential investment cost function can be found in Freidenfelds (1981, pp. 82-83). The remainder of this appendix gives a brief summary of the most important results.

The present value W of an infinite stream of investments in expansion can be represented as:

$$W = \frac{ax^b}{1 - e^{-r(x/g)}} \tag{G.1}$$

in which r represents the social discount rate.

[53] In Figure G.1, capacity is expanded if demand is equal to capacity. Meersman *et al*. (1997) observed however for the port of Antwerp that capacity was expanded *before* demand was equal to capacity. This corresponded to a maximum observed capacity utilization rate (for the container terminals) of about 72 to 86%.

In terms of the relief interval $\tau = x/g$ the present value can be represented as:

$$W = \frac{ag^b \tau^b}{1 - e^{-r\tau}} \tag{G.2}$$

The number of parameters can be reduced by looking at *W/a*, $r\tau$, and *g/r*:

$$W / a = \frac{(g / r)^b \cdot (r\tau)^b}{1 - e^{-r\tau}} \tag{G.3}$$

A necessary and sufficient condition for the optimal relief interval can be found by setting the derivative of Eq. G.3 to 0, which yields:

$$\frac{e^{r\tau} - 1}{r\tau} = \frac{1}{b} \tag{G.4}$$

Using a Taylor series approximation for $e^{r\tau}$, the optimal relief interval τ^* is approximated by:

$$\tau^* \approx \left(\frac{2}{r}\right) \cdot \left(\frac{1}{b} - 1\right) \tag{G.5}$$

It can be observed that the optimal relief interval is independent of the growth rate *g*. Furthermore, an increase of the scale factor *b* leads to a decrease of the optimal relief interval.

The above approach is illustrated with an application to the port expansion problem, as described in Chapter 7 of this thesis.

Suppose that demand grows at g = 64,000 TEU/year, and the investment cost of capacity expansion is given by $C(x) = 3.125x^{0.829}$, where x is the number of TEU's and C is expressed in millions of euros. The social discount rate r is 0.04.

From Eq. F.5 follows that the optimal relief interval is $\tau^* = 10.3$ years, thus the optimal size $x^* = g\tau^* = 659{,}200$ TEU. Because a port productivity of 24,000 TEU/ha/year is assumed, this corresponds to a port area expansion of about 27.5 hectares. The associated investment cost is € 48.8 million.

The above-approach can be used to determine the *optimal phasing* of an expansion strategy. A most relevant inter-related issue is the *optimal timing* of implementing the first capacity increment. A first approximation can be found by setting the decrease - in time - of the discounted investment cost[54] equal to the increase - in time - of the discounted flow of the increase of total congestion costs due to delaying the investment.

[54] The present value of the investment cost decreases in time by shifting the investment further into the future.

This concept has been applied to the port expansion strategy as determined above. The reference equilibrium of Chapter 7 is taken as starting situation. Figure G.2 presents the result in function of time (in years) after the entry of the new route via Gioia Tauro; the optimal timing is indicated at 10 years.

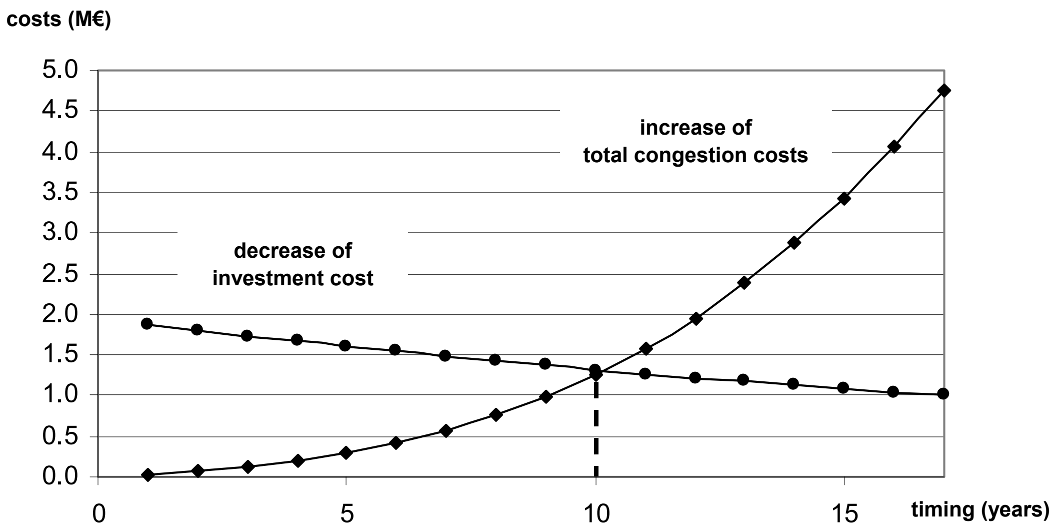

FIGURE G.2 Optimal timing of capacity expansion incorporating demand growth and congestion.

The solution indicates that if no further competition and only demand growth and congestion are taken into account, the planner should wait about 10 years before implementing a new capacity increment. The size of the increment (27.5 hectares) has been determined with Freidenfelds (see above). The capacity utilization rate just before the optimal timing is 94%.

A further extension can be made if the dynamics of competition is also incorporated in the problem of determining the optimal timing of port expansion strategies. The state variables 'demand growth' and 'market share' interact then with the control variable 'timing' (in addition to 'expansion size' and 'relief interval'). The theory of optimal control can then be helpful in finding the optimal expansion strategy. The basics of this theory can be found in various textbooks such as Seierstad and Sydsaeter (1987).

Major characteristics of port investment decisions are their irreversibility and the ongoing uncertainty of the (economic) environment in which those decisions are made. For example, future demand growth and reactions of competing ports are difficult to predict. The theory of real options incorporates these characteristics by recognizing the option value of delaying an investment. For the port expansion problem, this option value can be based on the decrease – in time – of the discounted investment cost (see above), and the lost market share (shifted to competing ports) and associated lost benefits due to increasing congestion costs. The theory of real options is thoroughly discussed in Dixit and Pindyck (1994).

Appendix 7H Dynamics of Port Competition - Indications on the Decision Space for Rotterdam

In order to obtain some indications on the decision space for the Port of Rotterdam, a scenario is worked out to demonstrate the dynamics of port competition. It considers the competition between the North Sea ports Hamburg and Bremen in North-Germany, Rotterdam in the Netherlands and Antwerp in Belgium on the competition area as defined in Section 7.2 of this thesis.

The present (1995) equilibrium for Rotterdam is taken as starting situation. For this situation, the traffic assignment resulted in an equilibrium demand of 1,071,794 TEU/year. The capacity is assumed to remain constant at a value of 1,531,135 TEU/year. For the starting situation, this results in a capacity utilization rate of 70%.

To increase its market share pro-actively, Rotterdam decides to implement a tariff strategy. A comparison of port tariffs (i.e. the sum of port dues and terminal charges) makes clear that only Antwerp has a lower tariff than Rotterdam (€ 154/TEU versus € 160/TEU, see Appendix 7B). Therefore, Rotterdam decreases its tariff with € 20/TEU to become the cheapest port - in terms of out-of-pocket cost - in the network. The resulting equilibrium demand for Rotterdam is then 1,089,059 TEU/year (utilization rate = 71.1%), which means an increase of its market share with 17,265 TEU/year.

Because Antwerp doesn't want to stay behind, this port decreases its tariff too with € 20/TEU. This affects Rotterdam's market share with a decrease (of 4,239 TEU/year) to 1,084,820 TEU/year (utilization rate = 70,9%).

From the overview in Appendix 7B follows that the ports of Hamburg and Bremen are much more expensive than the ports of Rotterdam and Antwerp. Therefore, Hamburg and Bremen decide to decrease their tariffs with €50/TEU. Rotterdam's market share is then 1,065,797 TEU/year (utilization rate = 69,6%), which means an additional decrease of 19,023 TEU/year.

What should be the next competitive strategy for Rotterdam? A further decrease of its tariff would probably not be wise with a view on recovery of previous investments. An alternative could be a decrease of its dwell times, for instance, by making terminal logistics more efficient. A decrease of 2 day results for Rotterdam in a market share of 1,077,448 TEU/year (utilization rate = 70,4%), which comprises an increase of 11,651 TEU/year.

The above scenario demonstrates the dynamics of port competition. It addresses also the development of a pro-active strategy by Rotterdam and its triggering effect on decisions of other ports. The results indicate further the potential of other (less capital-intensive) competitive strategies.

IV. Findings

8. Reflections and Recommendations

This chapter, which reflects on the main findings of this thesis and gives some recommendations, is divided into four sections. Section 8.1 gives a brief summary of the findings this thesis. Section 8.2 elaborates on the findings and offers observations and conclusions. Section 8.3 comments on the limitations of this study. Section 8.4 discusses five specific recommendations for further improvement of the methodology as developed in this study.

8.1 Brief Summary of the Study

Substantial investments are being made in the Port of Rotterdam. Examples are the construction of a rail connection between the Port of Rotterdam and Germany - the Betuwe line project - and the second seaward expansion of the Port of Rotterdam - the Maasvlakte 2 project. These investments essentially aim at enhancing the competitive position of the port in international transportation networks.

Experiences with increasing costs, uncertain demands and benefits, and the argument that port operation is in fact a commercial activity intensified the debate on the usefulness and necessity of government contributions to Rotterdam port investments. An interesting question is then if port investment (more in particular investment in port expansion) can be self-financing.

The overall objective of this study has been to support strategic planning of a node in a (transportation) service network, which is characterized by competition. The present thesis contributed to this objective by the development of a methodology for planning of port capacity in which modeling of the system and (pragmatic) application of economic concepts are major components. The challenge was to integrate port-commercial and public interests in such methodology, and to incorporate competition, autonomous growth of demand, economies of scale and technological development.

The focus of this study has been the reaction of a particular port on a change in the transportation network. A scenario for such disturbance is the entry of new routes via a competing port. This leads to decreased demands and benefits for the particular port and the nation in which the port is located. Potential reactions of the port on such change include investment in port expansion and improvement of hinterland connections. The reaction that has been worked out in this study is expansion of the port's surface area, which allows also for autonomous growth of port demand due to, for instance, economic growth.

Although there are various interesting questions that might arise while considering the proposed focus from legal, economic and technological viewpoints, this study addressed in particular the following two research questions:

1) What is the optimal expansion strategy for a single port to deal with route competition and to facilitate further growth of the port's demand?
2) Can the expansion strategy be self-financing?

The present study addressed also the issue of 'leakage' of port investment benefits to other countries and related this with economies of scale and scope in port operation.

The methodology as developed in this study is based on competition analysis in a partial equilibrium model. This modeling approach - building on partial approaches for network design, capacity expansion, transportation modeling, investment financing and congestion-based design - addresses the simultaneous solution of determining the optimal set of 1) proposed capacity, and 2) investment recovery period. This efficiency problem has been treated as an optimization problem, which was decomposed in two parts. The first main part, optimization of the port expansion size, is followed by the part that accounts for improvement of the hinterland connections. An approach has been used to trace the response surface (increase of consumers' surplus) in order to identify the optimal set among a large number of alternative sets.

Further elaboration of the methodology for planning of port capacity has been focused on 1) modeling port demand and supply, and 2) incorporating developments in container transportation technology.

Ports constitute nodes in transportation networks connecting origins and destinations for freight flows. Determination of port demand has therefore essentially been based on competition between transportation routes. This involved simulation of port demand with a traffic assignment model. Port supply has been schematized with a marginal cost curve that is often used for research on passenger transport. The assumption was that a curve with similar characteristics can be used to simulate port congestion.

A particularly important development in container transportation technology is the trend of increasing mode sizes. This leads to transportation cost reductions due to economies of scale. This has been incorporated in the methodology for planning of port capacity by inclusion of relationships between mode sizes and transportation costs in the traffic assignment model.

To demonstrate the methodology, an application has been carried out to the Port of Rotterdam in the Netherlands. This study focused on a hypothetical port expansion for non-domestic container flows by means of expansion of the port surface area by land reclamation. It was assumed that only the port's surface area is relevant for capacity expansion; the capacities of the hinterland connections were assumed to automatically follow port capacity.

The character of this application was explorative: tracing the decision space for the Port of Rotterdam. The scenario of the entry of new competing routes via the Italian port Gioia Tauro was used to illustrate the impact of route competition. The emphasis was on the trade offs in a port's investment planning rather than the choice of the most effective strategy to deal with competition.

8.2 Observations and Conclusions

The development of a methodology for planning of port capacity, the focus on port expansion and the application to the Port of Rotterdam have led to the following observations and conclusions:

1) The methodology is based on an assumed match between supply of port capacity, characterized by economies of scale, and demand for port services, which is obtained in competition between alternative routes and characterized by further growth.
2) Physical expansion of port capacity leads to a reduction of port-congestion costs. This makes a port more attractive for freight flows, which can be used to recover a loss of demand to some extent.
3) The response surface for the increase of consumers' surplus has been established in function of proposed capacity and investment recovery period. Tracing this response surface in a spreadsheet, based on maximizing the increase of consumers' surplus, appears to be an appropriate approach to identify the optimum set of proposed capacity and investment recovery period, and to establish sensitivity analysis.
4) It can be observed from the results of the application that port expansion by land reclamation can be self-financing. It should however be noted that the costs due to investment in sea defense structures and maintenance are not included in the self-financing principle as applied to Rotterdam. Furthermore, the effect of reactions by competing ports during the investment recovery period of Rotterdam is not accounted for.
5) The outcome of sensitivity analysis indicates that the optimum set of proposed capacity and investment recovery period is highly sensitive for economies of scale in the investment cost. This highlights the need to account for economies of scale in planning of port capacity.
6) Developments in container transportation technology are widely considered to be critical for port development, particularly with a view on port competitiveness. This study contributed to incorporating developments in container transportation technology by inclusion of relationships between mode sizes and transportation costs to express economies of scale in container transportation. Inclusion of the effects of alternative fuels and horizontal and vertical integration of container transportation activities on transportation costs should further improve the approach.
7) In the application to Rotterdam port, there was almost no congestion in the reference situation; this highlights the question if port expansion is then the most obvious strategy to deal with a loss of demand. A tariff strategy, for instance, would then be more obvious. This should be traded off against the potential of port expansion to facilitate future demand growth due to exogenous factors such as trade growth (which is however very uncertain).
8) The port users in the application case comprise only non-domestic users. The increase of their consumers' surplus is for the benefit of other countries instead of the Netherlands. This highlights the issue of 'leakage' of port investment benefits to other countries. It supports the arguments of those opposing government subsidies for (large-scale) port

investment projects, because the government should not invest for the benefit of other countries. This should however be traded off against efficiency gains for domestic users due to economies of scale (and scope) in port operation, which requires the presence of non-domestic users to obtain sufficiently large cargo volumes.

8.3 Limitations of this Study

Considerations of feasibility, analytic tractability, availability of data and specific issues in the Port of Rotterdam have led to a number of limitations in the focus and content of this study. Major limitations are:

- Due to limitations of available data, this study has been focused on strategic design rather than tactical and operational design.
- This study has considered a port as a point entity with an overall capacity instead of as a set of inter-dependent stages or links, which need to be optimally tuned to each other.
- It has been assumed that a port operates as an organizational entity instead of as a combination of public institutions and private firms, which need to cooperate optimally to support a quick implementation of competition strategies.
- A planning methodology that integrates port-commercial and public interests has been developed, but some public interests (increase of value added and employment, reduction of social costs and the equity issue) have not been considered in the application. Furthermore, elaboration of the various interests within a port is necessary for further disentangling of public and private issues.
- The focus has been the reaction of a single port on a change in the transportation network. The full dynamics of port competition due to, for instance, reactions of competing ports during the investment recovery period of the particular port, has not been captured by the methodology.
- Incorporating economies of scale in planning of port capacity has been focused on economies of scale in investment cost; economies of scale and scope in port operation have not been worked out in the application.
- Only expansion of a port's surface area has been considered to deal with port competition. Other (less capital-intensive) strategies that can improve port competitiveness have not been considered.
- Improvement of hinterland connections has been addressed at the conceptual level, but not further elaborated in the application.
- Application of the planning methodology has been focused on non-domestic container flows associated with a part of the European hinterland of Rotterdam port. More cargo flows and a larger hinterland have not been studied.
- The character of the application was to illustrate trade offs in a port's investment planning. Extensive model calibration has therefore not been established.

A number of topics, which are discussed below, are recommended for further study to address some of these limitations.

8.4 Recommendations

The development and application of a methodology for planning of port capacity has been focused on port expansion as strategy for a single port to deal with competition as well as with autonomous demand growth. Restrictions relate to the analysis of port congestion, the degree of integration of public interests and incorporation of economies of scale, (the lack of) modeling the full dynamics of port competition, and the considered strategy to deal with competition.

There is a range of possibilities to widen the scope of planning of port capacity. The reflections as discussed above have triggered some thoughts about a number of related topics that fit into this wider scope, and that should receive particular attention with a view on developments in the Port of Rotterdam. The following five topics can be mentioned:

Further analysis of port congestion
In this study, a port is considered as a point entity with an overall capacity instead of as a set of inter-dependent stages or links, which need to be optimally tuned to each other. Any inefficiencies in these links and their joint functioning lead to higher service times than ideally can be performed by the port. These higher service times are interpreted in this study as port congestion.

Port congestion depends however on waiting times between the different links in the port. This system is sensitive for disturbances in one or more of these links causing overall port congestion. Further analysis of port congestion and its impact on competitiveness requires therefore a thorough analysis of the entire port system including estimation of link capacities and determination of potential bottlenecks. Tuning between strategic port design, providing knowledge on a port's competitive position in transportation networks, and tactical port design, providing knowledge on port operation and technology, is needed to establish such analysis.

Full integration of public interests
Integrated planning of port capacity supposes full integration of public interests including minimizing social costs and enhancing indirect effects. Full integration of public interests is required if the government contributes to port investment.

Social costs of freight handling and (hinterland) transportation comprise, in addition to congestion costs, costs due to accidents, air pollution and noise. Quantification and expression of these cost components in financial terms is in progress and sometimes, such as for air pollution, reaching completion. An important aspect of social costs is the accident issue. Although accidents due to, for instance, accidents in (hinterland) transportation of hazardous materials are expected to contribute significantly to social costs, their inclusion in planning is a difficult issue due to their uncertain character.

As already mentioned in this study, the occurrence and determination of indirect effects of port investment is still under debate. Estimation of these effects is therefore an important issue of ongoing research efforts. A generic and transparent method for the estimation of indirect effects of port investment would substantially improve strategic planning for (node-type) infrastructure in general.

Public interests can be further integrated in the methodology as developed in this study by including additional social cost components in the marginal social cost-curve. Indirect effects can be evaluated in a separate economic evaluation of port investment. Such integration would be an important further step towards a generic approach for integrated planning of port capacity.

Further incorporation of economies of scale

One of the goals of this study has been to incorporate economies of scale in planning of port capacity. The results of the application case, more in particular the results of the sensitivity analysis, have confirmed the need to do so. Incorporation of economies of scale has however been focused on economies of scale in investment cost. Further extension with economies of scale (and scope) in port operation is interesting with a view on tracing a potential turning point in port development, which is determined by the transition from economies of scale, leading to efficiency gains, to diseconomies of scale due to port congestion, leading to a loss of market share.

Modeling the full dynamics of port competition

Substantial investments in the Port of Rotterdam (the Betuwe line and the Maasvlakte 2 projects) and potential reactions of other, competing ports have drawn attention to the dynamics of port competition. At the same time, the period needed for formal approval procedures for such projects has substantially increased in the Netherlands during the last decades.

The combination of these factors highlights the need to incorporate the full dynamics of port competition in planning of port capacity. Competitive strategies (reactions) of the different ports involved can then be simulated and the sensitivity of decisions on port investment for such strategies can be studied with such an approach. This requires however a dynamic model instead of a static model as has been used in the present study. Game theory, which is based on modeling interactions between different competing players with their strategies, is an interesting option to establish such modeling approach. Application of this theory in the field of transportation planning is in progress and resulting modeling concepts can be used to support port planning.

Consideration of less capital-intensive strategies to deal with competition

A most important challenge in port planning is to find the optimal strategy to deal with competition. In the methodology for planning of port capacity as developed in this study, three essential components can be distinguished, namely, 1) estimation of demand, 2) determination of supply, and 3) assessment of costs and benefits. Less capital-intensive strategies such as tariff strategies and cooperation between ports affect by definition the costs and are therefore particularly related to the third component. Whether demand and/or supply are affected, depends on the orientation of the strategy (demand and/or supply-oriented).

The methodology as developed in the present study can be further extended in order to analyze the effects of less capital-intensive alternatives on port competitiveness and economic performance. In practice, conflicting issues of port-commercial and public interests (particularly competitiveness of the port versus welfare of the nation) have often complicated such comparison. If less capital-intensive strategies are represented by appropriate cost-benefit streams, the methodology can also be used to assess economic efficiency of less capital-intensive competition strategies. Furthermore, demand and supply-oriented measures can be combined, which contributes to further development of commercially sound and economic-efficient competition strategies.

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Notation

a	parameter in investment cost function
b	scale factor in investment cost function
c	parameter in PBR-formula
g	growth rate of local port demand
i	commodity group
j	expansion alternative
k	scale factor in PBR-formula
l_{an}	maritime distance between region *a* and port *n*
l_r	hinterland distance of route *r*
pd_n	port dues at port *n*
p_t	charge at an hinterland terminal
t	time
t_n	travel time for using port *n*
$t_{ff,n}$	'ideal' service time without port congestion
tc_n	terminal charges at port *n*
x	expansion size
ASC	average social cost for a port user
$ASC^q{}_K$	derivative of the average social cost
B	economic benefit or increase of consumers' surplus
C	total investment cost
C_{an}	costs for maritime transportation between region *a* and port *n*
C_{nmr}	costs for hinterland transportation between port *n* and hinterland region *m* via route *r*
$C^k{}_K$	marginal investment cost
D	demand
D_{an}	number of days spent in maritime transit
GC	generalized transportation cost per unit
H_n	average time for container discharge in port *n*
H_{ndr}	dwell time
K	design capacity
K_0	capacity in the reference equilibrium
K_j	proposed capacity after expansion alternative *j*
MC	marginal cost for a port user
MPC	marginal private cost
MSC	marginal social cost
OC	opportunity cost of time
P	port productivity
Q	flow or throughput
Q^*	equilibrium demand

Q^*_0	equilibrium demand after demand shift
Q^*_j	equilibrium demand after capacity expansion j
S_j	hinterland transportation speed
S_s	maritime transportation speed
T_j	investment recovery period for expansion alternative j
V_i	value per TEU of commodity group i
VOT	value-of-time
α	unit cost for maritime transportation
β	unit cost for hinterland transportation
μ	spreading parameter
ρ	daily unit cost of capital
τ	relief interval

Glossary of Economic Terms

Consumers' surplus: the difference between the amount consumers are willing to pay for a good or service and the amount they actually pay.

Direct effects: cost savings for users (consumers) and operator (producer) due to an investment (i.e. increase of consumers' and producers' surplus, respectively).

Economic efficiency: at least one individual becomes better off without making any other individual worse off (also referred to as Pareto-efficiency).

Economies of network structure: when a transportation firm' costs decrease due to cost savings arising from the production of similar services on different routes, which belong to the same network.

Economies of scale: when a firm's costs less than double in response to a doubling of output volume.

Economies of (product) scope: when a firm's costs less than double in response to a doubling of output types.

Economies of traffic density: when a transportation firm's costs less than double in response to a doubling of the number of goods or passengers carried.

Efficiency: skillfulness in reducing the use of scarce resources.

Efficiency gains: cost savings due to, for instance, economies of scale and scope (in transportation: transport-efficiency gains).

Equity: skillfulness in a 'fair' distribution of costs and benefits over time and between groups and locations.

External effects: effects (of an investment) that are passed on to third parties beyond the pricing mechanism.

General equilibrium model: a model that provides a simplified representation of the entire economy, i.e., of the many markets that constitute the economy.

Indirect effects: effects (of an investment) that are passed on to third parties via the pricing mechanism such as multiplier effects.

Network effects: transport-efficiency gains due to the combined occurrence of economies of traffic density, product scope and network structure.

Opportunity cost: the cost associated with opportunities (benefits) that are foregone by not putting the firm's resources to their highest value used.

Opportunity cost of capital: the rate of return that one could earn by investing in a different project with similar risk.

Opportunity cost of time: the cost associated with opportunities that are foregone by increasing service times, waiting times, delays, etc.

Partial equilibrium model: a model that concentrates on a single market or industry and ignores effects on other markets.

Producers' surplus: the sum over all units of production of the difference between the market price of a good or service and the marginal cost of production.

Social costs: costs (in terms of negative external effects) imposed on society.

Sunk costs: costs that cannot be recovered when a firm decides to leave the market.

Welfare effects: gains and losses (in terms of direct, indirect and external effects) brought about by, for instance, infrastructure investment.

Summary

Port Investment – Towards an Integrated Planning of Port Capacity

Sander Dekker

Substantial investments are being made in the Port of Rotterdam. Examples are the construction of a rail connection between the Port of Rotterdam and Germany - the Betuwe line project - and the second seaward expansion of the Port of Rotterdam - the Maasvlakte 2 project. These investments essentially aim at enhancing the competitive position of the port in international transportation networks.

Experiences with increasing costs, uncertain demands and benefits, and the argument that port operation is in fact a commercial activity intensified the debate on the usefulness and necessity of government contributions to Rotterdam port investments. An interesting question is then if port investment (more in particular investment in port expansion) can be self-financing.

The overall *objective* of this study is to support strategic planning of a node in a (transportation) service network, which is characterized by competition. The present thesis contributes to this objective by the development of a methodology for planning of port capacity in which modeling of the system and (pragmatic) application of economic concepts are major components. The challenge is to integrate port-commercial and public interests in such methodology, and to incorporate competition, autonomous growth of demand, economies of scale and technological development.

The *focus* of this study is the reaction of a particular port on a change in the transportation network. A scenario for such change is the entry of new routes via a competing port. This leads to decreased demands and benefits for the particular port and the nation in which the port is located. Potential reactions of the port on this change include investment in port expansion and improvement of hinterland connections. The reaction that has been worked out in this study is expansion of the port's surface area, which allows also for autonomous growth of port demand due to, for instance, economic growth.

Although there are various interesting questions that might arise while considering the proposed focus from legal, economic and technological viewpoints, this study addresses in particular the following two *research questions*:

1) What is the optimal expansion strategy for a single port to deal with route competition and to facilitate further growth of the port's demand?
2) Can the expansion strategy be self-financing?

The present study addressed also the issue of ‘leakage’ of port investment benefits to other countries and related this with economies of scale (and scope) in port operation.

In *Chapter 2*, a comparison is made between European and Dutch port policy regarding port pricing and investment financing. This comparison indicates some friction between both policies. Where European port policy tends towards pricing according to usage and no investment funding by governments, Dutch port pricing practice is based on quay charges and port dues (in addition to terminal charges) and contributions of the national government to port investments are still adopted. Application of self-financing of port investment, based on congestion pricing, is therefore in accordance with European port policy. It is further observed that the Rotterdam port operates under strong competition. In addition to ports in the North Sea region such as Antwerp, the development of the Mediterranean ports such as the Italian port Gioia Tauro may become an additional threat for Rotterdam. Government subsidies for large-scale Rotterdam port investment projects such as the Betuwe line and the Maasvlakte 2 have initiated a heated debate in the Netherlands. This debate concerns the potential and desired role of the Dutch ports in international transportation, their contribution to national welfare and further enhancement by physical expansion.

In *Chapter 3*, concepts for planning of port capacity, applied to port expansion, are reviewed. Port capacity problems can be solved by (a combination of) ‘structural’ measures leading to facility expansion, and ‘non-structural’ measures leading to a more efficient utilization of existing facilities. Port expansion by means of land reclamation can be considered as a structural measure. Ports combine their public role with a strong commercial perspective. Therefore, a viable set-up of port expansion projects requires integration of public interests (particularly economic efficiency) and port-commercial interests (investment recovery) in the planning problem. On a scale of increasing complexity of planning, the highest level should then be applied: integrated planning of port capacity. Integrated planning of port capacity is possible if congestion effects are incorporated in the design of port expansion. Reduction of congestion costs contributes to economic efficiency (a national public interest), and the revenues (if any!) from congestion pricing can be used to recover the investment cost of port expansion (a port-commercial interest).

In *Chapter 4*, a modeling approach is developed for planning of port capacity. The approach integrates port-commercial and public interests. It further incorporates competition, autonomous demand growth and economies of scale. The modeling approach can therefore be characterized as integrated planning of port capacity incorporating competition, autonomous demand growth and economies of scale. The modeling approach is applied to port expansion, which can be considered as a strategy for a single port to deal with competition. The basis for solving this planning problem comprises analysis of port demand and supply in a partial equilibrium model. With such an approach, the reaction of a single port on a disturbance in the network can be simulated. To establish the optimal expansion strategy, port expansion is combined with congestion pricing. This is used for the simultaneous determination of 1) the optimal expansion size, and 2) the investment recovery period.

In *Chapter 5*, the model structure and schematization of a network equilibrium model to simulate freight transportation in order to estimate port demand is described. The supply curve, represented by the marginal social cost curve, makes use of the so-called 'Bureau of Public Roads' (BPR) formula that is often used for research on passenger transport. The assumption is that a curve with similar characteristics can be used to simulate port congestion.

In *Chapter 6*, various developments in container transportation technology have been identified. The main developments include the introduction of larger ocean vessels, longer trucks, double-stack trains and bigger barges, and the introduction of alternative fuels. The introduction of larger ocean vessels has further induced horizontal integration of ocean carrier operations and vertical integration of maritime and land transportation. These developments affect transportation costs and may therefore influence port demand. Being aware of this influence, any decision on port expansion should incorporate the influence of developments in transportation technology. In the application, only the influence of larger modes will be examined. The influence of alternative fuels and horizontal and vertical integration of transportation activities might also be important, but will not be included in the application due to a lack of data.

In *Chapter 7*, the planning methodology as developed in this thesis is demonstrated by an application to the Port of Rotterdam. The character of this application is explorative: tracing the decision space for Rotterdam. The scenario of the entry of a new competing route via the Italian port Gioia Tauro is used to illustrate the impact of route competition. The emphasis is on the trade offs in investment planning rather than the choice of the most effective strategy to deal with competition. The results of the application indicate that port expansion contributes only to a partial recovery of a loss of demand due to competition. This is highly determined by the relatively low level of port congestion in the starting situation. A tariff strategy, for instance, would then be more obvious. On the other hand, port expansion allows for future demand growth due to exogenous factors such as trade growth. It can further be observed that port investment in land reclamation can be self-financing. It should however be noted that 1) the costs due to investment in sea defense structures and maintenance, and 2) the full dynamics of port competition are not included in the self-financing principle as applied in this chapter. The results of the economic evaluation in the application highlight the issue of 'leakage' of port investment benefits to other countries.

The main *findings* of this study are:

- Planning of port capacity can be based on an assumed match between supply of port capacity, characterized by economies of scale, and demand for port services, which is obtained in competition between alternative routes and characterized by further growth. Developments in transportation technology can also be incorporated in such planning.

- Physical port expansion leads to a reduction of port-congestion costs. This makes a port more attractive for freight flows, which can be used to recover a loss of demand to some extent.

- It can be observed from the results of the application to the Port of Rotterdam that port expansion by land reclamation can be self-financing. It should however be noted that 1) the costs due to investment in sea defense structures and maintenance, and 2) the full dynamics of port competition are not included in the self-financing principle as applied to Rotterdam.

- The port users in the application case comprise only non-domestic users. The increase of their consumers' surplus is for the benefit of other countries instead of the Netherlands. This highlights the issue of 'leakage' of port investment benefits to other countries. It supports the arguments of those opposing government subsidies for (large-scale) port investment projects, because the government should not only invest for the benefit of other countries. This should however be traded off against efficiency gains for domestic users due to economies of scale and scope in port operation, which requires the presence of non-domestic users to obtain sufficiently large cargo volumes.

- Topics recommended for further research in the field of planning of port capacity comprise 1) further analysis of port congestion, 2) full integration of public interests including minimizing social costs and enhancing indirect effects, 3) further incorporation of economies of scale including economies of scale (and scope) in port operation, 4) modeling the full dynamics of port competition, and 5) consideration of less capital-intensive strategies to deal with competition.

Samenvatting

Haveninvesteringen - Naar een Geïntegreerde Planning van Havencapaciteit

Sander Dekker

Er vinden momenteel aanzienlijke investeringen plaats in de haven van Rotterdam. Voorbeelden zijn de aanleg van een railverbinding tussen de haven van Rotterdam en Duitsland – de Betuwelijn – en de tweede uitbreiding (zeewaarts) van de Rotterdamse haven – de Tweede Maasvlakte. Deze investeringen zijn in essentie bedoeld ter verbetering van de concurrentiepositie van de haven in internationale transportnetwerken.

Ervaringen met stijgende kosten, een onzekere vraag en baten, en het argument dat het functioneren van een haven in feite een bedrijfseconomische activiteit is, intensiveerden het debat over nut en noodzaak van overheidsbijdragen aan investeringen in de Rotterdamse haven. Een interessante vraag is daarom of haveninvesteringen (in het bijzonder investeringen in havenuitbreiding) zelffinancierend kunnen zijn.

Het uiteindelijke *doel* van deze studie is ondersteuning van strategische planning van een commerciële knoop in een (transport-) dienstennetwerk dat wordt gekarakteriseerd door competitie. Dit proefschrift draagt aan dit doel bij middels de ontwikkeling van een methodologie voor planning van havencapaciteit waarin modellering van het geheel en het (pragmatisch) toepassen van economische concepten belangrijke componenten zijn. De uitdaging is om in een dergelijke methodologie haven- en publieke belangen te integreren en om competitie, autonome groei van de vraag, schaalvoordelen en technologische ontwikkeling in te voegen.

De *focus* van deze studie is de reactie van één bepaalde haven op een verstoring in het transportnetwerk. Een scenario voor een dergelijke verstoring is de toetreding van een nieuwe route via een concurrerende haven. Dit leidt tot een afgenomen vraag en lagere baten voor de bepaalde haven en het land waarin de haven is gesitueerd. Mogelijke reacties van de haven op deze verstoring zijn een investering in havenuitbreiding en verbetering van achterlandverbindingen. De reactie die is uitgewerkt in deze studie is uitbreiding van het havengebied. Dit maakt tevens autonome groei van de vraag door bijvoorbeeld economische groei mogelijk.

Hoewel verscheidene interessante vragen kunnen opkomen wanneer de voorgestelde focus wordt beschouwd vanuit een juridische, economische of technologische invalshoek, adresseert deze studie met name de volgende twee *onderzoeksvragen*:

1) Wat is de optimale uitbreidingsstrategie voor de betreffende haven om om te gaan met een dergelijke competitie en om verdere groei van de vraag mogelijk te maken?

2) Kan de uitbreidingsstrategie zelffinancierend zijn?

Deze studie adresseert verder de kwestie van het ‘weglekken’ van haveninvesteringsbaten naar andere landen. Dit wordt gerelateerd aan schaal- en breedtevoordelen bij de exploitatie van een haven.

In *hoofdstuk 2* wordt een vergelijking gemaakt tussen het Europese en Nederlandse havenbeleid met betrekking tot beprijzing en financiering. Deze vergelijking geeft enige frictie aan tussen beide beleidsniveaus. Waar het Europese havenbeleid tendeert naar beprijzing op basis van gebruik en geen overheidssteun, daar is de Nederlandse praktijk van beprijzing gebaseerd op kade- en havengelden (naast terminaltarieven) en overheidsbijdragen aan haveninvesteringen komen nog altijd voor. Toepassing van zelffinanciering van haveninvesteringen, gebaseerd op beprijzing van congestie, is daarom in overeenstemming met het Europese havenbeleid. De Rotterdamse haven opereert in een markt met forse concurrentie. Naast havens in het Noordzeegebied zoals Antwerpen, zou de ontwikkeling van havens in de Middellandse Zee zoals de Italiaanse haven Gioia Tauro een extra bedreiging kunnen vormen. Overheidssubsidies voor grootschalige haveninvesteringen zoals de Betuwelijn en de Tweede Maasvlakte hebben in Nederland een stevig debat geïnitieerd. Dit debat betreft de mogelijke en gewenste rol van Nederlandse havens in internationaal transport, hun bijdrage aan de nationale welvaart en verdere versterking middels fysieke uitbreiding.

In *hoofdstuk 3* worden concepten voor planning van havencapaciteit, toegepast op havenuitbreiding, verkend. Havencapaciteitsproblemen kunnen worden opgelost door (een combinatie van) ‘constructieve’ maatregelen die leiden tot uitbreiding en ‘niet-constructieve’ maatregelen die leiden tot een efficiënter gebruik van bestaande faciliteiten. Havenuitbreiding middels landaanwinning kan worden beschouwd als een constructieve maatregel; beprijzing van congestie is een voorbeeld van niet-constructieve maatregelen. Havens combineren hun publieke rol met een forse bedrijfseconomische invalshoek. Daarom, om een haalbaar havenuitbreidingsproject te krijgen, dienen publieke belangen (met name economische efficiëntie) en de bedrijfseconomische belangen van de haven (continuering/toename van doorvoer en terugverdienen van investeringen) te worden geïntegreerd in het planningsprobleem. Op een schaal van toenemende complexiteit van planning, dient het hoogste niveau te worden toegepast: geïntegreerde planning van havencapaciteit. Geïntegreerde planning van havencapaciteit is mogelijk indien een congestie-effecten worden meegenomen. Reductie van congestiekosten draagt bij aan economische efficiëntie (nationaal-publiek belang), en de revenuen (als ze er zijn!) kunnen worden gebruikt om de investeringskosten van een havenuitbreiding terug te verdienen (bedrijfseconomisch belang van de haven).

In *hoofdstuk 4* wordt een modelleringsaanpak voor planning van havencapaciteit ontwikkeld. De aanpak integreert bedrijfseconomische belangen van een haven en publieke belangen. Het voegt verder in competitie, autonome groei van de vraag en schaalvoordelen. De modelleringsaanpak kan daarom worden gekarakteriseerd als geïntegreerde planning van havencapaciteit dat invoegt competitie, autonome groei van de vraag en schaalvoordelen. De aanpak wordt toegepast op havenuitbreiding dat kan worden beschouwd als een concurrentiestrategie voor een haven. De basis voor de oplossing van dit planningsvraagstuk is analyse van havenvraag en –aanbod in een partieel evenwichtsmodel. Op deze wijze kan de reactie van één haven op een verstoring in het netwerk worden gesimuleerd. Om de optimale uitbreidingsstrategie te verkrijgen, wordt havenuitbreiding gecombineerd met beprijzing van congestie. Dit wordt gebruikt voor het simultaan oplossen van 1) de optimale uitbreidingsgrootte, en 2) de terugverdienperiode.

In *hoofdstuk 5* worden de modelstructuur en de schematisering van een netwerk-evenwichtsmodel beschreven. Hiermee kan de vraag van een haven worden bepaald. De aanbodcurve, gerepresenteerd door een marginale sociale kostencurve, maakt gebruik van de zogeheten ‘Bureau of Public Roads’ (BPR)-formule die vaak wordt gebruikt voor onderzoek naar personenvervoer. De aanname is dat een curve met soortgelijke karakteristieken kan worden gebruikt om havencongestie te simuleren.

In *hoofdstuk 6* worden verscheidene ontwikkelingen in containertransporttechnologie geïdentificeerd. De belangrijkste ontwikkelingen zijn de introductie van steeds grotere oceaanschepen, langere vrachtwagens, double-stack treinen en grotere binnenvaartschepen, en de ontwikkeling van alternatieve brandstoffen. De introductie van steeds grotere oceaanschepen heeft verder horizontale integratie van carriers en verticale integratie van maritiem and landtransport veroorzaakt. Deze ontwikkelingen beïnvloeden transportkosten en kunnen daarom effect hebben op de vraag van een haven. Zich bewust van dit effect dient men bij beslissingen over havenuitbreiding rekening te houden met ontwikkelingen in transporttechnologie. In het toepassingsdeel zal alleen de invloed van grotere voertuigen worden onderzocht. De invloed van alternatieve brandstoffen en horizontale en verticale integratie van transportactiviteiten zijn wellicht ook van belang maar zullen niet worden meegenomen in de toepassing wegens gebrek aan gegevens.

In *hoofdstuk 7* wordt de planningsmethodologie, zoals ontwikkeld in dit proefschrift, gedemonstreerd met een toepassing op de haven van Rotterdam. Het karakter van deze toepassing is exploratief: het aftasten van de beslissingsruimte voor Rotterdam. Het scenario van de toetreding van een nieuwe concurrerende route via de Italiaanse haven Gioia Tauro wordt gebruikt om de belangrijkste kenmerken van het functioneren van een haven in een netwerk met competitie te ‘vangen’. De nadruk ligt op de afwegingen in de investeringsplanning in plaats van op de keuze van de effectiefste strategie om met concurrentie om te gaan. De resultaten van de toepassing geven aan dat havenuitbreiding slechts in beperkte mate bijdraagt aan het terugwinnen van vraagverlies door competitie. Dit wordt in sterke mate bepaald door het relatief lage niveau van havencongestie in de uitgangssituatie. Aan de andere kant maakt havenuitbreiding toekomstige groei van de vraag door exogene factoren zoals groei van de handel, mogelijk. Er kan verder worden waargenomen dat een haveninvestering in landaanwinning zelffinancierend kan zijn. Wel dient te worden opgemerkt dat 1) de kosten van investeringen in zeeweringen en onderhoud, en 2) de volledige dynamiek van havenconcurrentie niet zijn meegenomen in het zelffinancieringsprincipe zoals toegepast in dit hoofdstuk. De resultaten van de economische evaluatie in de toepassing brengen de kwestie van het ‘weglekken’ van haveninvesteringsbaten onder de aandacht.

De belangrijkste *bevindingen* van deze studie zijn:

- Planning van havencapaciteit kan worden gebaseerd op een verondersteld match tussen aanbod van havencapaciteit, gekenmerkt door schaalvoordelen, en vraag naar havendiensten dat wordt verkregen in concurrentie met alternatieve routes en gekarakteriseerd door verdere groei. Ontwikkelingen in transporttechnologie kunnen ook worden ingevoegd in een dergelijke planning.

- Fysieke havenuitbreiding leidt tot een reductie van havencongestiekosten. Dit maakt een haven aantrekkelijker voor vrachtstromen dat kan worden gebruikt voor een gedeeltelijk terugwinnen van vraagverlies.

- Er kan worden geconcludeerd uit de resultaten van de toepassing op de haven van Rotterdam dat havenuitbreiding middels landaanwinning zelffinancierend kan zijn. Wel dient te worden opgemerkt dat 1) de kosten van investeringen in zeeweringen en onderhoud, en 2) de volledige dynamiek van havenconcurrentie niet zijn meegenomen in het zelffinancieringsprincipe zoals toegepast op Rotterdam.

- De havengebruikers in de toepassing zijn alleen buitenlandse gebruikers. De toename van hun consumentensurplus is ten bate van andere landen dan Nederland. Dit brengt het ‘weglekken’ van haveninvesteringsbaten naar andere landen voor het voetlicht. Het steunt de argumenten van hen die tegen overheidssteun voor (grootschalige) haveninvesteringsprojecten zijn, omdat de overheid niet behoort te investeren uitsluitend ten bate van andere landen. Dit dient echter te worden afgewogen tegen efficiëntiewinsten voor binnenlandse gebruikers ten gevolge van schaal- en breedtevoordelen bij de exploitatie van een haven. Dit vereist de aanwezigheid van buitenlandse gebruikers om voldoende vrachtvolumes te krijgen.

- Onderwerpen die worden voorgesteld voor verder onderzoek op het gebied van planning van havencapaciteit zijn: 1) verdere analyse van havencongestie, 2) volledige integratie van publieke belangen inclusief minimaliseren van maatschappelijke kosten en versterken van indirecte effecten, 3) verder meenemen van schaalvoordelen inclusief schaal (en breedte-) voordelen bij de exploitatie van een haven, 4) modellering van de volledige dynamiek van havenconcurrentie, en 5) beschouwen van minder kapitaalintensieve alternatieven om met concurrentie om te gaan.

About the Author

Sander Dekker was born in Den Helder, the Netherlands, in 1974. He finished the HAVO and the VWO (pre-university education) at the Etty Hillesum College in Den Helder in 1992 and 1994, respectively. In 1994, he started his study in Civil Engineering at the Delft University of Technology. In 2000, he graduated after writing his Master's theses on coastal engineering and philosophy of technology. In September 2000, Sander joined the Infrastructure Planning department of the Faculty of Civil Engineering and Geosciences of the Delft University of Technology to carry out his PhD research on strategic port planning. During this research, he has presented various papers at national and international conferences, and published articles in international journals. Presently, he is still working in the field of strategic port planning.

Major publications of Sander Dekker are:

Dekker, S., R.J. Verhaeghe, and A.A.J. Pols (2002). Expansion of the port of Rotterdam: framework for evaluation. *Transportation Research Records*, No. 1782, pp. 49-55.

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Gerard Reve, *Het Boek van Violet en Dood*