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A MODELLING APPROACH FOR INTEGRATED PLANNING OF PORT CAPACITY – TRADE-OFFS IN ROTTERDAM INVESTMENT PLANNING

ABSTRACT

This paper presents a modelling approach for planning of port capacity. The approach integrates port commercial and public interests. It further incorporates route competition and autonomous demand growth. It is applied to port expansion, which can be considered as a strategy for an individual port to deal with route competition. 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 the change in a transport network comprising alternative routes to a hinterland destination 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. The modelling approach will be applied to Rotterdam port focusing on port expansion by means of land reclamation. The scenario of the entry of a new competing route via the Italian port Gioia Tauro is used to address some trade-offs in Rotterdam investment planning.

KEY WORDS

port planning, port expansion, capacity planning, investment planning, cost-benefit analysis

1. INTRODUCTION

Major pressures exist to expand seaports in order to improve their competitiveness. Examples are the second seaward expansion of the Port of Rotterdam (the Maasvlakte 2 project) and developments in the ports of Antwerp and Houston. Public contributions to such investments are criticized due to relatively low economic rates of return and the supposed leakage of port investment benefits to other countries.

In planning port expansion, commercial interests of the port owner and public interests of port users and society need to be integrated. Major port-commercial interests are investment recovery/profit making. Public interests are in particular cost savings for the port users (increase of consumers surplus), which may induce further macro-economic development.

Mohring and Harwitz (1962) established an interesting balance between pricing and investment to meet commercial as well as public interests. They showed that under certain conditions the revenues from congestion pricing are sufficient for financing expansion works, provided that the increase of consumers surplus is maximized. The 'conditions' refer to 1) capacity is adjustable in continuous elements; 2) constant returns to scale in capacity construction; and 3) constant returns to scale in congestion technology. Application of this self-financing principle to port expansion is however complicated due to the presence of competition among ports and future growth of transport flows.

This paper presents the development and application of a modelling approach for integrated planning of port capacity that incorporates route competition and future growth of transport flows, and that leads to self-financing of port-expansion. It focuses on the reaction of a single port to a loss of market share due to the entry of a new transport route via a competing port. The heart of the modelling approach is the freight transportation model to simulate port demand. The modelling approach is applied to the Port of Rotterdam to address some trade-offs in its investment planning.

The remainder of this paper is divided into five sections. Section 2 presents the modelling approach. Section 3 presents the results of the application to the Port of Rotterdam and discusses some trade-offs in Rotterdam investment planning. Section 4 summarizes the findings.

2. MODELLING APPROACH

2.1. Ports in the transportation network

In this paper, ports constitute nodes in an elaborate network connecting origins and destinations for freight flows. Determination of demand for port services is essentially based on competition between routes.

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 the route choice by the carriers, a logit-type traffic assignment has been used. The aggregation of all containers going through a particular port in the network gives the simulated container transportation demand of that port.

2.2. Efficiency concepts

Integration of the public interests, mainly increase of consumers surplus, and the port-commercial interests, particularly investment recovery, is used here as the basis for planning the port capacity. It serves as input to the simultaneous solution of determining 1) the optimal expansion size, and 2) the investment recovery period. 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 paper, 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 response on the 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 1.

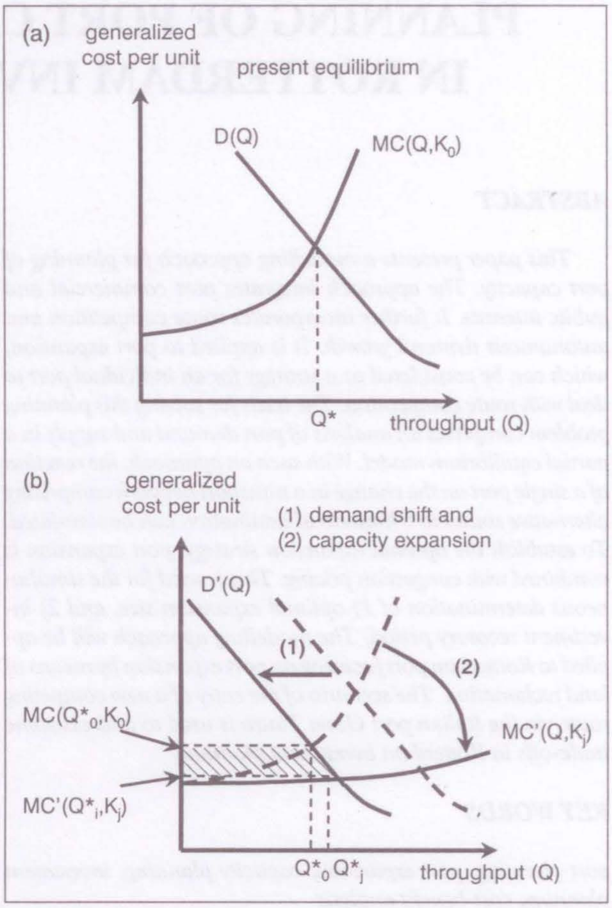

Figure 1 - Supply-demand interaction of a single port

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. The equilibrium between the supply curve $MC(Q, K_0)$ and the demand curve $D(Q)$ exists at the equilibrium demand Q^* (see Figure 1a).

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 1b). 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 in turn results in an increased equilibrium demand for the port (Q^*_j) as demonstrated in Figure 1b. 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 1b.

Congestion pricing

In the above elaboration on supply-demand interaction, the difference between the marginal private and marginal social cost is not considered. This is, however, necessary when congestion pricing is incorporated in the planning problem. The price that leads to internalized (external) congestion costs (i. e. the congestion price) is determined by the difference between the marginal private cost (MPC) and the marginal social cost (MSC). The MPC is equal to the average social cost (ASC) and includes port dues, cargo-handling charges and private congestion costs. The annual revenues from congestion are to be used in the modelling approach to recover the investment cost of port expansion.

Optimum 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., Dekker, 2005). The marginal benefit of port expansion (increase of consumers surplus) is based on the decrease of port congestion costs, which can be expressed by the reduction of the average social cost (*ASC*) as experienced by the port users.

Investment Recovery

The concept of congestion pricing and its contribution to investment recovery is introduced above. To establish the investment recovery, the growth of demand also has to be incorporated. In this study, this is implemented by an annual shift of the demand curve according to an exogenously determined growth rate of cargo flows.

2.3. Simulation of the present and reference equilibrium

Considering the port as part of a transportation network, a common (freight) transportation model using a network equilibrium concept can be used to simulate port demand. The input data describing the network are then adapted to include the relevant port characteristics. A function to simulate the port demand curve should be added to the simulation.

Following the formulation of components as outlined above, the procedure for simulation of port supply and demand to establish the current and reference equilibrium as defined above can be summarized in five steps:

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 1a).
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 1b).

The above simulation of the current and reference situation provides an essential piece of information in the present modelling approach.

For this study, an adapted version of the model by Luo and Grigalunas (2003) is used to estimate port demand; this model uses the least cost assignment criterion. For the present simulation model, a logit-type assignment modelling is used (see Section 2.1). This incorporates the uncertainty in traffic assignment because the generalized cost is but one factor in the selection of a particular route; other factors, including strategic behaviour, reliability of the port (e. g., probability 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 supply side of the port is schematized by the marginal social costs, *MSC*. The *MSC*-curve has been derived here from an expression for the marginal private costs, *MPC*, using a typical expression of congestion in transportation (the so-called 'Bureau of Public Roads' formula), which is often used in research on passenger transport. The assumption here is that a curve with similar characteristics can be used to simulate port congestion.

The port expansion problem can be formulated as an optimization problem that is characterized by non-linear relationships, interdependence between expansion and pricing, and uncertainties in modelling structure and estimating parameter values. Solving this problem in a closed mathematical format is complex and the best approximation, catching main elements, has to be found, comprising the objective function (maximization of increase of consumers surplus), decision variables (port capacity before and after expansion), and constraints (investment recovery, economic efficiency, pre-financing and ability to meet peak demand). The interested reader is referred to Dekker (2005) for the details of this optimization problem.

3. APPLICATION TO THE PORT OF ROTTERDAM

3.1. Case description

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. The question then is: what should be the optimal expansion strategy for Rotterdam to meet this threat?

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 'fighting area' is located around the area of the Alps (see Figure 2). 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).

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

– service characteristics of the ports including handling charges, port dues and productivity figures; and

– trade data (import and export flows) of the hinterland regions.

The modelling approach outlined in the previous section has been applied to the case. It has been implemented in a spreadsheet and contains a partial equilibrium model to simulate container demand and a scenario for trade growth that has been formulated as input. Below, only the main results of this application are presented. More details can be found in Dekker (2005).

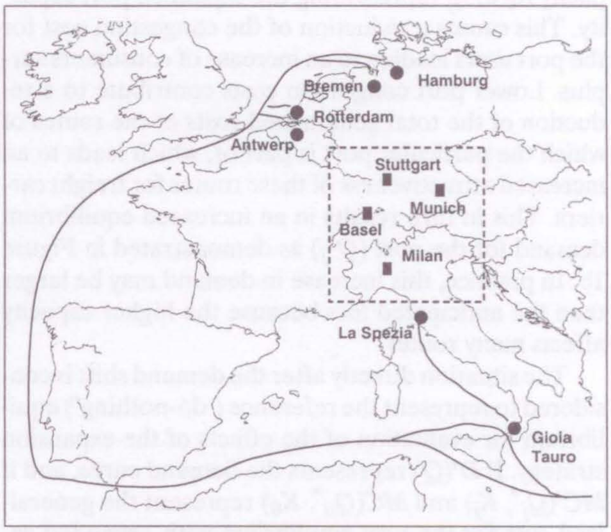

Figure 2 - Ports and their common hinterland in the application

3.3 Results and trade-offs

For the present equilibrium, the modelling approach results in an equilibrium demand of 1,071,794 TEU/year, which represents about 57% of the non-domestic container flows through Rotterdam in 1995. Because a capacity utilization rate of 70% is assumed (see Dekker, 2005), the present capacity (K_0) is then 1,531,135 TEU/year.

The addition of a new route via Gioia Tauro results for Rotterdam in a loss of demand (reference equilibrium). Assuming that container flows are not bounded to the port, for instance, by tradition or long-term agreements, Rotterdam equilibrium demand decreases in the year after the demand shift to 806,645 TEU. The capacity utilization rate decreases accordingly to 53%.

The simulated reaction of Rotterdam comprises an optimum expansion size of 7.9 hectares (i. e., given a productivity of 24,000 TEU/hectare, a capacity expansion of 195,254 TEU/year) with an investment cost of € 17.63 million and a financing cost of € 0.52 million. The resulting investment recovery period is 11 years. The capacity utilization rate at the end of this period is

88% (the autonomous demand growth is assumed to be 64,000 TEU/year).

The present value of the benefit increase of the expansion, calculated only over the investment recovery period, is €59.26 million (i. e. sum of increase of consumers and producers surplus). The total financial revenues from congestion pricing are €18.69 million; the overall financial return on investment, indicating the soundness of commercial exploitation, is then +6 %.

Because the lifetime of port expansion projects is much longer than 11 years, a longer planning horizon should be considered to incorporate more benefits. Future rounds of demand shifts and reactions by competing ports may complicate this.

In this paper, only expansion as strategy to deal with port competition has been considered. The potential of other measures such as tariff strategies should be traded off in making port development programs. Expansion leads to further increase of over-capacity that may intensify inter-port competition. This may lead in turn to inefficient utilization of the European transport facilities, which is less desired from a European welfare perspective. A tariff strategy, for instance, would then be more obvious.

Because only containers to and from the non-Dutch regions are considered, the increase of consumers surplus (here: €45.69 million) is here part of the 'leakage' of port investment benefits to other countries. This supports the arguments of those opposing government subsidies for port investment projects, because the government should not invest for the benefit of other countries. However, this should be traded off against efficiency gains for domestic users due to the economies of scale in port operation, which requires the presence of non-domestic users to obtain sufficiently large container volumes.

4. OBSERVATIONS

This paper presents a modelling approach for planning the port capacity. The approach integrates port commercial and public interests. It further incorporates route competition and autonomous demand growth. It is applied to port expansion, which can be considered as a strategy for an individual port to deal with route competition. 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 a transport network comprising alternative routes to a hinterland destination can be simulated.

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

In the application to Rotterdam, the model results demonstrate that port expansion contributes to recovering a loss of market share. Major trade-offs in large-scale investment decisions for Rotterdam include:

- structural versus non-structural port capacity measures; and
- port investment for the benefit of other countries versus efficiency gains for domestic users due to the economies of scale in port operation, which requires the presence of non-domestic port users.

Further research should aim at further refinement of the modelling approach such as incorporating the full dynamics of inter-port competition. With a view on their relevance for port strategy development, particular attention should be paid to the above described trade-offs in port investment planning.

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SAMENVATTING

EEN MODELLERINGSAANPAK VOOR INTEGRALE PLANNING VAN HAVENCAPACITEIT - AFWEGINGEN IN DE INVESTERINGSPLANNING VOOR ROTTERDAM

Dit paper presenteert een modelleringsaanpak voor planning van havencapaciteit. De aanpak integreert bedrijfseconomische en publieke belangen en houdt rekening met routecompetitie en autonome groei van de vraag. De modelleringsaanpak wordt toegepast op havenuitbreiding dat kan worden beschouwd als een strategie voor een haven om om te gaan met routecompetitie. De basis voor het oplossen van dit probleem bestaat uit een analyse van havenvraag en -aanbod in een partieel evenwichtsmodel. Met een dergelijke aanpak kan de reactie van één haven op een verandering in een transportnetwerk, dat bestaat uit alternatieve routes naar een achterlandbestemming, worden gesimuleerd. Om de optimale uitbreidinsstrategie te verkrijgen, wordt havenuitbreiding gecombineerd met beprijzing van congestie. Dit wordt gebruikt voor het simultaan bepalen van 1) de optimale omvang van de uitbreiding, en 2) de terugverdienperiode. Deze aanpak wordt vervolgens toegepast op Rotterdam en is met name gericht op havenuitbreiding middels landaanwinning. Het scenario 'toevoegen van een nieuwe concurrerende route via de Italiaanse haven

Gioia Tauro' wordt gebruikt om afwegingen in de investeringsplanning voor Rotterdam te adresseren.

TREFWOORDEN

havenplanning, havenuitbreiding, capaciteitsplanning, investeringsplanning, kosten-batenanalyse

LITERATURE

[1] **Dekker, S.** *Port Investment – Towards an Integrated Planning of Port Capacity*. PhD-thesis. TRAIL/Delft University of Technology, Delft, the Netherlands, 2005.

[2] **Luo, M.,** and **T. A. Grigalunas**. *A Spatial-Economic Multimodal Transportation Simulation Model for US Coastal Container Ports. Maritime Economics & Logistics*, Vol. 5, No. 2, pp. 158-178, 2003.

[3] **Mohring, H.,** and **M. Harwitz**. *Highway Benefits – An Analytical Framework*. Northwestern University Press, Evanston, Illinois, U. S., 1962.