Compte Rendu
de la Conférence
Internationale
sur la Recherche
en Matière
de Transport

Proceedings
of the
International
Conference on
Transportation
Research

PREMIÈRE CONFÉRENCE

FIRST CONFERENCE

Bruges, Belgium
Juin, 1973

Bruges, Belgium
June, 1973

COLLEGE
D'
EUROPE

TRANSPORTATION
RESEARCH
FORUM

THE FUNCTIONS of a port are usually to transfer goods between seaborne and inland transport modes. The criteria or objective in port design and operation may be to:

a. Maximize flow through the port.

b. Maximize revenue from port operations.

c. Maximize profit from port operations.

d. Maximize the capital recovery factor.

e. Achieve required capacity at minimal cost.

f. Achieve minimum total transportation cost by optimum mix of port and transport system components.

g. Minimize capital investment per unit capacity for a given flow.

h. Present value of future benefits.

i. Other.

To achieve a given defined objective or multi-objective, we usually analyze the problem of port design, investment, and operation to determine the required policy. This includes derivation of methods for the efficient use and allocation of investment, facilities, labor and equipment, and the introduction of incentives for increased productivity. Port analysis is usually concerned with a nonstatic situation in which consideration is given to the relation between growth over-time in shipping cargo flow and the facilities or resources to achieve a dynamic optimum.

A port is an operational system in which methods of operations research are effectively applied for decision-making. Basically, in structuring a port model or analysis, port operations are broken down into constituent parts and then expressed in mathematical notation in such a way that the capacity of the port or its component parts can be related to the cost of its provision or operation. The effect on the cost of ship and cargo time are obviously also important parameters.

Analysis can also be performed to determine a static optimum which is usually defined as the "Best Use of Existing Facilities" by planned investments or cost allocations for optimum operations in relation to a steady traffic and/or cargo flow.

Port Analysis can be performed on a single purpose port defined as one or more terminal facilities designed for the handling of one type of cargo. Cargo types are usually broken down into 4 major handling categories:

General Dry Cargo
Containerized and/or Unitized Cargo
Liquid Bulk Cargo
Dry Bulk Cargo

There obviously are other cargo handling types (such as rolling cargo) and handling types could be broken down into more detail. Yet these four categories usually suffice, as the general terminal characteristics implied cover basically all major types of cargo transfer.

Next in complexity is analysis of multipurpose ports which comprise facilities for handling more than one type of cargo. Finally, it may be desirable to structure multiport analysis or models in which some or all the constituent ports are multipurpose.

Models have always been used in Port Planning and Analysis, at least implicitly in the planners' mind.

The development of sophisticated mathematical techniques and the availability of data processing technology has emphasized the use of **explicit quantitative models**, i.e., logical and/or mathematical representation of the process under study. In this paper, a review of recent or still under process work in port planning an analysis is presented. Models will be briefly reviewed from simple analytical single purpose port models to the study of the more complex multiport multipurpose models.

Port Analysis

As a starting point in the construction of a model of a seaport, the following must be determined to derive the definition of relevant inputs:

1. What are the important characteristics of a seaport and its environment?

2. Where is it most convenient to draw the boundary between the port and its environment (i.e., what functions should be considered part of the port, and what considered exogenous?)

3. What quantities or processes are inputs, and what are outputs to the chosen "Control Volume"?

4. What is the causal structure relating outputs to inputs within the control volume?

The operation of a real seaport and the interaction with its environment are in reality highly complex phenomena, involving the interrelationship of many complicated processes. An attempt has, therefore, been made to break the system down into major "building blocks" representing conceptually distinct facets of port operation. The structure within these blocks may then be examined in more detail.

The breakdown is shown schematically in Figure 1. The character of the port is represented by three sorts of information:

1. Physical state (configuration of facilities, utilization, etc.).

2. Day-to-day operating schedules

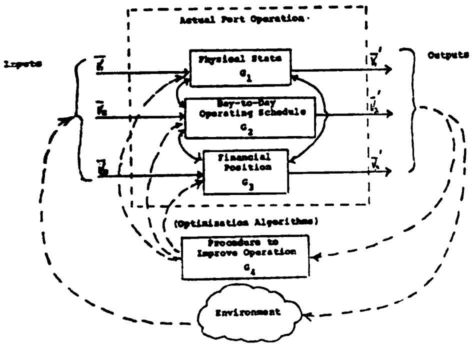
Port Analysis and Planning

by

P. Wilmes*

E. Frankel**

Figure 1. Over-All Structure of a Seaport System



(priorities for serving different ships, pricing policy for seaport services, etc.).

3. Financial position (income, expenditure, debt, capital investment).

Each of these may be considered as a "black box," with a state which varies over time, inputs, and outputs. The inputs include the state of the other black boxes. The details of the actual physical objects and information lying within each box are discussed in more detail in the following section.

In addition to the three blocks representing the actual seaport operation, there are two nested outer "control" or feedback loops.

One of these represents the effects of the seaport designer or management who react to whatever information they can get about the state and inputs of the seaport, and make changes in the structure of the system (configuration within the boxes) in response to these inputs. Typical changes would be additional berth space or shed facilities, a change in charges made for port services, borrowing capital or paying off outstanding debts, etc.

A larger loop surrounds this, and represents the interaction of the seaport with its environment. The demand for port facilities depends in part upon the quality and quantity of service which the port offers. These influences are usually considered exogenous, and the outer loop left "disconnected," because it is felt that the first priority is a simulation of the port itself.

Considering the analysis of a set of ports, we must include all the factors imposed by the environment. The demand is imposed by commodity generation which generates a flow and a service demand for transportation from inland points of commodity generation to overseas point of commodity receipt. This is refined by route and/or port distribution demand. To fill this generated or postulated demand we select among inland feeder, port, ocean transportation and foreign port alternatives which constitute the supply as shown in Figure 2. The level of demand may be affected by total transport impedence expressed by transport cost, time and level of service. Similarly, supply capacity or availability will be affected by total transport cost, time and level of service. As a result, a "Demand-Supply Analysis" can theoretically be performed. Such analysis requires consideration of the port as an interfacing link in the transport supply chain in which inland feeder and ocean transportation is represented by the network of all alternative routes, modes, and quality of service while alternative ports are represented by their capacities for handling the model interface and other service factors. The alternative route and mode selection may be affected by a desired port distribution which determines preferred port use. Total transport impedence is the sum of all transport and transfer costs including the cost of quality of service factors such as transit time, etc.

Considering the port analysis in this context, the port boundary may be defined as a control volume into which enter inland feeder and ocean transport vehicles for the purpose of transfer of commodities which constitute the demand on the port (Figure 3). The port supplies a capacity for handling such transport vehicles and for Transfer of cargo between such vehicles including intermediate storage. Because of the vast differences in unit vehicle size and, therefore, great differences in the interarrival times and queue characteris-

**Assistant Professor, University of Louvain.*

***Professor of Ocean Engineering, M.I.T.*

Fig. 2 Demand-Supply Equilibrium Analysis

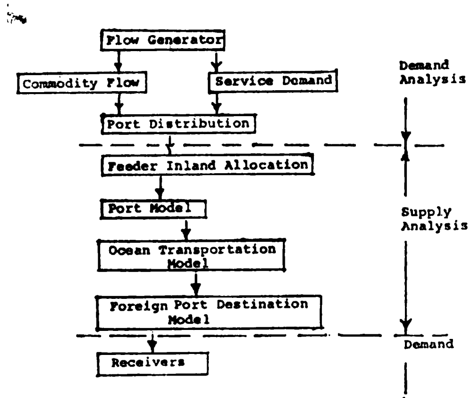
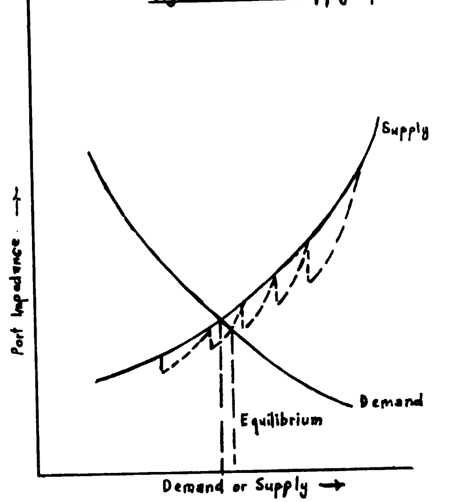


Fig. 4 Demand - Supply Equilibrium



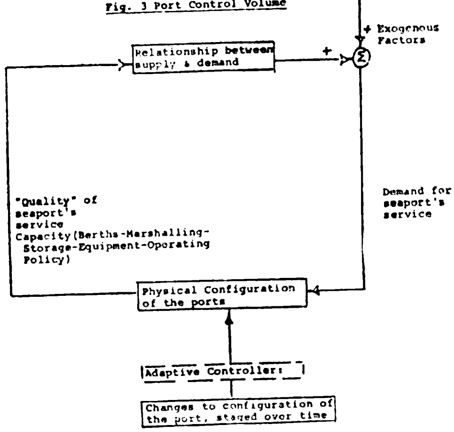
tics between inland feeder and ocean transport vehicles, vehicle marshalling and commodity storage capacity form an important measure of port capacity.

The port impedence can be considered an integrated congestion cost. As capacity in terms of throughput is increased, these costs go up. While this is generally true for a static situation in which port expansion is not considered and increased capacity is supplied by increasing congestion until a limit is reached when supply becomes assymptotic, the more usual case will include incremental investment which will result in a stepwise increase in port supply capacity with port impedence as shown as in Figure 4.

Basic Seaport Model Structure

The modeling of the physical makeup and day-to-day operation of a port facility is presented in Figure 5. The flow through a port is usually discrete

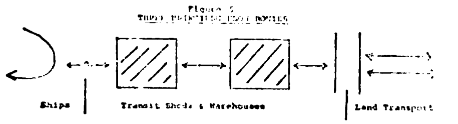
Fig. 3 Port Control Volume

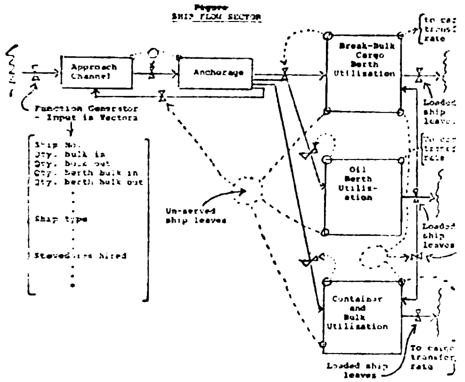


(e.g., ships, containers, tank-cars, palletized loads).

In accommodation of the idea of modeling the entire port operation by "level" and "flow rate," the whole flow from ships entering the approach channel of the port to cargo leaving the backside of the port (and alternatively cargo arriving at backside and ships leaving) can be divided at two points, the loading (off-loading) platform (mooring for lightering and buoy-discharged tankers) and the port end of the inland transportation system. Consequently, there are three principle flow routes which, when jointed together by the appropriate rates and transfer functions, become the flow operations model of the entire port. The three flows are those involving ships, cargo (in the transit sheds and warehouses) and land transports (trains, trucks, pipeline). The division into these particular categories is called for mostly by the fact that such choices minimize the amount of cross-linkage between the flow sectors. We must also note that although these particular flow representations are models of import flow, they are substantially equivalent (with changes and/or additions of arrows) to models of export flow.

The starting point for the flow modeling of ships in the port is the rate of flow of ships into the approach channel. For our purposes this rate is determined by the function generator whose input is vectors describing various parameters of the ships entering the approach. These parameters include ship number, quantity of various cargo types going in, quantity of various cargo going out, ship type, allocation of





labor specified by the ship, etc. The number of ships in the approach channel is considered a level and the rate out of the approach channel and into (or through) the anchorage is a function of both the level in the approach and the level of the anchorage.

Flow out of the anchorage may be split three ways: ships go to either break-bulk cargo berths, oil or tankage berths, or container and bulk loading (off-loading) berths. Ships may not come out of the anchorage at all. If forced to spend too much time waiting for a berth or lighter, they may turn around and leave unloaded. There is also cross-flow of ships from one type of berth to another for combination-cargo vessels. This will exist between any of the berths (all combinations are possible) although for clarity only one cross-flow of ships is shown on the diagram. Ship flow out of the berth-utilization levels loaded or unloaded and leave the approach channel level and with it the port itself.

Starting with the cargo flow emanating from the break-bulk cargo berth level of utilization, there is a rate of flow into the transit shed utilization level which is determined by the function describing the ship-to-shed unloading rate. Inputs into this function come from the levels of small cargo berth utilization, equipment (handling facilities) labor allocated to small cargo handling, transit shed utilization and from the warehouse transfer rate.

Flow out of the transit shed can be split three ways. It may go directly to the inland transportation system (rate is exogenous), it may go to a user-owned warehouse on the premises of the port using the intra-port cargo movement facility, or it may go to the port-owned warehouse. The rate of flow from the transit shed to the user-owned warehouse is determined by the same function which determines the ship-to-shed rate of flow except as modified (probably significantly) by an input from the user. The shed-to-port's warehouse rate of cargo flow is a function of the ship-to-shed unloading rate (and of all its inputs) as well as of the levels of equipment and labor allocated to this movement of cargo.

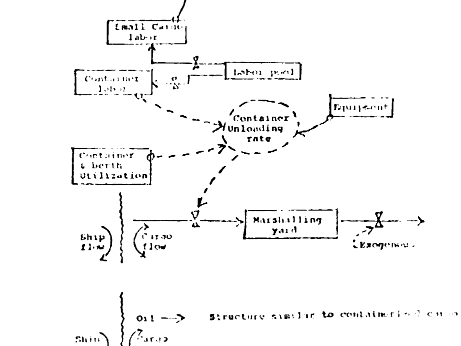
The flow patterns associated with the modeling of the container and bulk handling berth as well as the oil and tankage handling berth are very similar to those described above, although actually much more simplified. There is interaction across the berth categories in such areas as the labor situation even in the day-to-day operations and in more of the levels in the larger-run outlook, as shown in Figure 6.

Port Criteria and Planning

For the purpose of port planning, questions of optimal capacity arise in several contexts. One of these is a short run question; given a particular port design (and its consequent physical capacity), how many vehicles (ships, land transport) or equivalently, how many cargo or passenger units could be served. Another is the long run question; given projected demand for service, what port design should be

Fig. 6

CARGO FLOW (TRANSIT SHEDS & WAREHOUSES) SECTOR



built or to what level should the port be expanded.

Economic analysis provides the criteria of economic efficiency which can be used to determine a level of economic capacity in these two cases. The short run case corresponds to short run equilibrium through an appropriate choice of port operating variables and pricing. The long range decision corresponds to the appropriate choice of investment, design and operating policy for the port determined through effectiveness and/or investment analysis.

Methodology for the selection of measures of "optimal" design and operation of ports and for the evaluation of port productivity or profitability, is varied.[1] While in the past port capacity or productivity were simply measured by the transfer rate per unit of berth length and labor applied. Such criteria have little use in evaluating the effectiveness of a total multipurpose port or set of regional multipurpose ports. In fact, the measure of port performance must include:

1) Port Cargo Transfer Effectiveness.
2) Ocean Transport Turnaround Effectiveness.
3) Inland Transport Turnaround Effectiveness.
4) Cargo Storage Effectiveness.
5) Effectiveness of Utilization of Port Resources (Equipment, land facilities, labor, etc.).
6) Working Capital Utilization.

The first four factors are usually expressed as a congestion cost while the latter is a financial cost, which can be divided into fixed and variable costs and determined as a function of capacity. Capacity on the other hand is a multivariable function as well; which depends on the vehicle and cargo types (and forms) put through the port. Ideally, a port will only encourage use of berths by the maximum size of ship the berth can handle. Similarly, only the ideal type of inland feeder would be accommodated. In practice a common user port must serve all courses and, therefore, accommodate all types of transport vehicles and forms of cargo. The resulting degradation of capacity and effectiveness forces an increasing development of specialized port facilities which are often user controlled.

Port planning suffers under the unpredictability of demand both by quantity and quality of cargo flow (form, type, etc.) as well as transport technology. Although forecasting techniques have been greatly improved, reliable costs seldomly cover periods extending over more than one or two years, a period of which is but a fraction of the time required for the planning and development of new or improved port facilities. As a result, ports are often overdesigned and provided with excess capacity of facilities which are obsolete before completion. The simple approach to demand projection by regression or other forecasting techniques based on past trends in commodity flow and technology is not valid at a time of rapid change in economic relationships, trading patterns, technology, environmental effects and socio/political factors. One problem is the derivation of the planning objective with particular reference to port investment planning. It can generally be shown, that from a microeconomic point of view, most port projects do not provide a reasonable return on investment. The port investment planning objectives are, therefore, historically defined as "effectiveness in providing demanded service" although current practice is to take a more macro-economic viewpoint which results in port investment criteria which at least minimizes loss if not actually aiming at a limited return on investment. The problem is complicated by the many diverse parties usually involved in port planning and investment. These comprise public (non-port) agencies who provide dredging and navigational aids, to private terminal investors. The port management itself is usually somewhat in between. As a result, the totality of port investment may be subject to more than one criteria, though all investment components depend on the same plan.

Methods for Port Planning and Analysis

The recognition, that a port constitutes more than a ship to shore transfer facility designed to effectuate safe ship berthing and cargo handling has resulted in an extension of the simple and useful but restrictive queuing models which served largely to derive berth assignment and investment strategies. More recent work emphasizes the total port function, which includes intermodal transfer and various in-port operations. The first extensive effort in this direction was the development of a simple single purpose port simulation by UNCTAD (14) in 1969. This model has since been used in a variety of port analysis. The hierarchy of the development of models can be seen from TABLE 1 which shows the growth from the static, closed form single purpose port model, to regional multipurpose models.

Analytical Models of a Specialized Port

The basic models used in port planning and analysis have been simple analytical models of specialized or single purpose ports. These are widely found in the literature (1), (2), (3), (4), (5), (6) and usually deal only with the ship to port or berth interface. As a result they usually cope with berth allocation and/or the design of berth requirements. Generally, queueing theory (7) is used in these models. In relation with the assumptions of these models, they may be classified into three main categories:

1. Poisson arrivals and exponential service times, N station models (M/M/C queue models).

2. Poisson arrivals, Kth order Erlangian service distributions, N stations models (M/EK/C models).

3. Independently distributed interarrival times according to a general A(t) probability distribution, service time described by a general G(t) distribution, N stations models making use of the extension of Pollaczeck—Khintchine formula.

These models generally have the advantages of analytical models, in that they provide a good insight in the system under study and give a neat closed form and inexpensive solutions to some specific problems. On the other side, their use is usually restricted to problems of limited scope because of their necessarily restrictive assumptions.

They have proven nevertheless very useful and have been widely used in port planning and analysis mainly for problems of berth and equipment investment or assignment. The results obtained from these models are often in the form of mean waiting time, probability of having a waiting time lower than a given criteria and similar measures. The objective function is usually a cost function in the form of:

$$\bar{K} = \bar{A} + \bar{B}$$

$\bar{K}$ cost function of a given throughput

$\bar{A}$ ship and cargo waiting times aggregated variables

$\bar{B}$ capital and operating costs of the facilities aggregated variable; similar profit criteria can be utilized.

Optimization of limited harbor resource allocation is obtained by the testing of a sequence of alternative designs.

Published data or graphs allow the derivation of results for precomputed or given situation. The recent paper by A. G. Novaes (8) provides a review of these models and gives an interesting application to the port of Santos.

TABLE 1

Port Planning and Analysis Models

Regional port models including noncommensurate factors (technological, economic, environmental, etc.).

Analytical or simulation model of port and intercontinental network of flows.

Analytical network plus simulation model for regional port analysis.

Analytical network models for regional port analysis.

Simulation model of whole multipurpose port.

Simulation dynamic model of a whole specialized port.

Simulation model of a whole specialized port.

Analytical dynamic model of a partial-specialized port.

Analytical-static Model of a partial-specialized port (sea-side) berths allocation.

Specialized Harbor Analytical Dynamic Models

These queueing models are static, i.e., they assume a single investment decision through time, for a given demand. They may be used in a dynamic way, i.e., in connection with a sequence of decisions which are taken through time for port growth and development. One such illustration is the work performed by TABORGA (9).

The TABORGA model is a simple Dynamic Programming recursion algorithm (10) defined over a set of possible configurations over time. Preliminary decision rules reduce the policy space while retaining the optimal policy throughout. Operational aspects of port activity as well as capital availability are treated as the key to the definition of alternative decisions. This model has different restrictive assumptions. It is assumed that only one homogeneous commodity will flow through the port facilities, that only one type of ship operates in the port, and that constant elasticities of demand with respect to all demand variables apply. This model is nevertheless interesting and of use for decision making for investment in port development for underdeveloped countries, or in the planning of a single purpose port. A more recent work, of great interest, by Devanney, deals with similar types of problems (1).

Simulation Models of a Specialized Harbor

The development of data processing and resulting data collection, storage and aggregation methods now permit removal of the restrictive assumptions and the limited scope of the queuing theory type of analytical models through the use of simulation methods (12). Such simulation models permit study of the behavior of extended port models which include the land side (port transfer equipment, storage areas, inland model interface) and a broader range of assumptions (such as non-stationary, normally distributed interarrival times for ship, etc.) (13), (14). Simulation models have been developed for tanker, containerships and other single purpose ports or terminals. These models are used, for instance, for the generation of cost congestion or port impedence curves for given ports such as the ORNER model (13), which has been applied to derive the past and potential future cost of congestion for the nine major U.S. Atlantic seacoast ports.

Another interesting use of these models is to test alternative designs of single purpose ports such as specialized container terminals (15), (16).

The design of ports may be "optimized" by the application of a variety of search procedures to these models (17) (18) when the "optimal" set of port resource requirements (tugs, berths, cranes, yard transfer equipment, storage areas, etc.) may be found for a specific demand situation. The system criteria for such models is usually also a cost, profit or level of service measure. Due to the extension of the model boundaries, more factors than for analytical models must be included. These factors are often statistical estimates of the model state variables.

An extensive system measure of performance may be of the following type:

$$K = aSWt + bSBt + cCWt_1 + cCWt_2 + cCWt_3 + AFi/T + BFI/T_2 + BI/T_3 + GCi/T_4 + YTEI/T_5 + (LTEI/T_9) + IHTFi/T_6 + SAGCI/T_7 + SA/T_8 + HMCA + HMCBF + HMCG + HMCSAGC + HMCTE + HMCSA + (HMCLTE) + HMCiHTF$$

where:

a = cost of one ship waiting time unit

SWt = estimate of the ship waiting time average

b = cost of one ship berthing time unit

SBt = estimate of ship berthing time average

c = cost of one cargo unit waiting time unit

CWt_1 = estimate of the cargo waiting time average under the gantry crane facilities

CWt_2 = estimate of the cargo waiting time average on the storage area

CWt_3 = estimate of the cargo waiting time average within the inner harbor facilities

AFI = "Land" allocation investment for anchorage facilities

T_1 = life period of the investment

BFI = berthing facilities, i.e., tugs-investments

T_2 = life period of the investment

B_1 = berths investment

T_3 = life period of the investment

GCI = gantry cranes investment

T_4 = life period of the investment

SAGCI = land allocation investment for storage area near gantry cranes area

T_7 = life period of the investment

YTEI = yard transfer equipment investment

T_5 = life period of the investment

LTEi = land transportation equipment investment

T_9 = life of these investments

A parenthesis means that this investment will usually not be taken into consideration

SA = storage area investment

T_8 = life period of the investment

iHTFi = inner harbor transportation facilities investment

T_6 = life period of the investment

HMCA = handling and maintenance cost of anchorage, per time unit

HMCBF = handling and maintenance cost of berthing facilities per time unit

HMCB = handling and maintenance cost of berths per time unit

HMCSAGC = handling and maintenance cost of area near the gantry crane

HMCTE = handling and maintenance cost of transfer equipment

HMCSA = handling and maintenance cost of storage area

HMCLTE = handling and maintenance cost of land transportation equipment

HMCiHTE = handling and maintenance cost of inner harbor transportation facilities.

One important problem with these models is to find the right level of aggregation of the state variables. Simulation models often fail to provide an effective analytical tool because of the number of unnecessary details included. This usually due to a lack of analysis of the problem and the model just simulates the ignorance of the author.

Another problem is the rapidly increasing computer time required to run

a simulation, particularly if designed for solution by application of a search type optimization procedure. Once again a right level of aggregation and a deep preliminary analysis is an important prerequisite.

Simulation models are too often opposed to analytical models. In fact, it is the opinion of the authors that they must be viewed as complementary. In this respect the preliminary use of analytical models helps to give a good insight in the system and to validate the simulation results. It furthermore permits an effective structuring of the simulation models and selection of an "optimization" or search routine.

Specialized Port Dynamic Simulation Models

The results obtained from specialized port simulation models may be used in a dynamic way for port development. This is, for instance, the case in the liquid bulk or tanker port simulation model as proposed by Parsons and Hill (19). The results of the simulation model are used in connection with a dynamic programming algorithm. A profit function allows the port management an addition through time of berths and tank farm. The seaport operations generate a given quality of service which in turn influence the demand.

The demand loop in such models may be disaggregated in order to study the interactions between the regional industrial growth and the physical port operations. This is the case, for instance, of the industrial dynamics simulation model of Hill (20) which studies mainly the effect of port delays and shipping costs on the region's industrial growth rate through seaport operations and seaport economics study. This model has been oriented towards the industrial development of underdeveloped countries.

An extension of this model could readily be applied to the decision alternatives of harbor-industrial growth development in Europe or the U.S.

Simulation Models of Multi-purpose Port

Multi-purpose port models by their very complexity, usually require application of simulation models. Multi-purpose ports are considered as an interconnected set of the four basic types of specialized port vice: dry bulk, liquid bulk, containers and general cargo ports. (21)

Constraints in the mixing of these subsystems due to limited interchangeability of loading/unloading and storage technologies are presented under the form of Boolean variables (0 - 1) square matrices in (21). These models are used to investigate the optimal structure of multipurpose port under a set of given constraints due to the physical limitations of the physical situation under study. They may be used too to study the effects on the whole port or the adjunction of a given specialized harbor (liquid bulk, container harbor, etc.).

Regional Analysis, Multiport Network Models for Multiport Differential Investments

The results obtained from the analytical or simulation analysis of multiple purpose port models may be fed into a multiport network, i.e., a sea-to-land transportation network with interconnected ports. The solution of a multiport network may provide the port planner with a good insight into the feasibility of closing down one or more ports and is of great help in macroeconomic planning for the development of port facilities.

A first step into the solution of this problem would be to determine, for a given situation, the optimum throughput of each port of a multiport network. This in turn would indicate which ports are being significantly underutilized and would lead to a closer more comprehensive inspection to determine whether or not they should be closed. A solution to this problem is presented by K. Chelst. (22)

The problem is to minimize the following nonanalytic objective function which is neither convex (because of possible economies of scale) nor concave (congestion costs) and does not explicitly incorporate fixed costs.

$$\min \quad \sum_i \sum_j Cij\ Xij + \sum_i fi\ (\sum_j Xij)$$

subject to $\sum_i Xij = Ai$ for $i = 1,2 \ldots n$

$j = 1,2 \ldots m$

with

Xij = amount shipped to hinterland j via port i

Cij = cost per unit for transportation from i to j

$Fi\ (\sum_j Xij)$ = function of the throughput (Xij) of port i which includes the cost of handling this volume and any congestion costs which may be incurred.

Ai = demand of port i.

In order to reduce the problem size, this objective function may be rewritten

$$\min \sum_j \sum_i Cij\ Xij + \sum_j fj\ (Vj)$$

subject to

$\sum_j Xij = Ai$ and

$\sum_i Xij = Vj$

The problem then reduces to a simple transportation problem which has been solved with an algorithm using a direct search procedure. This algorithm determines the optimum throughput at each port but **does not determine explicitly which ports should be closed.** An explicit solution to this problem is also presented by K. Chelst. (22)

This solution involves the consideration of three inter-related sub-systems which lead to the use of

a) An "Out-of-Kilter" algorithm to optimize a sea-land transportation network with convex variable costs. The costs associated with the port i to hinterland j will be the fixed land transportation costs. The costs associated with the multiple arcs between the source (foreign destination) and each of the ports will be used to represent a linear approximation of convex port handling cost curves obtained by simulation. In other words, for a given port, the total cost for a given throughput V* which falls between volumes Vi-1 will equal, excluding fixed costs

$C(V^*) = C1. (V1 - Vo) + C2. (V2 - V1) + \dots Ci. (V^* - Vi{-}1)$

subject to $C1 \leqslant C2 \leqslant \dots \leqslant Ci - 1 \leqslant Ci$

b) An improved Steepest-Descent; One-Point Move algorithm to solve the fixed cost transportation problem. In that case, the problem objective function is

$\min \Sigma_j \Sigma_i Cij\ Xij + \Sigma_i f_i\ (\Sigma_j Xij) + FC_i . Yi$

subject to

$\Sigma_i Xij = Ai$ and $Yi - o$ or 1

with

Xij = amount shipped to hinterland j via port i

Fi $(\Sigma_j\ Xij)$ = function of the throughput $(\Sigma_j\ Xij)$ of port i which include the cost of handling this volume and any congestion costs

Fci = fixed cost assigned to port i

Ai = demand of port i

Yi = determines whether port i is open or closed

c) A three-stage use of the improved Steepest-Descent, One-Point Move algorithm to solve the following problem, which is an extension of the preceding one, and includes the trade routes problem:

$$\min \Sigma_i \Sigma_j Cij\ Xij + \Sigma_i fi\ ({}_0\Sigma Xij) + {}_i\Sigma FCi\ Yi + \sum_{R=1}^{N} \sum_{i}^{q} CRi\ Ri$$

subject to

(1) $\Sigma_i Xij = Aj$

(2) $Yi \leqslant {}_R\Sigma\ Z_{Ri} \leqslant N.\ Yi$

(3) $Yi = o$ or 1 and $ZRi = o$ or 1

with

Cij = port hinterland transportation cost

Xij = amount shipped to hinterland j via port i

fi $(\Sigma_i\ Xij)$ = congestion cost

FCi = fixed cost assigned to port i

CRi = fixed cost of maintaining the trade route from foreign port R to port i

Yi determines whether port i is open or closed

Z_{Ri} determines whether trade route Ri is open or closed

Partial investment or partial closing of a port facility or reinvesting the facilities of a port elsewhere are not acceptable alternatives. Similarly, this model deals only with homogeneous commodity flows, in both directions. This last assumption is in the process of being removed by an appropriate algorithm provided by B. Golden (23).

Regional Analysis Multiport Network Model for Minimal Transfer Cost with Quadratic Function

It is also possible to view the multiple seaport problem as a multiple seaport transportation network with quadratic costs.

In that case a set of ports is visualized as being imbedded in a transportation network responsible for the movement of different commodities Xi from a set of origin ports Pn to a set of inland destinations Dj or vice versa. We have then a sea-port-land transportation network and the costs are assumed to be the sea-port and land transportation charges.

The sea and land transportation charges are assumed to be fixed cost/unit charges being dependent upon commodity type and route taken. We shall name them respectively b_{imn}, sea cost of commodity i from port origin n to port m, and S_{ijm}, land transportation cost of commodity i from port m to a destination j. The port costs will be assumed to be composed of two parts:

(1) a fixed cost/unit charge similar to that for the land and sea links, and that we shall name 1_{im}, fixed transfer cost for commodity i in port m.

(2) a variable cost, function of port congestion. We shall name W_{im} the congestion coefficient for commodity i in port m.

We may then write that the total

commodity transfer cost C_{im} is equal to:

$Cim = e_{im} + him\ Wm$

with

e_{im} = fixed transfer cost for commodity i in port m

him = congestion cost of commodity i in port m

$Wm = \Sigma_i W_{im}\ Y_{im}$ Congestion of port m,

with Wim congestion coefficient for commodity in port m

$Yim = \Sigma_n \Sigma_j Xijm$, rate of flow of commodity i through port m.

Hence,

$Cim = Eim + him\ \Sigma_i\ Wim\ \Sigma_n\ \Sigma_j\ Xijmn$

Limitations on commodity mixes and rates of flows are assumed to be modeled by simple linear constraints such as

$\Sigma_i \Sigma_j \Sigma_n\ FRijmn\ Xijmn \quad Dhm \leqslant h = 1,2 \ldots H$

where Fhijmn is the constraint coefficient for port m, commodity i, origin n, destination j, and constraint equation h, while DRm is the constraint for a port m with constraint equation h.

Commodity routing through the transportation network is based on total minimum cost of transfer from origin to destination subject to the port constraints and cost structure.

Each origin will be assumed to have its own scheduling algorithm, and attempts to minimize its own shipment costs which implies multiple objective function, i.e., a total overall cost objective function and a cost incurred by origin n objective functions are:

– total overall cost t

$t = \Sigma_i \Sigma_j \Sigma_m \Sigma_n (b_{imn} + S_{ijm} + C_{im}) X_{ijm}$

– cost incurred by origin m, tn

$tn = {}_i\Sigma\ \Sigma_j\ {}_m\ (b_{imn} + S_{ijm} + C_{im})\ Xijmn$

subject to

$a_{ijn} = {}_m\ Xijmn$ for all n, i, j

and

$\Sigma_i \Sigma_j \Sigma_n\ Fhymn\ Xijmn < D_{hm}$ for $h = 1, 2 \ldots H$

which can be rewritten as

– total overall cost, t

$t = \Sigma_i \Sigma_j \Sigma_m \Sigma_n (b_{imn} + S_{ijm} + e_{im} + h_{im} \Sigma_i W_{im\ xijmn}) X_{ijmn}$

– Cost incurred by origin n, tn

$tn = \Sigma_i \Sigma_j \Sigma_m (b_{imn} + S_{ijm} + e_{im} + h_{im} \Sigma_i W_{im} \Sigma_i \Sigma_j X_{ijmn}) X_{ijmn}$

One can immediately see that the objective functions are quadratic in X. Simultaneous minimization of such interacting objective functions could be performed by combining the separate objective functions into an overall or weighted sum of shipping costs.

A solution to this problem is proposed by R. Parsons using Dantzig's Simplex Algorithm for quadratic programming. (24)

Conversely, simulation through time of the development of schedule could be performed by starting with a feasible routing schedule in which all routings except that of one origin are fixed.

A Monte-Carlo method then selects another origin and this origin's algorithm would next be allowed to modify its routing. This process is repeated until the overall routing schedule either converges to a stable solution or settles into oscillation.

Intercontinental Multiport Network Analysis

The boundaries of the preceding models may be expanded in order to include both sides of the ocean. The study is related to a land-to-sea-to-land transportation network. Such a model is presented by Noble-Potts (25) in a linear programming model of the United Kingdom to Australia containers network. This model gives an optimal policy for the shipping of empty containers to inhibit imbalances between the imports and exports of the two sides of the ocean. This model assumes a constant demand. A dynamic model of a similar containers network is studied in ref. (26).

This model is a dynamic continuous simulation model which investigates the behavior of container networks in response to endogenous or exogenous demand changes. A search procedure linked with this model enables us to find the optimum policies for the shipping of empty containers and for the acquisition of new transportation capacity. Finally, the imnortance of information degradation in relation with inventories and sales is also studied with this model. These models are complementary for the study of the difficult tactical and strategical problems in relation with containers network development.

Conclusions and Recommendations

In this paper we have presented a review of a broad sample of different models used in port planning and analysis. We can now try to derive the basic features of methodology in port planning and analysis.

1) The first and most difficult prob-

lem for the port planner is the definition of its problem level. The difficulty of the solution and the amount of work will be generally a direct function of this level. High strategic level problems need the inputs of more basic models.

2) The second point is then to define the set of cascading models necessary to feed the appropriate data to the model under study. For instance, the results of simple analytical models are used to feed or to validate more complex single or multi-purpose harbor simulation models. The results of these models may be used then under the aggregated form of cost congestion curves, in a higher level multiport analytical or simulation network. It is the authors' opinion that there is no basic opposition between simulation and analytical models but that they are complementary.

3) As a result of the high cost of building quantitative models and acquiring reliable data and because of the great diversity of specific port situations, it is necessary to build up a set of general tools applicable to any particular situation in relation to any form of system measure of performance.

There is still a great deal of work to be done to develop a truly effective set of analytical models and techniques of use to port designers and decision-makers. A broader body of knowledge in this field is needed and the necessary inclusion of qualitative factors (technological, environmental, etc.) will be quite a problem. Real implementation will be the final test of the validity and usefulness of the models under study.

BIBLIOGRAPHY

1. Nicoloan, Stairos N., "Berth Planning by Evaluation of Congestion and Cost," Journal of the Waterways and Harbor Division, Proceedings of the American Society of Civil Engineers, November 1967.

2. Ahrenholz, O. J., "Network Analysis of a Water Port Complex," Transportation Network Analysis, System and Terminal, Proceedings of Meeting, April 17-18, 1969, R.S.M.A., October 1969.

3. Pepin, Jacques, "Etude des Facteurs Relatifs au Dimensionment Economique des Ports Commerciaux," Universite Catholique de Louvain, 1970.

4. Agerochoen, H., and Koresgaard, S., "System Analysis for Port Planning," Dock and Harbor Authority V. 30, N. 581, March 1969.

5. Thornton, R. C. and Williamson, E., "Improving Berth Utilization," Dock and Harbor Authority V. 30, N. 594, June 1969.

6. Kaufmann, A., "Methods et Nodels de la Recherche Operationnelle," pp. 154-164, Paris: Dunod 1962.

7. Morse, Queue, Inventories and Maintenance, John Wiley.

8. Novaes, A. G., Commodity Transportation and Economic Development Laboratory, M.I.T., 1972.

9. Taborga, Pedro, N., "Determination of an Optimal Policy for Seaport Growth and Development," Research Paper R 69-43 under Prof. E. G. Frankel's supervision, M.I.T., July 1969.

10. Kaufman, Arnold, Dynamic Programmin Sequential Scientific Management, Academic Press, New York, 1967.

11. Devanney, J. W. III, Loon, Kok Goon and Hock, Gim Thio, "Fundamentals of Port Pricing and Expansion," M.I.T. Report No. MITCTL 72-4, May 1972.

12. Gordon, G., System Simulation, Prentice-Hall, 1969.

13. Orner, Ron, "Port Simulation Program," Commodity Transportation and Economic Development Laboratory, M.I.T., March, 1973.

14. Unctad, "Development of Ports," 1969.

15. Creton, Jean-Michel, "Simulation of a Container Terminal," Commodity Transportation and Economic Development Laboratory, M.I.T., 1973.

16. Wilmes, Phillipe, "Container Terminal Optimal Design," M.I.T., Commodity Transportation Lab. No. 73-2.

17. Creton, Jean-Michel, "Review of Optimization Methods Applicable to a Computer Aided Design of A Queuing System Using a Simulation Model with Stochastic Processes," Memorandum Commodity Transportation and Economic Development Laboratory, M.I.T., January 1973.

18. Dieudonne Dominique, "Utilization d'un Algorithme Interne d'Optimisation avec un Modele GPSS 360/I, University of Louvain, Simulation Center, March 1973.

19. Parsons, Ron and Hill, Lawrence, "Analysis and Simulation of a Seaport," Research Paper under the Direction of Prof. E. F. Frankel, Commodity Transportation and Economic Development Laboratory, M.I.T., May 1971.

20. Hill, Lawrence—Parsons, Ron—Ross J., Scheldon and Scheldon, Seaport Operations: Applications of Dynamic Programming, Adaptive Control Processes and Industrial Dynamics, Research Paper, Department of Mechanical Engineering, M.I.T., April 1970.

21. Wilmes, Phillipe, "Port Analysis and Simulation," Commodity Transportation and Economic Development Laboratory, M.I.T., December 1972.

22. Chelst, Ken, "An Approximate Algorithm for Minimizing a Sea-Land Transportation Net-Work with Interrelated Fixed Costs," M.I.T., Commodity Transportation and Economic Development Laboratory, No. 73-1.

23. Golden, Bruce, "System Optimizing Algorithm Applied to the Import-Export Network Flow Problem," Memorandum Commodity Transportation Laboratory, March 1973.

24. Parsons, Ron, "Multiple Seaport Transportation Network with Quadratic Costs," M.I.T., Commodity Transportation and Economic Development Laboratory, No. 72-4.

25. Noble-Potts, "In Traffic Flow and Transportation—Proceedings of the Fifth International Symposium on the Theory of Traffic Flow and Transportation," American Elsevier Publishing Co., New York, 1972.

26. Wilmes, Phillipe, "Etude du Comportement d'un Reseau de Distribution Physique de Conteneurs, a l'aide d'un modele de simulation," University of Louvain, (forthcoming).