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The application of computer science in port planning and operation.

Application des techniques de l'informatique dans la conception et l'exploitation des ports.

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S. II - 5

Section II - Ocean Navigation - Subject 5

The Application of Computer Science in Port Planning and Operation.

GENERAL REPORT

by

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Although the electronic computer has become, during the last decade, as common a feature in any administrative or engineering office as was the slide rule thirty years ago, one must begin by devoting a few words to making clear the basic concepts upon which these machines and their use rest, so that we may analyse and summarise the papers which have been presented on the subject which concern us. In this context, it will be helpful to bear in mind what follows :

The electronic computer is a machine capable of receiving, storing, and processing data, and of yielding the results of these operations; it does all this automatically, and without the need for intermediate instructions.

It is capable of receiving data, and giving the results, in numerical, graphic, or analytical form, of storage, be it of input data or results, and of the modification of such data in accordance with pre-established commands.

There is a basic distinction between analogue and digital computers, according to whether they can accept data in graphic or analytical form, or whether numerical expression is required; and also, between simultaneous and sequential computers, according to whether they can carry out a closed process which runs concurrently throughout its duration, or whether, on the other hand, they process in succession several phases of a single operation.

The computer in most general use is the digital sequential, which, basically, comprises the following : one unit for the input, or receipt, of data; another for the output of results; one or more arithmetical units for calculation; one control unit; and a memory, or store.

Normally, simultaneous computers are designed and built for a particular process, which often has to be worked out with several variations in its input data. The sequentials, on the other hand, can be made to handle various mathematical operations, which are programmed by their processing in series.

It is easy to understand that the simultaneous computer is the fastest; but, at the same time, it is the more complex, because it requires the existence of several calculating units in simultaneous operation. The sequential computer, on the other hand, is slower, but also simpler, in that one calculating unit on its own can process successively different parts of the same operation.

When one wishes to employ a computer to analyse a problem, one must do as follows : *a*) Organise the input data, and the desired results, in either analytical or mathematical form. *b*) Analyse the operation that one wishes it to study, breaking this down into a series of stages, or phases, defined in terms of mathematical operations. *c*) Draw up a diagram, or open or closed circuit, comprising those separate stages. *d*) Organise the units of the computer which are to receive the data, do the processing, and yield the results mentioned. And finally, *e*), codify the data, results, and instructions, in such a way as to allow them to be introduced into, and accepted by, the computer.

If we add these basic ideas, already known by everybody, to the factors of the enormous speed at which this machine calculates, and of its ability to accept or process very large quantities of data, one can see how its use could become very helpful in the wide variety of operations involved in port planning and operation.

Indeed, the papers presented on this theme at our Congress numbered ten, from the following countries : the Federal Republic of Germany, Canada, Denmark, Spain, the United States of America, Finland, France, the Netherlands, Poland, and the United Kingdom. Before commenting on their content as a whole, let us consider the summaries of each.

SUMMARIES OF THE PAPERS

Federal Republic of Germany

For the past two years the Port of Hamburg has used a computer system for the collection of data, in order to consolidate, and have quick access to, all the data concerning the transportation of goods, from the point of consignment by the shipper to that of receipt by the consignee.

This system became indispensable as a result of the speed in the handling of cargoes, often caused by the arrival of the goods before that of the documents relating to the consignment.

After these preliminaries, Messrs Bisschoff and Steinecke continue their paper by explaining the nature of the work of the various intermediaries encoun-

tered by the port traffic in Hamburg. Basically, these comprise the forwarding agent or shipper, the port loading service, the ship broker, and the inspector of shipments (tally). All these people, to arrange their work properly, need to use more or less the same information, the greater part of which is supplied by the shipper and the inspector of shipments.

Since it was considered preferable to collect this information in one operation, a Data Bank of the Port of Hamburg was created, under the auspices of the leading firm of shippers and shipment inspectors. Acting by mutual agreement, the destination, types of goods, types of packaging, etc., have been coded.

The information concerning each lot of goods loaded is sent by telephone, duly coded, from the shippers' offices to the central control office. The efficiency of the communication of the information is ensured by the use of T.V. and telex.

The assembled information, which combines the characteristics of each lot of goods, provides the necessary data for invoicing, statistics, etc., helps in the calculation of freight by the ship's agent, and the rapid preparation of the loading list, as well as in the planning of storage space, and handling on the quay.

It is hoped that this project for the systematic collection of data will be realised in its entirety in 1974.

Another application revealed by the authors in their paper is that developed by the Hamburg Port and Warehousing Co., for a system of operations control in their container terminals in the port of Hamburg.

The system being introduced aims at the supervision and control of all movements of containers, of chassis, and of goods to be put into containers, at the organisation of documents, and the regularisation of links with other, conventional, systems of cargo-handling.

The system has been begun with a control carried out by an IBM 360/20 computer, which processes the shipment and discharge operations, the loading and unloading of containers into and from rolling stock, and transfer from rail to road transport.

Canada

The Canadian paper confines itself to a detailed description of the complex system of traffic control through the length of the St. Lawrence Waterway and the Great Lakes, a system the plans for which, as a whole, are now well advanced. It is based on a wide application of computer science, and part of the service planned is already in operation.

The paper begins with a description of the sections of this waterway, under the responsibility of the St. Lawrence Seaway Authority, a branch of the Canadian Ministry of Transport. It explains the reasons which necessitated the introduction of the services described, a result of the difficulties which increased traffic, the use of new types of vessels, and the opening of the 190 miles long Montreal-Lake

Ontario section would have produced, from 1967 onwards, in the traffic flow throughout the length of the Welland Canal, 28 miles.

In outline, the problem was to obtain an optimum use of the installations, by determining, over as short as possible a fixed period, the best solution as regards the organisation of traffic, and of the service.

A solution was first attempted by manual means, but one had to yield to the fact that such methods were clearly impossible if proper use was to be made of all the initial data to arrive, in the time available, at the best solution.

The use of the appropriate techniques leads to one's obtaining a better operation, through the realisation of a stage as a whole, equipped with good connections, and covered in a limited time; to a centralisation of traffic control, resulting in a simplification of decision-making; and to the use of a suitable network of communications by VHF radio and closed-circuit television.

The dynamics of the system are based on the determination of input data relating to the random order of arrival of vessels, the order of appearance in the locks, and the normal service time in the installations; to the carrying out of other operations, such as loading and unloading, pilotage, etc.; and, finally, to breaks in the service.

The rules which these input data follow have been established on the basis of the law of distribution of Poisson and Erland, with the coefficient $K=2$.

Next are explained the functions that it was aimed to fulfil with the initial project for the system, drawn up in 1968-69, which consisted essentially in the collection of data, its processing, the location of vessels, the planning of traffic, and information.

As the dynamic of the system took shape, it became clear that the earlier obtaining of the information relating to the movements of approaching vessels would reduce the randomness of arrivals, and, as a result, would allow the waterway a higher traffic capacity, or would reduce the waiting time.

Since these input data came from separate sources, however, a new proposal was made in 1970, aimed at combining in one single centre all the work of the bodies who provided the data, numbering six Canadian, and two US. At the beginning of 1971, the Canadian bodies accepted the integration of their data, and at present negotiations are in progress with the Americans, to get them to agree as well.

During this time, advantages had accrued in the technology and prices of industrial computers, whose introduction had permitted the extension and better definition of the information required by the system, as well as of the output data that it could provide.

This information relates to the characteristics of vessels and the immediate knowledge of their precise whereabouts, as well as to immediate knowledge regarding the positions of lock gates, of bridges, of the berth situation in the ports, and finally, to meteorological observations.

A preliminary object of the system is that of detecting and warning of abnormal conditions, drawing up reports, where necessary, and consolidating the information coming from the various agencies, eliminating it the moment it ceases to be of use.

Next, one comes to the true aim of the system, that is, planning in such a way as to improve as far as possible on the transit time for each vessel, or on the capacity of the installations. To this end, the drawing up of simulation programmes is being attempted, to decide upon the ideal solution, as is the establishment of a system for the analysis of the variations relating to such a solution. This part of the project has not yet been realised.

It is clear that the use of the system described depends upon the immediate identification of vessels, and the certainty of a continuous communication between them and the control centre. With this in mind, a study has been made of a special system by VHF radio, using special radio-telephones which the pilots take on board the vessels, and which the latter must use during their passage along the waterway. The possible application of a Loran system is also under study.

The paper ends by pointing out that the cost of the system, excluding research and development costs, will be in the order of 5 million dollars, of which 3.5 million is accounted for by the systems for the location and identification of vessels. The economies will be in the region of 2 million dollars per annum, 1.5 million for the transport industry, and the rest for other agencies.

Denmark

Professor Hansen's paper concerns a very practical study of the optimum dimensions or other characteristics of a container terminal.

The author makes certain simplificatory assumptions, assuming that the storage area is of an infinite capacity, and taking no account of the stages of filling and emptying, of the formalities that determine the length of a container's stay on land, or of any of the stages of their removal or arrival by land transport.

He thus limits the input data to the percentages of ocean-going vessels and feeders, to the maximum variations in forecasts of arrival times, to the number of days worked per day and per week, and to the total volume of traffic which the terminal has to serve.

The principal results, or output data, supplied by the model are the length of quay and the number of cranes, and the costs of handling in each case.

In that the example presented is intended to lead, and succeeds in leading, to very concrete results, the author takes as his point of departure for the calculation of costs certain assumptions concerning the cost of labour and plant, the writing-down periods, and the return on capital that the investment in the quay can be made to yield. Equally, he starts from very precise data as regards analogous cost levels in the case of vessels.

Beginning as he does on a basis of very precise initial costs and very clear and simple simplificatory hypotheses, the author presents the basic plan of the simulation model which served as the norm for the programming of the computer.

This diagram, prepared for processing by an analogue computer, is very clear and very simple, and leads to very concrete results, summarised by the author at the end of his paper.

Spain

The Spanish paper sees the employment of computers as useful in four directions : port planning; the design and execution of works; port operation; and the study of relations with outside economies.

It describes their use in port planning in the form of simulation models; starting from input data relating to social, economic, and industrial trends, which result, in turn, from existing studies and statistics, duly consolidated, they should lead to one's obtaining results sufficiently detailed to be capable of serving as a basis for planning and investment decisions.

One is led to remark that, given the enormous complexity of a general model aspiring to cover all the possibilities of a port in its totality, one has in practice to subdivide the study of the whole into a series of sub-systems, or sections, which the port comprises. Furthermore, the type of planning which demands study can be carried out in short or long term perspective, and is equally applicable to new installations as to the improvement of those existing. Clearly, the initial limitation and precise definition of one's objectives simplifies the problem, and, as a result, the simulation model to be programmed.

In the field of planning and construction, the authors estimate that the applications most often concerned are those analogous to the applications in other branches of civil engineering, although there exist certain specialised areas, such as the study of jetties, factors exclusive to ports; nevertheless, the types of problem are the same.

The authors find a clear application of computer science in port operation; it has here a double role, firstly, of speeding up and rationalising administrative processes (invoicing, pay-rolls, etc.) which, as they say, are common to other industrial enterprises; and, secondly, in the field of the organisation and the increase in efficiency of the operations of handling goods, that is, in its aspect of making the optimum and most profitable use of the installations available, through a more rational organisation of the work.

To this end, also, one can study simulation models, more practical and easier to draw up than those relating to the planning field, which were mentioned as the first application of computer science. In this case, the initial, or input, data would be derived essentially from statistics based, not, as in the first case, on the future, but on the immediate past.

The possibility of applying this technique in practice in the case of single unit cargoes (containers, bulk cargoes, etc.) gives room for a gradual extension of the use of computer science in the progress in port operation.

Finally, the fourth application thought possible, that is, in the relationship with outside economies, concerns the choice, in a comparative study of routes from port of origin to port of destination of which would be the most economic route, in terms of both time and money, amongst all those theoretically available.

In this case, of course, the periods of time required, and the port charges, should be combined with corresponding data concerning freight rates, transport by land, and intermediate storage.

The study, and the subsequent taking of decisions, can take the form of deferred time, for general planning, or, on the other hand, of real time for immediate decisions, although in order to realise the last application, one has to be able to rely on a network of telecommunications allowing transmission of the decision.

In the second part of the paper, three concrete cases are discussed, relating to the first three applications mentioned in the first part.

The simulation model for port operations, described in detail, relates to the study of the working of two terminals, one for containers, the other for cereals. It is programmed in FORTRAN IV language, and takes one minute for each hypothesis studied.

Starting from certain simplificatory assumptions as regards berths, mooring ground, storage, etc., the model allows one to calculate, on different hypotheses as to the time worked by the harbour service and the times of arrival of vessels, the continuity in the rate of arrivals and departures, the type and tonnage of each vessel, the waiting time and servicing time per vessel, and per type of vessel, the cargo volume handled per vessel and per type of vessel in total over the period studied.

The input data are the tonnages to be handled, and their rules of variation, data as to the distribution of types of vessel and their cargoes, the efficiency of the installations, the norms of time spent servicing, and the period of simulation.

The data and results obtained by this model are explained in detail.

The case of the application to proposed structures relates to the obtaining, the storage, and the processing of data on the swell, as a necessary stage in the planning of jetties in ports.

The installation built for this purpose in Spain during 1972 is described. This comprises a system of measuring apparatus, linked by telegraph and radio to the « Ramon Iribarren » Port Laboratory in Madrid, where processing of the data is carried out.

The information received in this way from ten observation points is fed into an analogue or Fourier computer, which has up to 70 basic instructions, and 8 instantaneous programming instructions. By these means, one can achieve

the processing of all the data in accordance with various mathematical hypotheses, in the form required for its storage, analysis, or transformation.

Finally, details are given of the work being undertaken at the moment in the Port of Barcelona in the field of computer science application to administrative operations.

Here, the large volume of information arising from the carrying-on of port operations is coded, and punched onto tape, on which a computer, in accordance with previous programming, relies, on the one hand, to compile the summaries of necessary statistics, and on the other, to calculate, print, and prepare the total sums and the invoices of the services of the Port Administration that carry a charge in respect of vessels, goods, and stevedores.

The authors analyse in detail the system followed, and comment upon some inconveniences in the tape system, in view of the complexity of the tariffs to be applied. They consider preferable, for this type of application, the card system, to which it is intended to reconvert the equipment, since, slower though it may be, it allows partial corrections and verifications to be made more easily, without producing delays in the working of the system as a whole.

They also discuss the application, without problems, that is being made of computer processing in the calculation and the making-up of pay-rolls and pay-slips for employees' wages.

United States of America

The USA paper is divided into several parts. In one of the first, it examines the general field of application of the various types of computer to the different aspects of port activity. It describes very clearly the various ideas of programming, that is, the translation of the problem posed into a language that can be understood by the computer, as well as the classes of operation that can be carried out by these machines, and the degree of precision in the results they give.

In the result, it determines the areas of application most appropriate to each model for the different and complex questions which have to be settled in modern port operation techniques.

In concrete terms, the paper considers that the present applications for these kinds of computer are as follows :

— Processing of normal administrative operations;
— The gathering of statistics, and forecasting on the basis of their extrapolation;
— The establishment of an orderly traffic system by the use of simulation models;
— Determination of the optimum decisions as regards planning and construction;
— Co-operation with other means, such as radar, to obtain greater security in navigation in the port approaches.

After summarising the results of consultation with several hundred ports, one arrives at the conclusion that, at present, there are several ports which use

computers in their operations. For the most part, the work they carry out consists of the compilation of data and statistics, and in the port's administrative tasks.

It is believed, however, that their development will be in the direction of establishing forecasts and optimum decisions in relation to the problems both of efficient exploitation and of financing.

Next, the paper examines the different types of simulation model, which it divides into those using deterministic mathematics, those using stochastic mathematics, and the physical. It further sets out the basic characteristics, and the objective, application, and accuracy of each type.

The second part of the paper is devoted to a very detailed description of the basic concepts of the « Monte Carlo » simulation model, which belongs to the stochastic mathematics type, and the different languages that one can apply to it; it goes through several examples of the breakdown of operations that makes their mathematical programming possible.

In the third part of the paper, two diagrams of an entire port complex are presented, one for imports, and the other for exports, each with their particular kind of breakdown of operations, which will allow their programming; attention is drawn to their application to the San Fransisco Bay, considered as a single port.

Finally, a brief reference is made to the application of computer technology to traffic safety, giving as an example the system introduced by the Coast Guard for the control of traffic in San Fransisco Bay and its approaches.

In the summary and conclusions with which the study ends, the opinion is expressed that the widest application of the techniques in question will be found in the realm of the collection and analysis of statistics to determine the future needs of ports. It is also considered that simulation models will find increasing use in the future in the solution of problems of port operation and planning.

As regards the economic advantages which will be obtainable, for example, in the field of construction, through the use of computers, the author makes an estimate as regards the actual cost of the construction of the model or programme which is of interest : he concludes that this technique will not be an economic proposition unless the plans involve an investment of more than 10 million dollars.

Finland

The Finnish paper refers to the study carried out in that country to discover which approach routes were the most appropriate, economically speaking, for use by long distance commercial traffic coming to or going from Finland. In making this choice, the principal factor is to be found in the difficulties arising from the presence or absence, according to the time of year, of ice off the coast.

Finland receives, and exports, 95%, and 80%, respectively, of its goods by sea, and the approach routes cross the Baltic, and continue into the gulfs of

Bothnia and Finland; the traffic comes up against the problems of the pack-ice and drift ice which exist for periods varying between 2.9 and 3.3 months of the year, on average.

However, the availability of ice-breakers, and the increase in the number of merchant ships specially equipped for navigation in ice-floes has rendered technically possible, nine years out of ten, the access of vessels to all the Finnish ports.

This capacity is, however, related to the expense, which is variable, but often large, of opening the routes across the ice-floes; it was, therefore, considered appropriate to carry out a study, which is explained in the paper, to determine the most economical routes for the access of Finnish foreign trade during the winter months. As a matter of logic, one must combine the various possibilities, and the costs of access by sea with the costs of transport inside Finland in getting from the ports of access to the destination of the goods, and all that at different times of year when navigational conditions necessarily vary.

There follow the bases of the study, or input data :

a) A precise and complete table of prices and monetary depreciation up to 1980.

b) The size of vessels, and the extent to which they are fully-laden.

c) Weights, and the possibility of using fully-loaded trains for transport by land.

d) The quantity of goods transported with the aid of ice-breakers.

e) The classification of goods by groups, according to their nature, and, also, according to whether they have to be transported all year long, or can be stored through the winter.

f) The traffic, and its growth, in terms of both quantity and type.

g) The need for modifications in the type of transport, changing from sea transport to land, as a result of unforeseen climatological conditions.

In accordance with these factors, diagrams were initially drawn up of the different combinations of routes between ports of origin and destination.

The study relating to the diagram was carried out using three mathematical models. The most important covers the whole system of sea transport, and the two others, in a supporting role, relate, one to a single port, and the other, to a study of delays in the arrival of vessels.

The principal model was subdivided, in turn, into three study sections, each of which was devoted to different times of year, characterised by differing weather conditions.

The paper sets out the simplificatory hypotheses that had to be made, and the division of variations in the input data into uncontrollable (climatic conditions, etc.) and controllable (choice of routes).

As a result of the study made, very specific conclusions were reached in this case in the determination of the optimum routes for traffic.

France

The French paper, after some initial comments on the vast range of port activities in which computer science finds an application, explains how the French ports use this new science in the following manner :

In hydrodynamic studies, carried out by several official laboratories and private undertakings, computers are used to receive, store, and analyse, in statistical form, data on the swell, soundings, and the propagation of tidal currents, etc. With the help of these analyses, it has been possible to replace the original, manual compilation by graphic records, obtained mechanically, infinitely quicker and more reliable, and to carry out calculations by extrapolation which were wholly impracticable up to now.

In the field of hydrodynamic studies, the computer is also used in combination with small-scale models to take in, and analyse, not data about natural phenomena, but data produced and established by such models.

Also mentioned in this section on hydrodynamics research is the analysis of the operation of the systems of the filling and emptying of locks, and of the movements at their moorings of large vessels, from the point of view of the hydrodynamics that such vessels involve.

In the field of construction, computer science is applied in ports for the calculation of construction works, and landslips in the laying of foundations, etc. This application, although not exclusive to port activity, being shared with other branches of civil engineering, was the first application to be used in French ports.

In the field of economic studies, the use of traffic simulators is frequent as far as French ports are concerned. For these simulation models, some of the input data are hypotheses, and some actual statistics. Amongst the data, one should draw attention to : the flow of goods, the freight rates on the different routes, the composition of the fleets and the characteristics of the vessels, as well as the data concerning the tides in the port approaches, and the simulation models, which are capable of working out the waiting periods, the most suitable port equipment, and the most economic route. These simulation models have been used in the port of Dunkirk, as much to compare the usefulness of a pipe-line in relation to sea-traffic for the supply of petrol to Western Europe, as for the study of the traffic flow in general. The technical department of the Ministry of Works has also built a basic simulation model for a terminal for container-ships.

As for the use of computer science in port administration, the French paper distinguishes between applications peculiar to ports and those also found in undertakings other than ports, that is, between those applications relating to accounting operations, calculation of invoices, the making-up of staff pay-slips, etc., and those others which are specific to port operations. Amongst the latter are, to begin with the most important, the statistics of goods handled, compiled with the help of the Customs Service, and those relating to operation, as well as the applications in the planning of tug services and pilotage.

Again, according to this paper, computer science is equally widely used in the operations of consignment by sea carried out by French agencies, especially where container traffic is concerned. Particular mention is made of the organisations of shipping lines, and the Cie Générale Transatlantique, whose purpose is to carry out the processing of data on the making-up and breaking-down of bulk cargoes, on loading and discharge, and on origins and destinations; this information is then transferred to the administrative documents, and is sent by rapid, automatic, means to the ports of call.

Finally, in this description of the applications realised in France, attention is drawn to the fact that computers are not used by road transport dealing with the ports; on the other hand, the French railways normally do use them in the marshalling yards, and especially in those located in ports, with the object of facilitating the organisation and operation of the rolling stock depot.

M. Giauffret concludes his paper by making it clear that computer science already finds wide application in French ports, representing between 1% and 1.5% of their running costs. He expresses the opinion that this application will continue to increase, and that it will assume greater importance, in particular, in the field of simulation models, which will themselves be improved.

He foresees expansion of the system in the vertical sense, that is, to cover a growing number of activities in a single work centre, be they official or private, and in the horizontal sense, understanding by that the progressive co-ordination of the activities of different centres or agencies.

To arrive at this result, he considers it desirable, indeed, almost indispensable, to reduce to the minimum the number of decision centres, and to harmonise the terms and the codes for the classification of goods and other input data.

The Netherlands

The Dutch paper begins by setting out some general considerations on the present need to take rapid decisions as regards the planning of port extensions, and also during their periods of operation. It also draws attention to the fact that the use of computers facilitates the necessary work in testing and research.

The choice of the type of extension cannot be decided upon except on the basis of a careful weighing of the various possible solutions, as much from a technical point of view as from the economic and financial.

The factors to be taken into account daily increase in number, owing to the growing economic interdependence between ports and their surrounding regions.

The paper groups as follows the principal factors which have to be taken into account :

1. The different possibilities as to extension.
2. The new types of packaging and new types of vessels.
3. The economic planning and development of the areas around the port.

Next, the problems that are to be studied are divided between those that are static, and those which are dynamic; the former are those which involve only limited investment for the improvement of existing installations; the latter are those which require forecasts of future developments, and which presuppose considerable investment, exposed to heavy financial risk.

Those in the first group, that is, the static problems, are tackled by means of a model suitable to the simulation technique which permits the arrangement of the input data.

It must be borne in mind that the variables in the input data, as much those relating to decisions to test as those arising from available statistics, as well as the output data that are dependent on the behaviour of the model, should be studied according to the appropriate mathematical rules; this involves a considerable effort in terms of the practical results obtained.

Naturally, the complexity of the model increases with the size of the installation studied; that is why these types of project have to be confined to port units of a limited size.

As regards the dynamic problems, they present much greater difficulties, for the simulation model must take into account variables which are more difficult to assess, such as the types of vessel and of packaging, the methods of handling, transport, and storage, etc., which will be needed in ten to fifteen years time.

These problems are also tackled by special analysis techniques, and one also breaks the whole down into stages which can be studied separately.

The authors refer to the « line », and to the combinations of solutions which must be studied as the « best guess » for the basis, after discussion, of the planning and definition of the variables to be introduced into the model.

Next, the paper describes the general procedure known as « decision-analysis », distinguishing the following three stages : the deterministic phase, in which one builds a model with the desired interdependence between the input and output variables; the stochastic phase, in which one adverts to the rules of variation in the input variables; and finally, the phase of information processing, in which one tests the economic sensitivity of the model, and corrects it, in such a way as to eliminate the possible existence of small variations in the input variables of uncertain value, which could have an excessive influence on the output variables.

The authors consider that this system does not arrive at a mathematical exactitude, but falls short of it in the necessity to : adopt definite opinions; remember that the solutions are probability solutions, not certain ones; and to keep in mind the limitations of the model, and not forget to take into account the circumstances of the area surrounding the zone studied.

In its second part, the paper describes two examples of the system of « decision-analysis » in operation.

In the first, the problem was to decide upon the propriety of investing to enlarge and improve two container terminals in the Port of Rotterdam which

had been set up amongst some already existing installations which had at first been intended for other purposes; or whether it was preferable to undertake the construction of a completely new terminal.

The authors explain the idea of the deterministic stage of the model, and of its most important variables, and also show a very clear diagram of the model structure.

The second example given relates to the determination of the best type of new construction for an African port. The problem posed itself of knowing whether the quays should be planned on conventional lines, or whether, in contrast, one should allow for investment in terminals for container-ships : the present tendency towards this type of cargo could, in a short time, render obsolete costly installations designed for non-container cargoes.

The variables considered are set out; they relate to the return on, and the costs of, vessels, labour, and equipment; and the authors go in detail into the degrees of sensitivity determined by the model.

In this case, the system of « decision-analysis » allowed very concrete recommendations to be arrived at.

Poland

Mr. Kondratowicz' paper is a practical study of the technique of constructing a simulation model for port operation.

This technique, which he calls « modular », rests on the conception of the model as the combination of a series of modules which are capable of assembly in a different way, so that the model can be built up or modified without the need for total reconstruction.

In truth, the programming of computer simulation system in a classical manner, that is, a separate system for each type of model and each research objective, was far too laborious and costly. A much more effective solution, from the point of view of practical applicability and costs of realisation is to be found in a single computer simulation system able to process a model of any dynamic system.

The principle was adopted that the structure of the system model could not be fixed in an invariable way. On the other hand, it should be possible to construct a modular system in such a way as to satisfy the objective, and the current requirements of research, allowing the obtaining of the desired information. That involves that the same simulation algorithm should always accept any composition of model components, of their quantitative and qualitative characteristics, and of the degree of aggregation of the model. The method of interpretation of the original components of the systems should remain constant regardless of the type and number of components included in the model. The simulation algorithm, that is, the simulator, should be absolutely independent

of the peculiarities of the given model variant. Another essential principe adopted in the concept of the universal simulation algorithm is its capacity to imitate various human decisions, which can, or ought to, come into play in the original systems, depending upon the situation simulated in the model, in order to improve or organise certain processes.

The United Kingdom

Messrs. Ordman and Sinclare begin their paper with some general observations of great relevance and interest.

In their opinion, although use of computers could be made in numerous sectors of port activity where considerable quantities of information and data have to be processed, it is nonetheless true that at the moment port management seems to suffer from a certain disillusionment as to the applicability of these techniques. This follows the initial period of euphoria during which, perhaps light-headedly, all sorts of virtues were attributed to the computer, which was thought of as some sort of magic wand capable of automatically solving any problem whatsoever.

The authors put this recession down to an initial over-estimate of the difficulties involved in adapting to the new techniques, of the need to build up gradually the equipment and the specialised staff for it, of the time indispensable to the development of the idea and of carrying out such an advance, and, finally, to the need to compare at the outset the cost of instalment of such systems with the increase in profitability which its use will bring.

The authors hope, however, that despite this temporary disillusionment, the advantages of the system will quickly make themselves felt in the following areas : Planning; Operation; Management; External Interfaces.

They draw attention to the fact that, despite the diversity of these activities, a large amount of the data stored and processed is common to them, which in itself gives the system an advantage.

Next the authors examine the different fields of computer application, in the following order :

Planning. — In this field, we are told that the computer can receive and store data, and process them through simulation models, to arrive at the most suitable course to follow, both in the field of construction and that of financial investment.

In this context, attention is drawn to the fact that the National Ports Council has used the general model constructed by Cambridge University for the study of imports and exports. Similarly, the Port of London Authority has used a simulation model to justify the need for a new entrance lock to Tilbury Docks.

The authors make it clear that these applications have been no more than partial realisations, and that in the United Kingdom no simulation model of an entire port complex has yet been constructed. However, they do not consider such a project impossible, believing it to be a question only of time and money.

Finally, in the planning field, there can be no doubt about the application to civil engineering techniques, although this application is not confined to ports, but can be found in equal measure in other branches of construction.

Port Operation. — The authors consider that in port operation a vast field of application of these techniques is to be found. They express surprise, moreover, that the results in this area should be so meagre. The use of computers is particularly appropriate in the following specialised areas :

a) Regulation of vessel movements in the port vicinity, as is already conducted in the case of air traffic. The authors point out that, in this specialised field, the only practical application of which they know is the regulation of navigation in the St. Lawrence Seaway.

b) Control of the movement of goods, as much conventional cargo traffic as container traffic. In the first case, no practical applications have come about, but a computer system is in regular use for containers in Liverpool.

Management. — Using the term to cover the whole of the routine administration of ports, the field of application is enormous : pay-rolls, inventories, invoicing, statistics, accounting procedures; these activities are of a mathematical nature, and can be regulated perfectly by computer programme. The decision for its progressive adoption raises only the question of the price of installation against the degree of rapidity and the economies obtained.

The authors deal in detail with the general conditions which a programme for this specific area of application must fulfil.

External Interfaces. — When it is considered that a port does not exist in isolation, but is one link in the chain of international transportation, one can see that the exchange of information between all ports is essential to the proper organisation of traffic as a whole. In this regard, if sea transport wishes to retain a competitive position in relation to air transport, the necessary networks of information on a reciprocal and multiple basis must be established, a result obtainable only by the use of the rapid calculation and capacity for storage that the computer offers.

Another factor is that to achieve any positive results in this area, international commercial procedures and the codes upon which the statistics are based must be harmonised. To this end, a body known as SITPRO has been formed in the United Kingdom.

The authors finish by voicing the opinion that the field of application of computers in ports is so enormous that the port authorities should consider these problems with the greatest interest, without forgetting the questions of price and the work involved in their installation.

GENERAL RESULTS

It is to be noticed that the papers which have just been summarised show slightly different characteristics, as regards the degree of specialisation in the problems discussed.

While the British and French papers approach the application of computer science from a general viewpoint, without going into the details of programming, the Polish and Dutch papers turn out, on the contrary, to be highly specialised, and go into considerable detail over the development of simulation programmes. Other papers, after giving a general picture, go into certain practical applications in a more concrete fashion.

The purpose of this general report is to consolidate the subject overall, in the belief that the finer points of the analyses or programmes should not become the subject of debate during the Congress.

This is the first time that this question has been tackled in our Association, and one feels that the discussion while the Congress is in progress should be kept to the general aspects of computer science. It is only later, through a specialised Commission, that it will be possible to go into greater detail over the practical application of this science to our work.

Reading the papers received, it emerges clearly that computer science plays a central role in the following branches of our activity :

1. Civil engineering work (calculation in construction works, foundations, etc.).
2. Administrative processes.
3. The obtaining of the optimum results in operation.
4. The determination of the optimum decisions in planning.

Each of these four basic branches can in turn be subdivided into various aspects, which we will proceed to examine.

Construction. — Although the subject of the application of computer science to civil engineering calculations is well known, and the application is itself shared with any other activity requiring construction work, in ports or outside them, there are certain idiosyncrasies which are peculiar to our field. In this context, attention should be drawn to the application explained in the French paper, on the rapid obtaining of results in the tests relating to small-scale models, and the application described in the Spanish paper on the receipt and processing of data on swell.

Attention should particularly be drawn under this heading to the remark made in the United States' paper, to the effect that the application of computer science to the calculation of construction work must be justified by the economies one gains by its use, in relation to the cost of developing the programme.

Administrative operations. — In this field, just as in the previous one, the application of computer science is not peculiar to port administration. It was primarily in the calculation of employees' pay-slips, lists of payments, and

invoicing, that computers made their presence felt from the very first, as offering the simplest and most useful solution.

In port administration, a large number of operations exist to which computer science can, with neither doubts nor special difficulty, be applied, and among these processes one can cite : invoicing for services, staff pay-rolls, and the compilation of statistical data.

These applications are referred to principally in the Spanish paper, and one must emphasise the advice given on the use of the card system, rather than the tape system, as a result of the circumstances mentioned — the possibility of correcting errors more easily, without the corrections affecting the coding area.

Obtaining of optimum results in operation. — This application is more peculiar to our work than those summarised in the preceding paragraphs.

One can obtain better results in operation for the following reasons : the speed of the reception and processing of information, as the German paper showed, as regards the documentary procedure of the Port of Hamburg; a better return on the available installations, as the Canadian paper described, in the case of the traffic along the St. Lawrence Seaway, or, according to the United States' paper, through the operation of conventional port installations, or of large-scale units.

It is also an application which leads to better operation in everything relating to the safety of navigation.

The present state of the applications of computer science to port operation have been the subject of specific research on the part of the Swedish delegation of ICHCA, which has carried out an inquiry amongst 800 members of that Association.

The results have been collected in a paper titled UCICH, published by ICHCA, and it contains some interesting summaries regarding the types of application being carried out in 97 world ports in February 1972. Study of this paper is recommended, in view of the practical information it contains.

Determination of optimum decisions. — This fourth branch of application of computer science represents an enormous field which ties up in certain respects with the idea of improving operation. Thus, for example, the Finnish paper, which deals with the most suitable arrangement of the access routes to the country's coasts in the hard winter months experienced in such latitudes, presents the study of an optimum decision as to routes and investment in installations or equipment; however, this decision has fundamental consequences on the results of port operation.

Nevertheless, the typical application as regards the improvement of decisions relates to the financial aspect of the investment, and in this context one comes to the simulation models mentioned in the papers of the United States, Spain, the Netherlands, Poland and Denmark, quite apart from the other papers which deal with this subject more briefly, in accordance with the summary earlier on.

Clearly, this field of simulation is that which presents the greatest difficulties, in comparison with the other applications mentioned, in arriving at the determination of optimum decisions concerning financial investments; but it is also the field which offers the greatest scope for producing original work of enormous economic importance.

General considerations on the subject. — Up to now, we have examined the general questions of computer science, the summary of the papers presented, and the classification of the different applications relating to every aspect of port administration.

Some general considerations will now be discussed, on the remarks contained in the papers as a whole.

In the papers of the United States and the United Kingdom, one sees immediately the influence that computer science necessarily has in our work; that is, it involves not only an important change in equipment, but also the education of specialised staff in sufficient numbers. In this context, the observation in the British paper is of particular interest, as regards the disillusion noticed after an initial enthusiasm as to the possible applications of computer science, with the realisation that the process of adaptation of this science to relatively simple tasks required a long period of instruction and preparation of staff.

This consideration is also related to the classification of the various activities already mentioned, given the undeniable fact that the techniques of computer construction are developing rapidly, with the result that these machines are becoming increasingly simple and cheap, and are in increasingly common use.

From all we have heard, the conclusion can be drawn that the easiest applications for computer science in our work are those relating to construction projects, and administrative and accounting operations. One can foresee that relatively soon all these tasks will be carried out by computers, provided that they justify the expense.

This last paragraph brings us to another, equally important, consideration, which the United States' paper deals with in a very concrete fashion; it advises the use of computers only where the advantages obtained by their use justify the costs involved in the application of the system. This is equally applicable to the cases of port exploitation, and of calculation for construction projects; and in this context, the United States' paper indicates a very precise limit as to the estimated cost of the project which is considered to justify economically the use of these machines. One must bear in mind, however, that this limit will continually diminish as the use of computers becomes cheaper and they become increasingly widely used; and also, as programming techniques are refined, and a larger specialised work-force becomes available to use them.

Although the calculations in construction work, or accounting, do not present any great difficulties for the use of computers on a wide scale, other activities are in a less advanced state; and amongst these, in turn, the study of

improving long term investment cannot yet be considered to have resulted in any tangible, practical, widespread applications.

It seems clear that one of the difficulties that the development of this type of calculation can present is in the need for sufficient quantities of accurate basic data.

It is equally certain that a large amount of the data on commercial movement in ports has many different applications, including both the compilation of statistics and the improvement of the process of port operation and management. Thus, the advantage of being able to obtain the greatest possible harmonisation in all the elements that have to be taken into considerations can be clearly seen; that is, the physical characteristics of units of cargo, the origins and different types of vessel, routes, characteristics of equipment, etc., should, as far as possible, be harmonised, and coded in the same way all over the world. Thus, the ideal would be to arrive at the collection of all types of data, duly classified, in a world bank on the lines of that established in Hamburg, to which the various researches could turn for the data needed for their simulation models. This is, certainly, an objective that is unattainable on an international scale in practice, but it marks the direction in which progress must be made.

Another subject which could be studied with a view to harmonisation lies in regulating the processes of simulation modelling, that is, the collection of ascertainable rules on the groups of activities which can be the object of partial simulation models, in such a way that the general conception is always the same, and would allow subsequent integration in more complex models, by means of the necessary substitutions or assembly.

CONCLUSIONS

In the light of the examination made of all that has been said up to now, I propose to the Congress, if I may, that the following conclusions be discussed :

1. — The use of computers is becoming increasingly widespread, without any special problems, in the work relating to construction projects and accounting and administrative procedures in port management.

The Association wishes, however, to draw attention to the fact that the adoption of these techniques inevitably requires a relatively long period for the preparation of staff and to carry out investments of any size.

Our advice is, therefore, that before installing this type of machine, one must examine whether any real economies will be obtainable, after a reasonable initial period, from the conversion of machines and the adaptation of administrative staff.

2. — The use of computer science in the processes of cargo-handling requires as large as possible a co-ordination of input data.

3. — The use of computers for simulation models, to determine economic decisions, such as those relating to planning and investment, is not yet considered sufficiently developed, but it is hoped to be able to obtain positive results in the near future.

4. — The use of computer science for the regulation of sea traffic gives good results, and is to be advised without exception, both as regards better exploitation of waterways, and as regards improving safety conditions.

5. — The input data for computer processes which have different objectives is often the same. The usefulness of speed in information often lies in the possibility of making decisions which come under one single command.

It is considered, as a result, that the usefulness of computers in these fields is linked to an effective co-ordination in the storage of data for different purposes, and to the concentration of decision-making in a single centre.

In view of the preceding considerations, the establishment of a Commission is proposed, with the following terms of reference :

a) To propose a nomenclature for duly classified data, covering all those data considered useful, whether for port operation, or for economic simulation models.

b) To propose a practical codification for the aforementioned data, which could be adopted internationally.

c) To study and propose a uniform approach to simulation for sectional processes fundamental to port technology, which, duly combined, would provide an overall diagrammatical plan for each case.

XXIIIe CONGRÈS INTERNATIONAL DE NAVIGATION

S. II - 5

Section II - Navigation Maritime - Sujet 5

Applications des techniques de l'informatique dans la conception et l'exploitation des ports.

RAPPORT GÉNÉRAL

par

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Bien que l'ordinateur électronique soit devenu au cours de notre décade un élément aussi courant, dans n'importe quel bureau administratif ou du Génie Civil, que l'était la règle à calcul il y a trente ans, il faut commencer par préciser en quelques lignes les idées de base sur lesquelles s'appuient ces machines et leur emploi, afin d'analyser et de résumer les rapports présentés concernant le sujet qui nous occupe. A ce propos, il convient de rappeler ce qui suit :

L'ordinateur électronique est une machine capable de recevoir des données, de les emmagasiner, de les développer et de donner les résultats de ces processus; tout cela automatiquement et sans annotations intermédiaires.

Il est capable de recevoir les données et de fournir les résultats sous forme numérique, graphique ou analytique, d'emmagasiner autant de données que de résultats et de modifier les dites données, d'accord avec les lois établies préalablement.

Les ordinateurs se divisent fondamentalement en analogiques et digitaux, selon qu'ils soient capables de recevoir les données en forme graphique ou analytique continue, ou bien en forme d'expression numérique; et aussi, en simultanés ou séquentiels, selon qu'ils puissent réaliser un processus fermé qui se produit de façon simultanée le long de son parcours, ou bien développer successivement plusieurs phases d'un même processus.

L'ordinateur le plus employé en général est le digital séquentiel, lequel se compose fondamentalement des parties suivantes : une unité pour l'entrée ou le

recueil de données, une autre pour la sortie des résultats, une ou plusieurs unités arithmétiques de calcul, une unité de contrôle et une mémoire ou magasin.

Normalement, les ordinateurs simultanés sont projetés et construits pour un processus déterminé, qui devra être souvent calculé avec plusieurs variations parmi ses données de input. Les séquentiels, au contraire, sont adaptables à plusieurs processus mathématiques, qui sont programmés par leur développement en série.

On comprend aisément que l'ordinateur simultané est le plus rapide, mais par contre il est plus compliqué, car il exige l'existence de plusieurs unités de calcul travaillant simultanément. L'ordinateur séquentiel est au contraire plus lent, mais aussi plus simple, puisqu'une seule unité de calcul peut développer successivement des opérations différentes dans un même processus.

Lorsqu'on veut employer un calculateur pour analyser une question, il faut faire ce qui suit : *a*) Systématiser les données de input et les résultats désirés, en forme analytique ou bien mathématique. *b*) Analyser le processus que l'on veut étudier, en décomposant celui-ci dans une série d'étapes ou phases définies par opérations mathématiques. *c*) Dessiner un schéma ou circuit ouvert ou fermé composé des étapes partielles antérieures. *d*) Organiser les éléments d'ordinateur destinés à recueillir, réaliser et rendre les données, opérations et résultats antérieurs. Et finalement *e*) Codifier les données, résultats et instructions, de façon à pouvoir être introduits et recueillis dans l'ordinateur.

Si nous ajoutons ces idées de base déjà connues par tout le monde aux concepts de l'énorme rapidité de calcul de cette machine et à sa possibilité de recevoir ou de réaliser des processus sur un nombre très élevé de données, on comprend que son application peut devenir très utile parmi la grande variété de travaux compris dans la construction et l'exploitation des ports.

En effet, les rapports présentés sur ce sujet dans notre Congrès ont été au nombre de dix et se rapportent aux pays suivants : Allemagne (R. F.), Canada, Danemark, Espagne, Etats-Unis d'Amérique, Finlande, France, Pays-Bas, Pologne et Royaume-Uni. Avant de commenter leur contenu dans son ensemble, nous allons rendre compte du résumé des dits rapports.

RÉSUMÉ DES RAPPORTS

Allemagne (R.F.)

Depuis deux ans on utilise à Hambourg un système de collecte de données par un ordinateur, afin de synthétiser et connaître rapidement toutes celles concernant le transport des marchandises de l'expéditeur au réceptionnaire.

Ce système devint obligatoire dû à la rapidité de la manutention des charges, causée souvent par l'arrivée de la marchandise avant la documentation concernant l'envoi.

Après ces considérations préliminaires, Messieurs Bischoff et Steinecke continuent leur rapport, exposant les caractéristiques du travail des différents agents qui interviennent dans le trafic du port de Hambourg. Ceux-ci sont essentiellement le transitair Forwarding Agent) ou chargeur, le service portuaire de chargement, le courtier maritime et le vérificateur des embarquements. Tous ces Agents ont besoin, pour bien organiser leur tâche, d'utiliser à peu près les mêmes renseignements, dont la plupart sont fournis par le chargeur et le vérificateur.

Ayant estimé préférable de réaliser dans l'ensemble le processus de ces renseignements, on a créé la Banque de Renseignements du Port de Hambourg, sous la protection des plus importantes compagnies de chargeurs et de vérificateurs. En agissant d'un commun accord, on a codifié les adresses, les genres de marchandises, les emballages, etc.

Les renseignements concernant chaque lot de marchandise chargée, sont envoyés par téléphone, dûment codifiés, dès les bureaux des chargeurs au bureau central du contrôle. L'envoi des renseignements est perfectionné moyennant l'emploi de la T.V. et du telex.

L'information synthétisée qui rassemble les caractéristiques de chaque lot de marchandises, fournit les données nécessaires pour les facturations, statistiques, etc., facilite le calcul des frets par le courtier maritime et la prompte préparation de la liste d'embarquement, ainsi que la planification des lieux de stockage et des manutentions sur le quai.

On espère qu'en 1974 ce projet de recueil systématique de données sera complètement développé.

Une autre application exposée par les auteurs dans leur rapport, est celle développée par la Hambourg Port and Warehousing C° pour un système de contrôle d'opérations dans leurs terminaux de conteneurs du Port de Hambourg.

Le système que l'on introduit a pour objet la supervision et le contrôle de tous les mouvements de conteneurs et de trailers, les marchandises à placer dans les conteneurs, la régularisation de documents et rapports avec d'autres systèmes conventionnels de manutention de charges.

On a initié ce système avec un contrôle effectué par un ordinateur IBM 360/20, qui programme les opérations d'embarquement et débarquement, chargement et déchargement de conteneurs sur wagon et transbordement de chemin de fer à camion.

Canada

Le rapport canadien se limite à une description détaillée du complexe système de contrôle du trafic le long de la voie navigable de Saint-Laurent et des Grands Lacs, système dont le projet dans son ensemble, est actuellement assez avancé; il se fonde sur une large application de l'informatique, et une partie des services de ce projet a déjà été mise en fonctionnement.

Le rapport commence par une description des sections de ladite voie navigable, sous la responsabilité de l'Administration de la Voie maritime du Saint-Laurent, dépendant du Ministère Canadien des Transports; il expose les motifs qui ont obligé à introduire le service décrit, en raison des difficultés que l'accroissement du trafic, l'emploi de nouveaux modèles de bateaux et l'ouverture du tronçon Montréal-Lac Ontario (190 milles de longueur), produisirent dans le trafic, à partir de 1967, tout au long des 28 milles du Canal Welland.

En lignes générales, la difficulté consistait à obtenir une excellente utilisation des installations en déterminant, pendant une période de temps déterminée et aussi brève que possible, la meilleure solution quant aux régularisations du trafic et du service.

On a essayé d'abord la solution par l'emploi de moyens manuels, mais on a dû se rendre à l'évidence de l'impossibilité de tels moyens si on voulait utiliser convenablement toutes les données de départ dans le temps disponible, en arrivant à la meilleure solution.

L'emploi des techniques appropriées mène : à obtenir l'amélioration de l'exploitation, moyennant la réalisation d'une étape globale munie d'un bon rapport et effectuée dans un espace de temps limité; à une centralisation du contrôle du trafic afin de faciliter la prise de décisions; et à l'emploi d'un réseau convenable de communications par radio en VHF et de télévision en circuit fermé.

La dynamique du système s'appuie sur la détermination des données de input, relatives à l'ordre irrégulier de l'arrivée des bateaux, ordre de présentation dans les écluses, lois de temps de service dans les installations; à l'exécution d'autres opérations, telles que le chargement et déchargement, pilotage, etc. et finalement, aux interruptions du service.

Les lois auxquelles obéissent ces données de input ont été établies en partant de la loi de distribution de Poisson et de Erland, avec le coefficient $K = 2$.

Ensuite on expose les fonctions qu'on escomptait remplir avec le premier projet du système conçu en 1968-69, qui consistaient essentiellement dans la collecte de données, leurs processus, localisation des bateaux, planification du trafic et information.

A mesure que la dynamique du système prenait forme, il paraissait plus évident que si l'on pouvait obtenir plus à l'avance les informations relatives aux mouvements des bateaux, on pourrait diminuer les irrégularités dans les arrivées et, par conséquent, augmenter la capacité de trafic de la voie navigable ou réduire le temps d'attente.

Or, puisque ces données de input procédaient d'origines différentes, on présenta en 1970 une nouvelle proposition qui visait à réunir en un seul centre tous les travaux des organismes fournissant des données, lesquels étaient au nombre de six canadiens et deux des E.U. Au commencement de 1971, les organismes canadiens avaient accepté la fusion de leurs données et actuellement on négocie avec les américains en vue d'obtenir leur accord.

Pendant ce temps on avait obtenu des avantages dans la technique et les prix des ordinateurs industriels, dont l'introduction a permis d'étendre et de mieux définir les informations exigées par le système, ainsi que les données de output que celui-ci pouvait fournir.

Ces informations se rapportent aux caractéristiques des bateaux et à la connaissance exacte et instantanée de leurs mouvements, ainsi qu'à la connaissance immédiate des positions des portes d'écluse, des ponts et de la situation d'accostage dans les ports et, finalement, aux observations météorologiques.

Le premier but du système est celui de détecter et signaler les conditions anormales, rédiger des rapports dans les cas nécessaires et unifier et épurer les informations provenant des différentes Agences aussitôt qu'elles deviennent inutiles.

Ensuite, on arrive à la vraie finalité du système, c'est-à-dire, la planification, de sorte à améliorer au possible la durée des traversées pour chaque bateau ou la capacité des installations. A cette fin on essaie d'arriver à la confection de programmes de simulation pour déterminer la solution idéale et à l'établissement d'un système pour analyser les déviations concernant celui-ci. Cette partie du travail n'est pas encore développée.

Il est évident que l'utilité du système décrit, dépend de l'identification instantanée des bateaux et de l'assurance d'une communication continuelle entre ceux-ci et le centre de contrôle. A cette fin on a étudié un système spécial par radio en VHF, en utilisant des appareils radiotéléphoniques spéciaux que les pilotes remettent aux bateaux et que ceux-ci doivent utiliser pendant leur passage dans la voie navigable. On étudie aussi la possibilité d'appliquer un système Loran.

Le rapport finit en indiquant que le coût du système, non compris les recherches et la mise au point, sera de l'ordre de 5 millions de dollars, dont 3,5 millions pour les systèmes de localisation et d'identification des bateaux; les économies seraient de l'ordre de 2 millions de dollars par an, dont 1,5 million pour l'industrie du transport et le reste pour d'autres Agences.

Danemark

Le rapport du Professeur Hansen concerne une étude très concrète sur les dimensions optimales ou les caractéristiques d'un terminal pour conteneurs.

L'auteur exprime certaines hypothèses simplificatrices, en émettant la supposition que l'aire d'entreposage possède une capacité infinie et ne tenant pas compte des phases de remplissage ou vidange, des formalités qui déterminent le séjour à terre des conteneurs et toutes les phases de leur évacuation ou de leur arrivée par voie terrestre.

Il limite donc les données de input aux pourcentages des bateaux océaniques et de feeders, aux déviations maxima à l'égard des prévisions des horaires d'arrivée, au nombre d'heures de travail par jour et par semaine, et au trafic total que doit absorber le terminal.

Les principaux résultats ou données de output fournis par le modèle sont la longueur du quai et le nombre de grues, ainsi que les coûts de manutention dans chaque cas.

Puisque l'exemple présenté escompte conduire à des résultats très concrets, et en effet il y réussit, l'auteur prend comme point de départ, pour le calcul économique des coûts, des suppositions déterminées concernant le coût des travaux et de l'équipement, périodes d'amortissement et rentabilités exigibles aux investissements dans le quai.

Il part également de données très précises en chiffres analogues de coût, en ce qui concerne les bateaux.

En commençant donc par un schéma de coûts initiaux très concrets et d'hypothèses simplificatrices très claires et très simples, l'auteur présente le schéma de base du modèle de simulation qui a servi de règle pour la programmation de l'ordinateur.

Ce schéma, préparé pour être développé par un ordinateur analogique, est très clair et très simple et mène à des résultats très concrets, résumés par l'auteur à la fin de son rapport.

Espagne

Le rapport espagnol estime utile l'emploi de l'informatique vers quatre directions : la planification portuaire, la conception et l'exécution d'ouvrages, l'exploitation, et l'étude des relations avec les économies extérieures.

Il décrit l'utilisation pour la planification sous la forme de modèles de simulation; en partant de données de input relatives aux tendances sociales, économiques et industrielles, découlant à leur tour des études et des statistiques existantes, dûment synthétisées, ils doivent conduire à l'obtention de résultats possibles suffisamment détaillés pour pouvoir servir de base aux décisions de planification et d'investissements.

Il fait remarquer que, étant donné l'énorme complexité d'un modèle général prétendant embrasser toutes les possibilités d'un port dans sa totalité, il faut, dans la pratique, subdiviser l'étude d'ensemble en une série de sous-systèmes ou blocs relatifs à unités portuaires partielles. En outre, le type de planification qui devra faire l'objet de recherche peut se rapporter à court ou à long terme, et aussi bien aux installations nouvelles qu'à l'amélioration de celles déjà existantes. Evidemment la limitation ou définition d'objectifs préalables bien précis, simplifie le problème et, en conséquence, le modèle de simulation à programmer.

Dans le champ du projet et de la construction, les auteurs estiment qu'il s'agit le plus souvent d'applications analogues à celles d'autres champs du Génie Civil, bien qu'il existe certains cas de spécialisation, tels que l'étude des jetées, éléments spécifiques des ports, quoique le genre de problématique soit le même.

Les auteurs trouvent une application bien définie de l'informatique dans l'exploitation, en son double aspect d'accélération et de rationalisation des processus administratifs (facturations, listes de salaires, etc.) qui, dans leur exposé, sont communs à ceux d'autres entreprises industrielles; et dans celui de l'organisation et de l'augmentation du rendement des processus de manutention des marchandises, c'est-à-dire, dans le maximum et meilleur profit économique des installations disponibles, moyennant l'organisation la plus rationnelle du travail.

A cet effet on peut aussi étudier des modèles de simulation, plus concrets et plus faciles à réaliser que ceux relatifs à la planification et qui ont été mentionnés comme première application de l'informatique. En ce cas, les données d'entrée ou input seront basées essentiellement sur la statistique, dirigée non vers le futur comme dans le cas traité d'abord, mais vers le passé immédiat.

La possibilité d'appliquer cette technique en des circonstances concrètes pour charges unifiées (conteneurs, vrac, etc.) permet l'implantation progressive de l'informatique dans le progrès de l'exploitation portuaire.

Finalement, la quatrième application estimée possible, c'est-à-dire le rapport avec les économies extérieures, concerne le choix, dans une étude comparée d'itinéraires origine-destination, de celle qui serait plus économique aussi bien en temps qu'en argent, parmi toutes celles théoriquement possibles.

Dans ce cas, naturellement, les périodes de temps utilisées et les coûts relatifs aux ports, devront être conjugués aux données analogues concernant les frets, les transports terrestres et les stockages intermédiaires.

L'étude et la prise de décisions subséquentes peuvent revêtir le caractère de temps différé, pour des planifications générales, ou bien de temps réel pour des décisions immédiates, bien que pour arriver à cette dernière application il faut compter sur un réseau de communications par tele-processus, qui permettra la transmission.

Dans la deuxième partie de ce rapport on expose trois applications concrètes relatives aux trois premiers cas exposés dans la première partie.

Le modèle de simulation pour opérations portuaires, exposé en détail, se rapporte à l'étude du fonctionnement de deux terminaux, l'un pour conteneurs et l'autre pour céréales. Il est programmé en langage FORTRAN IV et met une minute pour chaque hypothèse étudiée.

En partant de certaines hypothèses simplificatrices quant aux lieux d'accostage, zone de mouillage, de stockage, etc., il permet de déterminer, pour différentes hypothèses de temps de service et d'arrivée de bateaux, la continuité concernant la chronologie d'arrivées et de sorties, le type et tonnage de chaque bateau, les temps d'attente et services par bateau et par type de bateau, le volume du chargement manipulé par bateau et par type de bateau au total pendant la période étudiée.

Les données de input sont les tonnages à manipuler et leurs lois de variation, celles de distribution des types de bateaux et leurs chargements, le rendement des installations, les lois des temps de service et la période de simulation.

Les données et les résultats obtenus par ce modèle sont exposés en détail.

Le cas d'application au projet d'ouvrages se rapporte à l'obtention, accumulation et processus des données de la houle, en tant qu'étape nécessaire pour le projet de jetées dans les ports.

On décrit l'installation qui a été construite dans ce but en Espagne pendant l'année 1972. Celle-ci se compose d'un système d'appareils de mesure, reliés par télégraphe et par radio au Laboratoire des Ports « Ramón Iribarren » à Madrid, où se fait le traitement des données.

L'information ainsi reçue de dix postes d'observation est recueillie par un ordinateur analogique ou de Fourier, lequel possède jusqu'à 70 instructions de base et 8 de programmation instantanée. Moyennant celles-ci on peut réaliser le traitement de toutes les données conformément aux différentes hypothèses mathématiques sous la forme intéressée par son accumulation, analyse ou transformation.

Enfin, des détails sont donnés sur l'application actuellement entreprise dans le Port de Barcelone, dans le domaine de l'informatique aux processus administratifs.

Ici, le gros volume d'information provenant de la réalisation des opérations portuaires, est codifié et perforé sur bande, sur laquelle s'appuie un ordinateur qui, conformément aux programmes préétablis, compile d'un côté les résumés statistiques nécessaires, et calcule, imprime, prépare les montants et les factures des services tarifés de l'Administration du Port aux bateaux, marchandises ou arrimeurs.

Les auteurs analysent en détail le système employé et ils remarquent des inconvénients dans le système de bande, étant donné la complexité des tarifs à appliquer. Ils estiment préférable, pour ce type d'applications, le système de cartes, auquel on a l'intention de reconvertir les installations car, tout en étant un peu plus lent, il permet de mieux effectuer les rectifications et vérifications partielles sans provoquer des retards dans le fonctionnement de l'ensemble.

Ils exposent aussi l'application, sans inconvénients, que l'on fait d'un processus informatique pour le calcul et la confection des listes et des feuilles de paye des salaires du personnel.

États-Unis d'Amérique

Le rapport des U.S.A. se subdivise en plusieurs parties. Dans l'une des premières, il examine le champ général d'application des divers types d'ordinateurs aux différents aspects de l'activité portuaire. Elle décrit très clairement les diverses idées de la programmation, c'est-à-dire, la traduction du problème posé, en un langage intelligible pour l'ordinateur, ainsi que les modalités des processus que ces machines peuvent réaliser et le degré d'exactitude des résultats qu'ils obtiennent.

En conséquence, elle détermine les champs d'application plus appropriés à chaque modèle pour les complexes et différentes questions qui doivent être réglées dans la technique portuaire moderne.

Concrètement elle estime que les applications actuelles de ce type de machines calculatrices sont les suivantes :

— Développement d'opérations administratives normales;
— Collecte de statistiques et prévisions obtenues par son extrapolation;
— Établissement de l'ordre dans le trafic moyennant des modèles de simulation;
— Détermination des décisions optimales quant à la planification et la construction.

Coopération, d'accord avec d'autres moyens tel que le radar, afin d'obtenir une plus grande sécurité de la navigation dans les accès aux ports.

Après avoir résumé le résultat d'une consultation avec plusieurs centaines de ports, on arrive à la conclusion que, actuellement, il existe encore quelques ports qui utilisent des ordinateurs dans leur travail; pour la plupart ce travail consiste en la compilation de données et de statistiques et en leurs tâches administratives. On croit cependant que leur développement tendra vers la détermination de prévisions et décisions optimales, aussi bien dans les problèmes d'exploitation que de financement.

Ensuite, le rapport examine les différents types de modèles de simulation, qu'elle subdivise en mathématiques déterminants, mathématiques probabilistes et physiques; et elle expose les caractéristiques de base, la finalité, l'application et l'exactitude de chacun d'eux.

La deuxième partie du rapport est consacrée à une description très détaillée des idées de base du modèle de simulation « Monte-Carlo », qui appartient au type mathématique probabiliste et les différents langages qu'on peut lui appliquer; elle développe quelques exemples de décomposition d'opérations pour rendre possible leur programmation mathématique.

Dans la troisième partie du rapport on présente deux schémas d'un complexe portuaire complet : l'un pour les importations et l'autre pour les exportations, avec leur décomposition typique d'opérations, qui permettront leur programmation; on signale leur application dans la baie de San Francisco, considérée comme un seul port.

Finalement, on fait une brève allusion à l'application de la technique des ordinateurs à la sécurité du trafic, citant le système introduit par la « Coast Guard » (gardes-côtes) pour contrôler le trafic maritime dans la baie de San Francisco et ses accès.

Dans le sommaire et les conclusions qui terminent le mémoire, on exprime l'opinion que le champ le plus vaste d'application de la technique en question se situera dans le domaine de la collecte et de l'analyse des statistiques pour déterminer les besoins futurs du port. On pense aussi que les modèles de simulation pour résoudre des problèmes d'exploitation et de planification des ports seront utilisés de plus en plus dans l'avenir.

Concernant les avantages économiques que l'on pourrait obtenir, par exemple, dans le champ de la technique de la construction grâce à l'emploi des ordinateurs, l'auteur fait une prévision intéressante en ce qui concerne le coût actuel de l'élaboration du modèle ou programme, il conclut que cette technique ne sera rentable que pour des projets impliquant un investissement supérieur à 10 millions de dollars.

Finlande

Le rapport finlandais fait allusion à l'étude réalisée dans ce pays pour déterminer les voies d'accès maritimes les plus aptes du point de vue économique à être utilisées par le trafic commercial au long cours, provenant de ou destiné à la Finlande. Dans ce choix, le facteur principal est constitué par les difficultés occasionnées, suivant la période de l'année, par la glace existante ou non dans le voisinage de la côte.

La Finlande reçoit et exporte, respectivement, 95% et 80% de ses produits par voie maritime, et ses routes d'accès pénètrent à travers la mer Baltique et se développent dans les golfes de Botnie et de Finlande; le trafic se heurte contre les difficultés des glaces solides et flottantes, existantes pendant des périodes de temps qui vont depuis 2,9 jusqu'à 3,3 mois de l'année, en moyenne.

Cependant, la disponibilité de bateaux brise-glace et l'accroissement d'unités de la flotte marchande de modèles spéciaux pour naviguer parmi les glaçons, rendent techniquement possible, neuf années sur dix, l'accès des bateaux à tous les ports finlandais.

Cette possibilité est pourtant liée à des coûts variables, mais souvent importants, dus à l'ouverture de routes à travers les glaces; on a donc estimé opportun de réaliser une étude que l'on expose dans le rapport, afin de déterminer les routes les plus économiques pour l'accès du commerce extérieur finlandais pendant les mois d'hiver. On doit logiquement conjuguer les diverses possibilités et les coûts des accès maritimes à ceux du transport intérieur pour arriver depuis les ports d'accès jusqu'aux points de destination des marchandises; tout cela pendant les diverses périodes de l'année, dont les conditions de navigation sont forcément différentes.

Voici dans la suite les bases de l'étude ou données de input :

a) Une définition et énumération exacte et complète des idées du prix et de dépréciation de la monnaie jusqu'à 1980.

b) Grandeur et degré des charges des bateaux.

c) Poids et possibilité d'emploi de trains complets pour le transport terrestre.

d) Nombre de marchandises déplacées à l'aide de brise-glace.

e) Classification des marchandises par groupes, d'après leur nature et aussi selon qu'elles doivent être transportées tout le long de l'année ou bien pouvant être stockées pendant l'hiver.

f) Le trafic et son évolution, aussi bien dans son aspect quantitatif que qualificatif.

g) Nécessité de modifications dans le type de transport, en passant du maritime au terrestre, à cause des conditions climatologiques inattendues.

D'accord avec ces facteurs, on a représenté initialement les schémas des différents itinéraires mixtes entre les points d'origine et ceux de destination.

L'étude concernant ledit schéma a été réalisée moyennant trois modèles mathématiques. Le plus important couvre tout le système de transport maritime, et les deux autres, en rôle auxiliaire, se rapportent à un port et à l'étude des retards dans l'arrivée des bateaux.

Le modèle principal a été divisé, à son tour, en trois blocs d'étude, ayant chacun d'eux trait à différentes périodes de l'année caractérisées par des conditions climatiques diverses.

Le rapport détaille les hypothèses simplificatrices qu'il a fallu réaliser et la division des variables de input parmi les incontrôlables (conditions du climat, etc.) ainsi que les contrôlables (choix de routes).

Comme résultat de l'étude effectuée, on est arrivé en ce cas à des conclusions très concrètes, en déterminant les itinéraires optimaux pour le trafic.

France

Le rapport français, après quelques considérations initiales sur la vaste gamme d'activités portuaires, où l'informatique trouve son application, explique comment les ports français utilisent cette nouvelle science dans la forme suivante :

Dans les études hydrauliques, réalisées par plusieurs laboratoires officiels et entreprises privées, on utilise des ordinateurs pour recueillir, emmagasiner et analyser, sous forme statistique, les données de la houle, de sondages, de la propagation des courants des marées, etc. Grâce à ces analyses on a pu substituer l'ancienne compilation manuelle par des registres graphiques obtenus de façon mécanique, infiniment plus sûrs et rapides, et effectuer des calculs d'extrapolation, pratiquement inabordables jusqu'à présent.

Dans le champ des études hydrauliques, on utilise aussi l'ordinateur combiné avec les modèles réduits pour recueillir et analyser, non pas les données des phénomènes naturels, mais celles produites et constatées par les modèles précités.

On mentionne aussi dans ce chapitre de recherches hydrauliques, l'analyse du fonctionnement des systèmes de vidange et remplissage d'écluses et les mouvements d'accostage des grands navires, du point de vue de la dynamique hydraulique qu'impliquent ces bateaux.

Dans le champ de la construction, l'informatique est appliquée dans les ports pour le calcul des ouvrages, des glissements de terres dans les projets d'assise des fondements, etc. Cette application, même n'étant pas caractéristique

de l'activité portuaire, car elle est commune à d'autres tâches du Génie Civil, a été cependant la première à être employée dans les ports français.

Dans le champ des études économiques, l'utilisation de simulateurs de trafic est fréquent pour les ports français. Ces modèles de simulation contiennent des hypothèses pour quelques-unes des données de input et pour d'autres, des statistiques réelles. Parmi ces données il faut signaler les flux de marchandises, les coûts d'affrètement selon les routes différentes, la composition des flottes et les caractéristiques des bateaux, ainsi que les données concernant les marées dans les accès aux ports et les modèles de simulation, capables de déterminer les périodes d'attente, le type le plus adéquat d'équipement portuaire et l'itinéraire le plus économique. Ces modèles de simulation ont été réalisés dans le port de Dunkerque, aussi bien pour comparer l'utilité d'un « pipe-line » appliqué au trafic maritime pour l'approvisionnement de pétrole à l'Europe Occidentale, que pour l'étude de l'affluence du trafic général. Le service technique du Ministère de l'Équipement a construit aussi un modèle type de simulation pour un terminal de navires porte-conteneurs.

En ce qui concerne l'utilisation de l'informatique dans l'administration des ports, le rapport français distingue entre les applications normales pour une entreprise portuaire et une autre non portuaire, c'est-à-dire, entre celles ayant trait à des opérations comptables, calcul de factures, confection de feuilles de paye du personnel, etc. et les autres qui caractérisent les opérations dans les ports. Parmi celles-ci, on cite d'abord, comme plus importantes, les statistiques des marchandises transitées, réalisées en collaboration avec les services des Douanes et celles d'exploitation, ainsi que les applications de planification des services de remorquage et de pilotage.

Toujours d'après ce rapport, l'informatique est également utilisée largement dans les opérations de consignations maritimes réalisées par les Agences françaises, spécialement en ce qui concerne le trafic de conteneurs. On mentionne particulièrement les organisations de Messageries Maritimes et la Cie Générale Transatlantique, dont l'objet est d'effectuer le traitement des données de groupage et dégroupage, de charge et décharge, et d'origine et destination; on passe alors ces informations à la documentation administrative et on les transmet en forme automatique et rapide aux ports d'escale.

Finalement, dans cette exposition des applications réalisées en France, on signale que le trafic routier ayant trait aux ports, n'utilise pas d'ordinateurs; par contre, les chemins de fer français les utilisent normalement dans les gares de triage et, spécialement, dans celles situées dans les ports, afin de faciliter l'administration et l'exploitation du parc des wagons.

M. Giauffret termine son rapport en précisant que l'informatique est déjà largement utilisée dans les ports français, représentant entre 1 et 1,5 % de leurs frais de fonctionnement. Il exprime l'opinion que cette utilisation augmentera de plus en plus et deviendra plus importante particulièrement dans le champ des modèles de simulation, lesquels deviendront aussi plus parfaits.

Il prévoit l'extension du système dans le sens vertical, c'est-à-dire, pour couvrir un nombre croissant d'activités d'un même centre de travail, aussi bien officiel que privé; et dans le sens horizontal, entendant par-là la coordination progressive d'activités de différents centres ou Agences.

Pour arriver à ce résultat il estime souhaitable et presque indispensable de réduire au minimum le nombre des centres de décision, et d'unifier les nomenclatures et les codes pour la classification de marchandises et les autres données de input.

Pays-Bas

Le rapport des Pays-Bas commence par exposer des considérations générales sur la nécessité actuelle de prendre des décisions rapides quant à la planification des extensions des ports et aussi pendant les phases d'exploitation; il signale aussi que l'utilisation des ordinateurs facilite les travaux nécessaires d'essai et de recherche.

Le choix du type d'extension ne peut être décidé qu'après une estimation soigneuse des différentes solutions, aussi bien dans le domaine technique qu'économique et financier.

Les facteurs qu'il faut considérer sont chaque jour plus nombreux, dus à la croissante interdépendance économique entre les ports et leurs alentours.

Le rapport groupe comme suit les principaux facteurs dont il faut tenir compte :

1. Les différents cadres pour les extensions.
2. Les nouvelles modalités d'emballage et les nouveaux types de bateaux.
3. Le développement économique et l'aménagement des zones environnantes du port.

Ensuite on divise les problèmes qu'il s'agit d'étudier en statiques et dynamiques; les premiers sont ceux qui impliquent seulement des investissements limités pour améliorer des installations déjà existantes, et les deuxièmes, ceux qui exigent une prévision face à l'avenir et qui supposent des investissements importants, exposés à de grands risques financiers.

Ceux du premier groupe, c'est-à-dire, les problèmes statiques, sont abordés moyennant un modèle approprié à la technique de simulation permettant la structure des données d'input.

Il faut considérer que les variables d'input, aussi bien celles concernant des décisions à essayer que celles provenant de statistiques disponibles, ainsi que celles d'output qui dépendent du comportement du modèle, doivent être étudiées de manière mathématique appropriée; ceci comporte un travail considérable en rapport avec les résultats pratiques obtenus.

Naturellement, la complication du modèle est d'autant plus grande selon l'étendue de l'installation étudiée; c'est pourquoi les travaux de ce type doivent être circonscrits aux unités portuaires d'une étendue limitée.

Quant aux problèmes dynamiques, ils présentent une difficulté beaucoup plus grande, car le modèle de simulation doit considérer des variables d'estimation plus difficile, tels les types de bateaux et d'emballages, les méthodes de manutention de transport et de stockage, etc., qui s'imposeront dans dix ou quinze années.

On aborde aussi ces difficultés moyennant des techniques spéciales d'analyse et on divise aussi l'ensemble de l'installation étudiée en blocs qui permettront des exposés partiels.

Les auteurs font allusion à la ligne et à l'ensemble de solutions qu'il faut étudier comme étant la « meilleure supposition » pour servir de base, après discussion, à la planification et définition des variables à introduire dans le modèle.

Ensuite, le rapport décrit le procédé général dénommé de « décision-analyse », en distinguant ces trois phases : la phase déterministe, au cours de laquelle on construit un modèle ayant l'interdépendance voulue entre les variables de input et de output; la phase probabiliste, dans laquelle on signale les lois de variation des variables de input; et enfin la phase d'information, dans laquelle on essaye la sensibilité économique du modèle et on le corrige, de façon à éliminer l'existence possible de petites variations des variables de input d'estimation incertaine, qui pourraient trop influencer celles de output.

Les auteurs estiment que ce système n'atteint pas un caractère mathématique exact, mais qu'il se distingue par la nécessité de : adopter des opinions définies; se rappeler la probabilité et l'incertitude des solutions; avoir conscience des limitations du modèle, et ne pas oublier de considérer les circonstances de l'environnement de la zone étudiée.

Dans la deuxième partie, le rapport décrit deux exemples de l'usage du système « décision-analyse ».

Dans le premier, il s'agissait de décider l'opportunité d'effectuer des investissements pour agrandir et améliorer deux terminaux pour conteneurs du Port de Rotterdam aménagés en des installations déjà existantes, projetées initialement pour d'autres buts, ou bien entreprendre la construction d'un terminal complètement nouveau.

Les auteurs exposent l'idée de la phase déterministe du modèle et de ses variables les plus importantes et montrent aussi un schéma très clair de la structure du modèle.

Le deuxième cas présenté se rapporte à la détermination du type de nouvelles constructions dans un port d'Afrique. On pose la question de savoir s'il conviendrait de programmer des quais de type conventionnel ou si, au contraire, on devrait prévoir des investissements pour des terminaux pour bateaux porte-conteneurs; la tendance actuelle à ce dernier type de charge pourrait, dans un bref délai, rendre désuètes des installations coûteuses prévues pour charges non placées dans des conteneurs.

On énumère les variables considérées, concernant les rendements et les coûts des bateaux, ouvriers et équipement, et on détaille les degrés de sensibilité déterminés par le modèle.

Dans ce cas, le système « décision-analyse » a permis d'arriver à des recommandations très concrètes.

Pologne

Le rapport de M. Kondratowicz traite concrètement la technique de construction d'un modèle de simulation pour des opérations portuaires.

Ladite technique, qu'il appelle «modulaire », s'appuie sur la conception du modèle comme l'intégration d'une série de modules qui, pouvant être assemblés d'une manière différente, permettent la construction du modèle ou sa modification sans nécessiter sa reconstruction complète.

En effet, la programmation classique des systèmes simulatifs d'ordinateur, élaborés séparément pour chaque genre de modèle et pour chaque objectif d'investigation, se sont révélés par trop laborieux et coûteux. Une solution beaucoup plus efficace au point de vue de l'applicabilité dans la pratique et frais de réalisation représente un seul système simulatif d'ordinateur apte à transformer un modèle d'un système dynamique quelconque. On a adopté le principe que la composition du modèle du système ne peut être fixée d'une manière invariable. Par contre il doit exister une possibilité de composer un tel système modulaire, qui donne satisfaction au but et aux exigences courantes de recherche, en permettant l'obtention des renseignements désirés. Cela signifie que toujours le même algorythme simulatif doit accepter une conception quelconque de la nature des composants du modèle, de leurs caractéristiques quantitatives et qualitatives et du degré d'agrégation du modèle. La méthode d'interprétation des composants originaux des systèmes doit toujours être identique, sans tenir compte de la nature et du nombre des composants inclus dans ce modèle. L'algorithme simulatif, c'est-à-dire le simulateur, doit être absolument indépendant de la caractéristique de la variante donnée du modèle. Un autre principe essentiel adopté dans la conception de l'algorithme universel simulatif est son aptitude à imiter différentes décisions humaines, qui peuvent ou doivent intervenir dans les systèmes originaux en dépendance de la situation simulée dans le modèle et cela dans le but d'améliorer ou de régler certains processus.

Royaume-Uni

MM. Ordman et Sinclare commencent leur rapport par quelques considérations générales très pertinentes et très intéressantes.

A leur avis, bien que l'utilisation des ordinateurs puisse être appliquée dans de nombreux secteurs des activités portuaires, dont il faut traiter un nombre

considérable de renseignements et de données, il n'en est pas moins vrai qu'en ce moment, une certaine déception semble régner dans les milieux portuaires quant à l'étendue de ces techniques; et cela après une première étape d'euphorie pendant laquelle on prêtait, peut-être à la légère, toutes sortes de vertus à l'ordinateur, que l'on considérait comme une espèce de baguette magique, pouvant résoudre automatiquement n'importe quel problème.

Les auteurs attribuent cette régression à une surestimation initiale des difficultés impliquées par l'adoption de la nouvelle technique, du besoin de créer peu à peu l'équipement et le personnel spécialisé à cet effet, du temps indispensable pour le développement de cette idée et de réaliser une telle évolution et, finalement, la nécessité de comparer préalablement le coût d'implantation de ces processus avec le bénéfice que l'on obtiendra de son utilisation.

Les auteurs espèrent cependant que, malgré cette déception momentanée, les avantages du système s'imposeront rapidement pour les applications suivantes : Planification — Exploitation — Gestion — Echanges.

Ils font remarquer que, nonobstant la diversité de ces activités, un grand nombre des données emmagasinées et développées leur sont communes, ce qui représente en soi un avantage du système.

Ensuite les auteurs examinent les différents champs d'application de l'ordinateur, dans la forme suivante :

Planification. — Dans ce champ on expose que l'ordinateur peut recueillir et emmagasiner des données, et les développer à travers les modèles de simulation jusqu'à déterminer la méthode la plus propice, aussi bien dans le champ de la construction que dans celui de l'investissement financier.

A cet égard, on signale que le Conseil National des Ports a utilisé le modèle général construit par l'Université de Cambridge pour l'étude des importations et des exportations. Egalement, l'Administration du Port de Londres a utilisé un modèle de simulation pour justifier la nécessité d'une nouvelle écluse d'accès aux bassins de Tilbury.

Les auteurs constatent que ces applications n'ont été réalisées que partiellement et que dans le Royaume-Uni on n'a pas encore abordé la construction d'un modèle de simulation pour un complexe portuaire complet; cependant ils ne considèrent pas ce projet comme impossible, estimant qu'il s'agit seulement d'une question de temps et de coût.

Enfin, il y a sans doute l'application à la technique du Génie Civil dans le champ de la planification, mais cette application-là n'est pas exclusive aux ports, puisqu'elle est utilisée également dans les constructions non portuaires.

Exploitation des ports. — Les auteurs estiment que l'exploitation des ports constitue un champ très vaste pour l'application de cette technique. Ils s'étonnent par ailleurs que les résultats dans ce domaine sont assez pauvres. L'utilisation des calculateurs est particulièrement adéquate dans les spécialités suivantes :

a) Contrôle du mouvement des bateaux dans le voisinage des ports, ainsi qu'on le fait déjà pour le trafic aérien. Les auteurs signalent que, dans cette spécialité, ils ne connaissent d'autre réalisation pratique que la régulation de la navigation dans le fleuve Saint-Laurent.

b) Contrôle du mouvement de marchandises, aussi bien dans le trafic d'unités conventionnelles que dans celui de conteneurs. Dans le premier cas on n'est pas arrivé à des applications pratiques, mais pour les conteneurs on l'utilise normalement à Liverpool.

Gestion. — En entendant par ce mot l'ensemble des opérations de routine administrative dans les ports, le champ d'application de l'ordinateur est énorme : listes de salaires, inventaires, facturations, statistiques et processus comptables; ces activités sont de type arithmétique et parfaitement contrôlées par les programmeurs de l'ordinateur. Pour décider son adoption progressive, il s'agit seulement d'une question de prix d'implantation, d'accord avec le degré d'économie et de rapidité que l'on obtiendra.

Les auteurs détaillent les conditions générales que doit remplir la programmation destinée à cette fin spécifique.

Echanges. — En considérant qu'un port n'est pas un élément isolé, mais un maillon de la chaîne de transports internationaux, on comprend que l'échange d'information entre tous les ports est essentiel pour l'organisation appropriée à l'ensemble du trafic. Dans cet aspect, si le transport maritime veut garder une position concurrentielle avec le transport aérien, il faut qu'il établisse les réseaux nécessaires d'information réciproque et multiple; ce qui s'obtient seulement moyennant le calcul rapide et la capacité d'emmagasinage de données fournies par l'utilisation des ordinateurs.

D'autre part, pour arriver à des résultats positifs dans ce domaine, il faut uniformiser les procédés commerciaux internationaux et les codes sur lesquels on basera les statistiques.

Dans ce but on a créé dans le Royaume-Uni un organisme, le SITPRO.

Les auteurs terminent en exprimant l'opinion que le champ d'application des ordinateurs dans les ports est si vaste, que les dirigeants de ceux-ci devraient considérer ces problèmes avec le plus grand intérêt, sans oublier les questions du prix et de l'effort à réaliser pour son implantation.

RÉSULTATS GÉNÉRAUX

On remarque que les rapports que nous venons de résumer, montrent des caractéristiques quelque peu hétérogènes quant au degré de spécialisation parmi les questions exposées.

Tandis que les rapports britannique et français abordent l'application de l'informatique de façon globale sans rentrer dans des détails de programmation,

les rapports de la Pologne et des Pays-Bas se révèlent au contraire très spécialisés, et font allusion à un détail assez avancé dans le développement des programmes de simulation; d'autres rapports, après avoir donné des considérations d'ordre général, développent quelques applications pratiques concrètes.

Ce rapport général tâche de synthétiser le sujet de manière générique et nous croyons que les particularités et les détails des analyses ou des programmes ne devraient pas faire l'objet de débats pendant le Congrès.

C'est la première fois qu'on aborde cette question dans notre Association et nous estimons que les discussions lors du Congrès doivent se borner au domaine général de l'informatique. Ce n'est que plus tard, par une Commission spécialisée, qu'on pourrait arriver à approfondir en détail la méthodologie concrète de cette science dans notre travail.

De la lecture des rapports reçus, il s'ensuit de manière évidente que l'informatique joue un rôle capital dans les aspects suivants de notre activité :

1. Les projets concernant le Génie Civil (calcul d'ouvrages d'art, fondations, etc.).
2. Les processus administratifs.
3. L'obtention des résultats optimaux dans l'exploitation.
4. La détermination des décisions optimales dans la planification.

Chacune de ces quatre branches fondamentales peut à son tour être subdivisée en différents aspects, que nous examinerons par la suite.

La construction. — Bien que le sujet de l'application de l'informatique aux calculs du Génie Civil soit parfaitement connu et commun à n'importe quelle activité exigeant un projet de travaux, soit dans les ports ou bien en dehors de ceux-ci, il y a dans notre travail quelques particularités qui diffèrent des autres. A cet égard, il faut signaler l'application exposée dans le rapport français, sur la rapide obtention de résultats dans les essais concernant les modèles réduits, et l'application décrite dans le rapport espagnol sur le recueil et le développement de données sur la houle.

On doit faire observer particulièrement dans cet alinéa la remarque faite dans le rapport des Etats-Unis dans le sens que l'application de l'informatique au calcul des structures doit être justifiée par l'économie qu'on obtient par son moyen, en rapport avec le prix du développement du programme.

Processus administratifs. — Dans ce domaine, à l'égal de l'antérieur, l'application de l'informatique n'est pas caractéristique de l'administration portuaire. Ce fut précisément pour le calcul de feuilles de paie du personnel, listes de paiements et facturation, que les ordinateurs se manifestèrent dès le premier moment comme moyens d'application les plus simples et les plus utiles.

Dans la gestion portuaire il existe un grand nombre de processus administratifs auxquels on peut appliquer l'informatique, sans aucun doute ni difficulté particulière et, parmi ces développements, on peut mentionner les facturations

par services, les listes de paie du personnel et la compilation de données statistiques.

Ces applications sont exposées essentiellement dans le rapport espagnol et il faut faire ressortir le conseil donné sur l'utilisation du système de cartes pour la codification de données d'input au lieu du système de bandes, en raison des circonstances mentionnées, quant à la possibilité de corriger les erreurs plus facilement, sans que les rectifications influencent sur les zones de codification.

Obtention des résultats optimaux dans l'exploitation. — Cette application est plus particulièrement caractéristique de notre tâche que celles résumées dans les paragraphes antérieurs.

On peut obtenir un meilleur résultat dans l'exploitation, dû aux raisons suivantes : la rapidité dans le recueil et les démarches sur l'information, d'après l'exposé du rapport allemand, en ce qui concerne l'itinéraire documentaire du Port de Hambourg; une meilleure utilisation des installations disponibles, d'après le rapport canadien, pour le trafic à travers la voie navigable du Saint-Laurent ou, d'après le rapport des Etats-Unis, par le fonctionnement des installations portuaires conventionnelles ou de grandes unités.

C'est aussi une application qui mène à une meilleure exploitation de tout ce qui concerne la sécurité de la navigation.

La situation actuelle des applications de l'informatique quant à l'exploitation a été l'objet d'une recherche spécifique de la part de la délégation suédoise de ICHCA, laquelle a effectué une enquête auprès de 800 membres de ladite Association.

Les résultats ont été rassemblés dans un rapport appelé UCICH, publié par ICHCA et il contient d'intéressants résumés concernant le type d'application que 97 ports mondiaux étaient en cours de réaliser en février 1972. Nous conseillons la lecture de ce rapport, étant donné les renseignements concrets qu'il contient.

Détermination de décisions optimales. — Cette quatrième branche de l'application de l'informatique constitue un champ très vaste qui pénètre en quelques aspects dans l'idée d'améliorer l'exploitation. Ainsi, par exemple, le rapport finlandais, qui se réfère à la programmation la plus appropriée pour les routes d'accès aux côtes de ce pays pendant les pénibles périodes d'hiver en de telles latitudes, représente l'étude d'une décision excellente quant aux itinéraires et aux investissements pour des installations ou équipements; cependant, cette décision influence aussi essentiellement les résultats de l'exploitation.

Pourtant, l'application typique pour améliorer les décisions, se rapporte à l'aspect financier de l'investissement, et dans ce but on arrive aux modèles de simulation mentionnés dans les rapports des Etats-Unis, de l'Espagne, des Pays-Bas, de la Pologne et du Danemark, outre d'autres rapports qui abordent aussi ce sujet plus brièvement, d'après le contenu du résumé antérieur.

Evidemment, ce champ de la simulation est celui qui présente les plus grandes difficultés quant aux applications précitées, pour arriver à la détermination

de décisions optimales concernant les investissements financiers; mais il est aussi celui qui offre une meilleure possibilité pour réaliser un travail original d'une énorme importance économique.

Considérations générales sur le sujet. — Jusqu'à présent nous avons examiné les questions générales de l'informatique, le résumé des rapports présentés et la classification des différentes applications, concernant tous les aspects de l'administration portuaire.

Il s'agit maintenant d'exposer quelques considérations de type général sur l'ensemble des remarques contenues dans les rapports présentés.

Dans les rapports des Etats-Unis et du Royaume-Uni on observe aussitôt l'influence que l'informatique a nécessairement dans notre travail; c'est-à-dire, non seulement une importante adaptation de l'équipement, mais aussi la préparation mentale du personnel spécialisé, en nombre suffisant. A cet égard, devient particulièrement intéressante l'observation contenue dans le rapport britannique à propos de la désillusion remarquée après un premier enthousiasme pour les applications possibles de l'informatique, et en constatant que le processus d'adaptation de cette science à des travaux relativement simples exigeait une longue période d'enseignement et de préparation du personnel.

Cette considération est aussi en rapport avec la classification des différentes activités que nous avons déjà mentionnées, étant donné le fait certain que la technique de la construction d'ordinateurs se développe rapidement, de telle façon que ces machines deviennent de plus en plus simples, bon marché et d'usage courant.

De tout ce qui précède on peut conclure que les champs d'application les plus faciles pour l'informatique dans notre travail sont ceux concernant les projets de construction et les processus administratifs et comptables; on prévoit donc, dans un délai relativement bref, que tous ces travaux seront réalisés au moyen d'ordinateurs, à condition que leur dépense soit justifiée.

Ce dernier paragraphe nous mène à une autre considération également importante, à laquelle se rapporte très concrètement le rapport des Etats-Unis; il conseille seulement l'emploi des ordinateurs lorsque les avantages obtenus par leur utilisation justifie les frais entraînés par l'application du système. Ceci est applicable aussi aux processus d'exploitation et aux calculs pour les projets de travaux; à ce propos, le rapport nord-américain signale une limite très précise pour les estimations des travaux qu'il considère économiquement justifiables d'être traités par ces machines. Il faut cependant remarquer que cette limite diminuera de plus en plus à mesure que l'utilisation des ordinateurs deviendra moins coûteuse et que leur diffusion augmentera; à mesure aussi que la technique de la programmation deviendra plus parfaite et que l'on disposera d'un personnel spécialisé plus nombreux, apte à son utilisation.

Bien que les calculs de la construction ou de la comptabilité ne présentent pas de grandes difficultés pour l'emploi massif des ordinateurs, les autres activités d'amélioration se trouvent dans un stade beaucoup moins avancé; parmi celles-ci,

à leur tour, l'étude de l'amélioration d'investissements à long terme ne peut pas encore être considérée comme ayant obtenu un résultat pratique, concret et courant.

Il semble évident qu'une des difficultés que peut présenter le développement de ce type de calculs consiste dans la nécessité de disposer de données de départ véridiques et en nombre suffisant.

Il est certain également qu'un grand nombre de ces données, en tout ce qui concerne les mouvements commerciaux qui ont lieu dans les ports, ont beaucoup d'applications différentes, aussi bien pour des effets statistiques que pour le perfectionnement de processus d'exploitation et d'aménagement; on comprend donc clairement l'avantage de pouvoir obtenir la plus grande unification possible dans tous les éléments devant être utilisés; c'est-à-dire, que les caractéristiques physiques des unités de charge, les origines et les différents types de bateaux, itinéraires, caractéristiques d'équipement, etc. doivent, autant que possible, être unifiés et codifiés de la même façon de par le monde. Ainsi, l'idéal serait d'arriver à la concentration de tous les types de données dûment groupées dans une banque mondiale analogue à celle établie pour le Port de Hambourg, et à laquelle les divers investigateurs pourraient demander les données nécessaires pour leurs modèles de simulation. Ceci est, certainement, à l'échelle internationale, un objectif pratiquement inaccessible, mais il marque la direction vers laquelle il faudrait essayer d'atteindre le progrès.

Un autre sujet qui peut devenir le but d'une étude d'unification est la méthodologie de la simulation, c'est-à-dire, l'ensemble de règles concrètes sur les groupes d'activités pouvant faire l'objet de modèles de simulation partiels, de telle façon que sa conception générale soit toujours la même et permette ensuite son intégration dans des modèles plus compliqués, moyennant les substitutions ou les assemblages nécessaires.

CONCLUSIONS

Comme résultat de l'examen réalisé et de tout ce qui a été exposé jusqu'à présent, je me permets de proposer au Congrès la discussion des conclusions suivantes :

1. — L'utilisation des ordinateurs se généralise de plus en plus sans difficultés spéciales dans des activités relatives à des projets de travaux et à des processus comptables et administratifs dans la gestion des ports.

L'Association désire, cependant, signaler que l'adoption de ces techniques exige forcément une période relativement longue pour la préparation du personnel et pour réaliser des investissements d'une certaine importance.

Nous conseillons donc que, préalablement à l'implantation de ce type de machines, il faut examiner l'économie réelle dans les conversions des machines et l'adaptation du personnel administratif, que l'on pourra obtenir dans un délai raisonnable.

2. — L'emploi de la science de l'informatique dans la technique de la manutention des charges exige une unification aussi vaste que possible dans la codification des données d'input.

3. — L'utilisation d'ordinateurs pour des modèles de simulation, déterminant des décisions économiques, comme celles concernant la planification et les investissements, n'est pas encore considérée assez développée actuellement, mais on espère pouvoir obtenir des résultats positifs dans un prochain avenir.

4. — L'utilisation de l'informatique pour la régulation du trafic maritime obtient des résultats favorables et doit être conseillé sans exception, aussi bien en ce qui concerne la meilleure utilisation des voies navigables, que pour l'accroissement des conditions de sécurité.

5. — Les données d'input pour les processus informatiques ayant des buts différents, sont souvent les mêmes. L'utilité de la rapidité d'information réside fréquemment dans la possibilité d'adoption de décisions dépendant d'une seule commande.

On estime en conséquence que l'utilité de l'usage des ordinateurs dans ces domaines est liée à une uniformité effective dans l'emmagasinage de données pour des finalités différentes et à une concentration de facultés de décision en un seul point.

Par suite des considérations précédentes, on propose la constitution d'une Commission ayant les objectifs concrets suivants :

a) Proposer une nomenclature de données dûment classifiées, comprenant toutes celles considérées utiles, aussi bien pour les processus d'exploitation que pour les modèles de simulation économique.

b) Proposer une codification pratique, pouvant être adoptée internationalement, pour les données mentionnées antérieurement.

c) Etudier et proposer la méthodologie unifiée de simulation pour les processus partiels fondamentaux de la technique portuaire, lesquels, dûment combinés, fourniront le dessin des schémas d'ensemble pour chaque cas.

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Section II

OCEAN NAVIGATION — NAVIGATION MARITIME

Subject 5 — Sujet 5

The application of computer science in port planning and operation.

Application des techniques de l'informatique dans la conception et l'exploitation des ports.

General Secretariat of P.I.A.N.C. — Secrétariat Général de l'A.I.P.C.N.
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PAPER

by

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COMPUTER-ASSISTED TRAFFIC CONTROL IN THE ST. LAWRENCE-GREAT LAKES WATERWAY

1. INTRODUCTION

A very brief description of the St. Lawrence-Great Lakes waterway would mention that it extends over a distance of approximately 2,300 miles from the Gulf of St. Lawrence to the head of the Great Lakes. The St. Lawrence Seaway Authority, a Canadian Crown Corporation reporting to the Minister of Transport, Ottawa, is responsible for that portion which starts at Montreal Harbour and ends 50 miles into Lake Erie. For administrative purposes, this portion was divided into two sections — the Montreal-Lake Ontario section, stretching 100 miles and containing 7 single locks and the Welland Canal section, 28 miles in length and containing 8 locks of which three are twinned and in flight. In the Montreal-Lake Ontario section, two locks are located on the American side of the international boundary and are administered by the Saint Lawrence Seaway Development Corporation, Massena, New York which reports to the Secretary of the Department of Transportation, Washington, D.C.

2. BACKGROUND

A gradual deterioration in the level of service at the Welland Canal following the 1959 opening of the new facilities in the Montreal-Lake Ontario section had made clear, by 1967, the need for the development of an automated traffic control system. This deterioration could be attributed to a large degree to the impact of changes such as the altered vessel mix, the growth in the size of vessels, the increased demand for services, the changes in safety procedures and other factors of a secondary nature.

3. THE PROBLEM

Very briefly, attempts to solve the problem began with a review and identification of

(1) the primary objectives of the system,

(2) the activities, both inside and outside the Seaway transportation mode that could be interpreted as demand and level of service indicators,

(3) those elements pertaining to the operations of the mode that influenced the efficiency of the system.

Following the many developments which arose from our attempts to employ more sophisticated manual procedures over a period of several years, it became increasingly evident that what was required was a system designed to provide on-line real-time capabilities.

Early attempts to model our system to determine and optimize the capacity brought into sharp focus those factors that were limiting the functioning of our traffic controllers who were using a manual system for scheduling. Specifically, it was found that (a) the time available to the controller was a key factor and this suggested the need for better tools; and (b) that a phased development of computer simulation would be necessary to approach optimization.

Pertinent to the time factor problems is the necessity to supply the decision maker (traffic controller) with

(1) the data related to given situations at a particular point in time in the system,

(2) a means that permits him to convert this data into information in the required time frame,

(3) a tool that permits the investigation of alternatives, again within the required time frame.

These sensitive areas having been identified, it was then possible to apply the various techniques of such disciplines as Management and Operational Research. Initially, these methods resulted in improving the existing facilities and operating procedures. The improvement in operations was realized from

(1) using a systems approach,

(2) centralizing traffic control,

(3) making more and better use of communication equipment (VHF), and

(4) the introduction of closed circuit television.

It soon became apparent that more was required than simply operating the facilities at a faster rate if a satisfactory level of service were to be realized under the new demand conditions.

4. DYNAMICS OF SYSTEM

Like all transportation systems, the St. Lawrence Seaway system is dynamic and an understanding of the interacting elements as well as their measurement is required if one is to achieve any degree of optimization of production and quality of service.

Studies indicated that the dynamics of our system are related to

(1) the random arrival pattern of the vessels,

(2) the in-series configuration of the locks and reaches,

(3) the variability of the service times at the facilities,

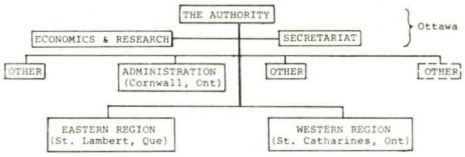
(4) the interruptions of navigation in the sections and/or the whole system from time to time; and

(5) the performance of auxiliary services e.g. pilotage, loading and unloading at ports.

Our Operational Research personnel succeeded in producing a set of curves which permit acceptable predictions of the overall level of service under varying conditions of demand and facility service times. These curves were derived from queueing theory by assuming that the arrival pattern follows a Poisson distribution and that the lock service time is an Erland (K=2) distribution.

5. ORGANIZATION

FIGURE 1 - ST. LAWRENCE SEAWAY AUTHORITY ORGANIZATION



At this point, we might take a quick look at our organization (Figure 1). It will be noted that our Economics and Research Branch, located in Ottawa and established in 1966, fulfills a staff function and reports to a senior executive of the Authority. We are very fortunate in that the Branch is staffed with highly competent professionals. In addition, we occasionally have recourse to the services of consultants for very specialized studies.

6. PROPOSED SYSTEM

The original proposal made to management in 1968/69 was for an Automated Traffic Control (ATC) system that embodied the following functions :

(1) On-line real time data gathering from terminals at the traffic control centres and associated agencies/entities,

(2) Automatic message switching and data communications,

(3) Information storage and retrieval (providing a comprehensive data base),

(4) Automatic data collection from structures and discrete points in the waterway,

(5) Automatic vessel location and identification,

(6) Traffic planning,

(7) Management information.

The system was composed of a computer network with a computing centre at each traffic control centre, at St. Lambert, Quebec and St. Catharines, Ontario, with a central machine at the Administrative Headquarters at Cornwall, Ontario. Each computing centre contained a central processing unit, a bulk information storage device (a disc), a printer, C.R.T. terminals for the traffic controllers and remote terminals (teletype) used by other agencies. The C.R.T. terminals provided the speed of response required by the traffic controllers. It was a dedicated system performing the functions enumerated above.

As our studies on the dynamics of the system progressed and as solutions were striven for, it became evident that if more lead time concerning the movement of approaching vessels could be obtained, the randomness of arrivals could be reduced and (a) under saturated conditions the facility utilization factor increased, and (b) under less than saturated conditions, the waiting time of vessels could be reduced. Given that all vessels do not proceed at the same speed and do not have the same manœuvrability characteristics, it does follow that the greater the lead time, the better the opportunity the decision maker has to set up his traffic pattern, (e.g. concerning tandems and position of tows — to mention only a few) and so to achieve improvement in the level of service.

In studying the base data required to carry out our responsibilities, we became aware that the data at the extremities of our system was available from other entities. And it also became evident that the many agencies involved in the transits of vessels between the Gulf of St. Lawrence and the Great Lakes all needed essentially the same data and that all were collecting it separately; indeed, there appeared to be considerable redundancy in the data collection functions.

During 1970/71, a revised proposal was accepted in principle by the Authority for what has subsequently been called an Integrated Marine Traffic Information and Control (IMTIC) system. We were essentially proposing a system which integrated data collection, information retrieval and automatic message switching for the whole St. Lawrence-Great Lakes basin while performing for the St. Lawrence Seaway Authority proper the functions originally proposed in the ATC system. A partial list of the agencies/entities involved would include :

(1) National Harbours Board,

(2) Marine Traffic Control (Quebec),

(3) Marine Information System,

(4) Pilotage,

(5) Information Canada (Statistics),

(6) Saint Lawrence Seaway Development Corporation,

(7) U.S. Coast Guard,

(8) U.S. Corps of Engineers.

Early 1971 saw the acceptance by all the Canadian agencies/entities of the principle of data integration as suggested.

The integration of data and information with our American counterparts is still in the negotiation stage.

The technical advances in the state-of-the-art relating to our proposed system which evolved and became available commercially during the protracted stages of our research and development were embodied in each subsequent proposal. Among the most notable of such advances during the period 1968 to 1971, we may cite

(1) the developments in the field of process control computers,

(2) the development of fully graphic displays at reasonable cost, and

(3) the lowering of costs for hardware and peripherals.

These developments influenced our design to the point that our final proposal included fully graphic CRT displays whereas originally we had considered computer driven « system mimics ».

At this juncture, it might be well to examine the data collected automatically and identify its uses. It includes information concerning

(1) the characteristics of the vessels,

(2) a detailed step by step record of the vessel's entrance into the Seaway and of its transit through the system,

(3) a detailed record of the operations of the key components of the Seaway facilities, e.g. traffic signals, lock gates, valves and bridges,

(4) navigational and environmental data, e.g. status of navigational aids, wind direction and velocities.

These data form the basis of the information system required to effectively operate the Seaway. Being automated, the system is capable of

(1) signalling abnormal conditions as they are sensed by generating action reports that must be acknowledged,

(2) producing trend reports on a prescribed time schedule to satisfy the various hierarchies of supervision,

(3) generating reports indicating the results of actions taken to correct abnormalities,

(4) generating periodic reports when and if required.

The reporting system for the day-to-day operations, as developed, may be divided into two categories — the exception reports and the trend reports. The rationale behind this division is that

(1) most agencies/entities produce too many reports containing too much data,

(2) if the situations are normal, why report « ad nauseam »,

(3) if abnormalities are reported, the corrective measures taken and their effectiveness should also be reported,

(4) the computer has been used by many agencies/entities to generate reports that are usually historical in nature and of little use for day to day operation,

(5) an agency having a tool that permits continuous monitoring and instant reports should incorporate it into its day to day operation,

(6) the CRTs are the ideal tool for the signal type of report — hard copy is available if required,

(7) the line printers offer considerable clerical savings.

Because of the validation and verification technique that one can incorporate in the software, the accuracy of the reporting is much superior to that produced manually.

The « planning function » is essentially a scheduling of all the clements of the waterway. One of the objectives of our operation is to optimize the transit time as the criterion of our level of service, or in periods approaching saturation, optimize the capabilities of our facilities. We propose to use real-time simulation techniques for this function. To this end, considerable research has been carried out to determine how this can be accomplished. We have no illusions about the difficulties nor are we overwhelmed by the apparent complexities.

Our approach will be evolutionary and developed without interfering with the day to day operations. It will consist of a foreground and a background activity. The foreground activity will provide a simulation model for the Traffic Superintendent at each Traffic Control Centre to pre-test one or more alternative traffic patterns and choose the one which will optimize system throughput. Once a plan is chosen, the system will continuously compare the progress of the vessels with the schedule for their transits, detect any deviations, and display to the Traffic Superintendent those corrections which will minimize the impacts of the deviations on the system. It will use decision rules tried and proven in the background activity.

The background activity carried on by Research will use the central computer and data base to evaluate the efficiency of the foreground system, to analyse further the dynamics of the system and to develop and pre-test new decision rules to upgrade the foreground model.

The implementation of such improvements will be transparent to the Traffic Superintendent. The conversational technique used permits the planning system to be self-instructing, thereby avoiding any re-learning on the part of the Traffic Superintendent.

It becomes evident that, in order to effectively carry out the « planning function », one must have recourse to an automatic vessel location and identific-

ation (AVLIS) system. Considerable effort has been expended to develop such a system to continuously monitor vessels. Conceptually, AVLIS will consist of transponders located aboard vessels. These transponders — on being polled from the Traffic Control Centre — will encode information on the vessels' location and identity and will transmit this information via VHF radio and land line to the Traffic Control Centre. These transponders, portable in size, will be carried aboard ocean vessels by the pilots whose services are mandatory for ocean vessels in the Seaway. Other arrangements will be made for the inland vessels which do not use pilots.

It is planned to study the feasibility of using either « Loran C » or OMEGA signals as the basis of our AVLIS system. It appears that either one would meet our requirements. Full implementation of the AVLIS system has been tentatively scheduled for post 1975.

7. COSTS

The estimated cost for such a system, not including research and development, will be in the neighborhood of $5 million, apportioned as follows :

(1) $1.5 million for the necessary hardware and software fully expanded to accomplish all the functions listed herein (except AVLIS),

(2) $3.5 million for the cost of AVLIS, including shipboard equipment and the telemetry of the digital data to the control centre computers.

8. JUSTIFICATION

The benefits and savings are extremely difficult to quantify. Tangible savings to the agencies/entities involved in the order of $500,000 per year have been identified. Savings to the shipping industry have been estimated at some $1.5 million per year. One finds it very difficult to assign a dollar value to savings made possible by the improved safety measures that would result from such a system. Even if we went through the exercise of working out probabilities of accidents and catastrophes which could be fairly accurate over a period of many years, such calculations historically have had little influence on the decisions taken.

9. IMPLEMENTATION

As might be expected, the implementation will be phased over a relatively long period of three years (see Figure 2).

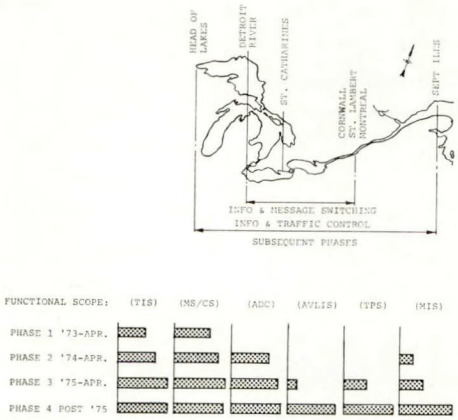


Fig. 2.

General scope of IMTIC implementation.

TIS = Traffic Information
MS/CS = Message Switching Communication
ADC = Automatic Data Collection
AVLIS = Automatic Vessel Location
TPS = Traffic Planning
MIS = Management Information

The first phase involves satisfying some of the basic functions and installing the basic hardware/software. The basic functions are the integration of the collecting and storage of data for computer retrieval and message switching. This phase permits establishing precisely the what, when and how concerning the collection and transmittal of information by and to the various related agencies/entities.

Each of the subsequent three phases will cover the development of additional functions and the expansion of the hardware and software to accommodate these added functions.

10. CONCLUSION

The IMTIC system, as described, culminates five years of research and development by many professionals from several disciplines. Only those state-of-the-art techniques and equipment that have been commercially accepted were recommended.

With the Request for Proposals for the first phase issued on June 1st, 1972, the St. Lawrence Seaway Authority has innovated an integrated system, expansible in nature, to cope with the growing demand for a safe, efficient inland marine transportation system.

RÉSUMÉ

Le traffic maritime partiellement contrôlé par ordinateur dans la voie navigable du Saint-Laurent et des Grands Lacs

Tel qu'il est projeté, le système de contrôle du trafic maritime, géré par ordinateur en liaison directe et exploité en temps réel, procurera les moyens d'information et de surveillance nécessaires pour faire face aux besoins croissants de sécurité et de service du réseau de la voie navigable du Saint-Laurent et des Grands Lacs. Le projet comporte la saisie des données, la commutation automatique des messages, une banque d'information, l'emploi de procédés de simulation pour l'optimisation et la préparation des rapports d'exploitation ainsi que des statistiques. Il comprend l'identification automatique des navires et de leur position, une télévision en circuit fermé, un système complet de transmission des données, des ordinateurs, des unités d'affichage à écran cathodique servant à la fois d'appareils d'entrée/sortie et de contrôle de la surveillance. La mise au point et les essais à grande échelle ont démontré la viabilité d'un tel système.

S. II - 5

PAPER

by

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ON THE PLANNING AND OPERATION OF CONTAINER TERMINALS

CONTENTS

1. INTRODUCTION

The optimum size of a container terminal depends on a great number of factors. In this paper the quay-side operations only are considered, and the optimum size is consequently given mainly by two figures :

1. The length of quay and
2. The number of container cranes (and associated straddle carriers).

For major container terminals, which are usually kept in operation around-the-clock seven days a week, the simulation method indicated in this paper may be used to determine the optimum physical size of the terminal.

For smaller terminals the method may further be used to determine the optimum number of working shifts or weekly working hours at different traffic levels, and may consequently give a complete scheme for the development of the loading/unloading capacity of the terminal.

2. COMPUTER SIMULATION OF TERMINAL OPERATION

The computer simulation programme previously developed by the author (1) has been modified for the purpose of this study to make it suitable for investigations of container terminal operations. A simplified flow chart of the programme is given in Figure 1.

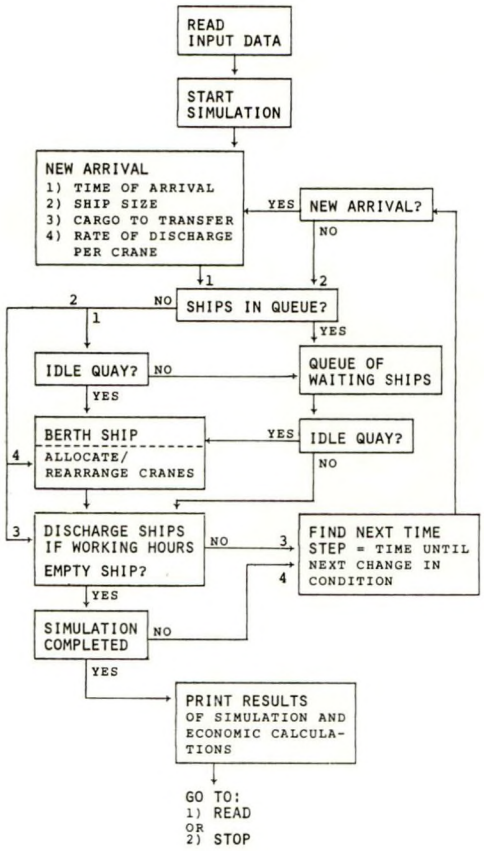

Fig. 1.

Simplified flow chart of simulation programme.

The ship traffic.

Most container terminals serve two types of container traffic : Feeder lines and ocean lines. The ships used for these two types of traffic are widely different, and the terminal in this paper is assumed to be used jointly by the two types of ships. Whether the terminal is mainly a feeder line terminal or mainly an ocean terminal is expressed by the percentage of ships being of either type.

The ships used in feeder services are generally of sizes 70-100 m in length with carrying capacities of 50-150 20 ft containers. A mean feeder ship size of 125 20 ft containers (95 m long) with a normal distribution of carrying capacities with standard deviation 25 20 ft containers is assumed in the examples quoted in this paper.

The ships used on ocean lines show much greater variations in size. In the examples quoted later a mean size of ocean going ships is arbitrarily chosen at 700 20 ft containers (170 m long) with a normal distribution of carrying capacities with standard deviation 140 20 ft containers.

Since this paper deals with the principles of terminal planning only, the actual size of the ships is not important in this context although it is of course very important in practice when deciding, for example, the water depth.

(1) J. Buhr Hansen : Optimizing Ports through Computer Simulation — Sensitivity analysis of pertinent parameters. Operational Research Quarterly. London. (In press Sep. 1972).

A very important parameter in relation to the optimum size of a terminal is undoubtedly the arrival rate distribution for ships. It is well known that random arrivals are most commonly experienced in traditional general cargo ports. In container traffic fixed time tables are usually applied, yielding (at least some) regularity in the arrivals of ships. On the other hand it is obvious that deviations from the expected time of arrivals will occur.

The importance of regularity of arrivals may be illustrated by the performance of a terminal serving 75% feeder ships and 25% ocean ships under different arrival distributions.

The terminal has one berth and one container crane and a 45% utilization of the berth when it is kept in operation around-the-clock seven days a week. The scheduled arrivals are planned such that congestion should be minimized by allowing a greater mean arrival interval for ships following ocean liners than for those following feeder ships. All arrivals are assumed to be normally distributed in time around the scheduled arrival hour. The probabilities of delay and the mean waiting time as a function of the standard deviation of arrival hours are given in Table I. The figures for random arrivals are included in the Table for comparison.

TABLE I

Delay of ships due to deviations from scheduled arrival hours

Mean arrival interval : 10 h. Mean ship size : 266 cont.
Mean service time : 4.5 h. Standard deviation on service time : 3.6 h.

Yearly throughput : 2 × 58,000 cont.

Standard deviation on arrival hours h		Mean size of waiting ships cont.	Mean waiting time h	Probability of delay
0		—	0	0
2		266	0.32	0.22
4		223	0.97	0.42
6		206	1.67	0.53
8		201	2.42	0.60
10		204	3.23*	0.66
Random arrivals	Simulation	266	2.89	0.45
	Queuing theory	266	3.00	0.45

* When the reduced size of the waiting ships is taken into account this is 17 % less waiting time in terms of waiting time × ship size than for random arrivals.

The ships arriving in accordance with a time-table are — here, as in the entire paper — assumed to be served in the order of the scheduled arrivals. This means that no overtaking is permitted, and that in some cases the rule first come-first served will be violated. This may be a somewhat unfavourable circumstance for a terminal, but it will increase the efforts towards punctual arrival. This causes the relatively high probabilities of delay shown in Table I for very unpunctual arrivals, but even in these cases the mean waiting time is reduced by the regularity of arrivals.

The figures in Table I are further based on a crane operation with 20 lifts per hour and a standard deviation of 4 lifts per hour following a normal distribution; and an additional stay of the ships at berth for 1 hour in total before and/or after the container handling. Each ship is further assumed to need that number of lifts required for 25% of the ship capacity in 20 ft container units. This is understood as a turn-over (replacement) of 25% of the ship capacity in case each lift handles one 20 ft container in and out, or a 50% turn-over in case 40 ft containers or a twin-lift system on 20 ft containers are used. When the throughput of the terminal is given in this paper as a number of containers per year, it may consequently be understood as either 20 ft units or as 40 ft units.

The terminal operations.

The size of a terminal in this paper will be given by two figures :

1. The length of quay;
2. The number of cranes.

In large container terminals serving a variety of ship sizes a great flexibility in the allocation of both berthing space and container cranes will yield better utilization of the terminal and faster turn-around for the ships on the whole.

To derive advantage from this concept of flexibility the terminal should be placed along one straight length of quay able to accommodate any number of ships. The length of quay occupied by each ship is taken as 15% more than the total length of the ship, and it is assumed that the ships, if necessary, are shifted along the quay during the handling in order to give space for additional berthings. This may sound awkward, but considering that it will be necessary to shift only a few per-cent of the ships at terminals having reasonable utilizations of quay, it may be possible to do so actually in practice. However, this assumption has no significant influence on the results.

The relation between the carrying capacity (C) in 20 ft container units and the length (L in m) for container ships is not well established yet. NPC (1) has published a graph showing ship's length against number of containers for a number of ships. From this graph the following approximate second order regression equation has been derived

$$C = 160 - 4.9 \cdot L + 0.047 \cdot L^2$$

This relation is applied here for $40 < C < 1200$.

(1) National Ports Council : Research and Technical Bulletin, No. 5, London 1969, p. 186-224.

Concerning the allocation of cranes, in addition to the obvious requirement that each ship at berth shall have one crane, the maximum number of cranes that can be allocated to any ship is limited by its size. For the simulation the maximum number of cranes adopted are shown on Table II.

TABLE II

Maximum number of cranes allocated to 1 ship

Ship length m	Max. no. of cranes
0-100	1
100-150	2
150-	3

The allocation of cranes is reconsidered each time an arrival or departure takes place, meaning e.g. that a ship may be served partly by 2 cranes simultaneously and partly by 1 crane only.

3. TERMINAL SIZE VERSUS TYPE OF TRAFFIC

It is of obvious importance for the planning of a container terminal to have a good estimate of the yearly throughput of containers. The expected ship sizes are further of importance for the design of the quay structure. However, it is not at all obvious how the combined handling of feeder ships and ocean ships may influence the optimum size of the terminal, understood as the optimum length of quay and the optimum number of cranes.

This is illustrated by the results of two sets of simulations for two different yearly throughputs and three different combinations of feeder and ocean traffic. The arrivals are assumed to take place around the scheduled hours with a standard deviation of 4 hours as detailed above. The three different combinations of feeder and ocean traffic are taken as 75%, 50%, and 25% feeder ships, respectively.

In the case of a yearly throughput of 2 × 118,000 containers the optimum terminal size for these ship traffic combinations is found to be 1 berth 230 m long equipped with 2 cranes, on the economic basis of the cost figures of the appendix. The total cost per container loaded or unloaded is found to be 5.93-6.20 $ covering

all cost elements except terminal labour cost. This is further based on terminal operation around-the-clock, and crane capacity and ship utilization as stated above.

Although the optimum size of the terminal is the same for the three different traffic patterns, and the total cost show variations of a few per-cent only, other figures do show considerable variations. Table III gives the main results in the three cases, and includes some of the figures that are greatly influenced by the changed mean ship size.

TABLE III

1 berth terminal with 2 cranes

Yearly throughput : 2 × 118,000 cont.

Per-cent feeder ships %	Mean ship size C	Mean arrival interval h	Probability of delay	Total waiting time* C.h/year	Total cost $/cont.	Utilization of berth
75	266	4.99	0.682	634,000	6.20	0.56
50	415	7.73	0.469	382,000	5.93	0.48
25	559	10.32	0.282	244,000	5.97	0.45

* This figure is calculated as ship capacity × waiting time on a yearly basis.

The figures of Table III indicate that the optimum size of the terminal in other cases might be different for different mean ship sizes. This is partly due to the unavoidable extra stay in port before and/or after the container handling period. This extra stay, as mentioned above, is taken as 1 hour, and has of course a greater influence on the utilization of quay when many small ships — feeder ships — are using the terminal. This accounts for the entire change in utilization of berth in Table III. The variations in waiting time and probability of delay is further greatly influenced by the relative standard deviation on arrival hours, which in this case is inversely proportional to the mean ship size.

If the yearly throughput of the terminal is increased to 2 × 180,000 cont/year, through reduced mean arrival intervals for the ships, then the optimum size of the terminal will increase. Table IV gives the total cost per container (excluding labour cost) for different terminal sizes and for the three combinations of feeder-ocean traffic.

In this case the optimum size of the terminal changes with changing mean ships size, but the cost changes around optimum are very limited. It appears that changes of the mean ship size have greater effect on the total cost than minor deviations from the optimum terminal size.

TABLE IV

Optimum terminal size

Yearly throughput : 2 × 180,000 cont.

Length of quay in m No. of cranes Max. no. of berths			250 2 2	300 2 2	300 3 3	350 3 3
Per-cent feeder ships %	Mean ship size C	Mean arrival interval h	Total cost $/cont loaded or unloaded (excluding labour cost)			
75	266	3.37	6.00	6.10	6.00	*5.95*
50	415	5.02	5.60	5.75	*5.55*	5.60
25	559	6.62	5.55	5.70	*5.40*	5.50

4. TERMINAL SIZE VERSUS TERMINAL OPERATION

It will often be a question how many hours a week the terminal having only a limited yearly throughput of containers should perform loading/unloading of the ships. This decision will of course have a very significant impact both on the optimum size of the terminal and on the total handling cost per container.

To illustrate this a terminal with a yearly throughput of 2 × 58,000 containers carried by ships of mean size 266 cont. (75% feeder ships and 25% ocean ships) is investigated. The ships are — as above — arriving according to a time table but with a standard deviation on the arrival hour of 4 hours. (The mean arrival interval for all ships is 10 h.)

When the terminal is kept in operation a limited number of hours a day, all arrivals are of course scheduled to take place within the working hours. However, some early or late arrivals will in this case take place when the terminal is closed causing a computed extra waiting time to some ships.

When the terminal is open only during a limited number of hours a day corresponding to 2 shifts and 1 shift working — as detailed in Table V — the mean service time will furthermore increase because a number of ships will have to stay overnight before the handling is completed. In Table V this is clearly seen for 1 shift irrespective of the increased number of cranes. This may in real life be compensated by a certain amount of overtime work on ships already being served, but the computer programme does not take this possibility into account. The increased service time for some ships does at the same time yield an increase in the standard deviation on service time. Relative to the mean service time the standard deviation increases from 0.8 for « 3 shifts » to 1.5 for 1 shift (in absolute units an increase from 3.6 h to 11.9 h). This in itself obviously causes increased probabilities of delay and increased waiting time even if the terminal is enlarged in size and equipment to obtain the same utilization.

TABLE V

75% feeder ships and 25% ocean ships. Mean ship size : 266 cont.
Mean arrival interval : 10 h. Yearly throughput : 2 × 58,000 cont.

	1 shift	2 shifts	3 shifts
Weekly opening hours	47	94	168
Distribution of opening hours			
Monday-Friday	5 × 9.35	5 × 16.83	5 × 24
Saturday	0	9.35	24
Sunday	0	0	24
Optimum terminal size			
Quay length (m)	350	230	230
No. of cranes	3	2	1
Max. no. of berths	3	1	1
Utilization of quay	.32	.30*	.31*
Utilization of cranes	.41	.31	.35
Mean service time (h)	7.83	4.53	4.49
Mean waiting time (h)	3.92	2.42	.81
Cost per container ($/cont)			
Cost of quay	3.01	1.96	1.96
Fixed cost of cranes and straddle carriers	4.39	3.52	2.08
Operation of cranes etc., excl. labour cost	*.53*	*.53*	*.53*
Total terminal cost excl. labour cost	7.92	6.01	4.58
Ships service time	5.01	2.90	2.87
Ships waiting time	*2.51*	*1.54*	*.51*
Total ship cost	*7.52*	*4.44*	*3.38*
Total cost per container excl. labour cost	15.44	10.45	7.95
Estimated labour cost for permanently employed gangs	*1.50*	*2.00*	*2.00*
Total cost per container ($)	16.94	12.45	9.95

* This *utilization of quay* is based on occupied quay length. The *utilization of berth* is in both these cases 0.45. (If all ships were of the same size corresponding to the length of quay the two utilization figures would be identical).

The cost figures in Table V show that all elements of cost increase when the weekly opening hours are reduced and that overtime work on ships already being served cannot change the main result.

To complete the economic results given in Table V the labour cost are estimated in the three cases. The estimate is based on a labour cost of 25-27 $ per hour per gang. The number of gangs is taken equal to the number of cranes, and the total labour force is assumed permanently employed. For comparison it may be mentioned, that if the total labour force was employed on an hourly basis the labour cost per container would be approximately 0.65 $. The increased cost of labour in case of additional working hours is found to be rather insignificant when the terminal size is adjusted to the working conditions.

Consequently it will be favourable to operate this terminal having yearly throughputs exceeding 2 × 58,000 units around-the-clock seven days a week. From additional simulations having the same traffic pattern as those referred to above the same conclusion is arrived at if the yearly throughput exceeds

2 × 30,000 units only. Further a 1 berth/1 crane terminal is found to be the optimum solution up to a yearly throughput of 70-80,000 units each way.

5. CONCLUSIONS

The traffic planning of a container terminal aiming at an optimum solution is a very difficult task. A solution having any reasonable degree of accuracy can only be obtained through numerical simulation on a computer. A number of simulations, upon which the results given in this paper are based, have led to the following conclusions :

In most container terminals the ships arrive according to a time table, and it is of great importance to the queuing of ships before berthing that the scheduled arrival hours are observed. The arrivals in these cases are probably normally distributed around the scheduled hours, and for terminals having reasonable utilizations (0.3-0.5) the waiting time will be reduced by a factor 2.5-3 if the standard deviation on arrival hours is halved. For practical applications of the simulation method, investigations of the accuracy of arrivals are essential. For this study a standard deviation of 4 hours is simply assumed.

Changes in the compound traffic through different combinations of feeder and ocean ships do not have any great influence on the optimum size of the terminal, when the yearly throughput of containers is kept constant. However, the total cost per container decreases with increasing mean ship size and simultaneously the length of quay may be reduced.

The weekly opening hours of the terminal have a very significant influence both on the optimum size of the terminal and on the total cost per container. Even ports handling only 30,000 containers a year each way should keep the terminal in operation 24 hours a day throughout the week to the best advantage. In this case 1 berth with 1 container crane will be the optimum up to a yearly throughput of 70-80,000 containers each way. These throughput figures are of course significantly influenced by the cost figures involved and by the accuracy to which ships arrive according to schedule, and both figures may rise if the accuracy of arrivals is better than the estimated 4 hours standard deviation.

APPENDIX

Estimated costs of investments, maintenance, and operation.

Cost of quay.

Dredging, reclamation, and land acquisition (1)	5,000 $/m
Quay wall structure (total height 13 m) (2)	1,500 $/m
Paving and surface cost (1)	1,000 $/m
Total investment	7,500 $/m
Interest, maintenance, and depreciation	15% p.a.
Total yearly cost of quay	∿ 1,000 $/m

(1) National Ports Council : Research and Technical Bulletin, No. 5, London 1969, p. 233-240.
(2) National Ports Council : Port Structures — An analysis of costs and design for quay walls, locks and transit sheds. London 1969.

Cost of cranes and straddle carriers.

Investments :

1 container crane	430,000 $
1 straddle carrier	140,000 $

The *fixed yearly cost* of 1 crane and the supporting 2 straddle carriers depends on the potential utilization as follows :

	1 shift		2 shifts		Around-the-clock	
	crane	str. car.	crane	str. car.	crane	str. car.
Interest and depreciation	16 %	20 %	20 %	26 %	26 %	31 %
Insurance	1 %	1 %	1 %	1 %	1 %	1 %
Maintenance	5 %	6 %	5 %	6 %	5 %	6 %
Total	22 %	27 %	26 %	33 %	32 %	38 %
Total in $/piece	94,000	38,000	112,000	47,000	135,000	54,000
Total in $/set per year .	170,000		206,000		243,000	

The *variable cost* per working hour covering additional maintenance and operation costs (excluding labour cost) per set of 1 crane and 2 straddle carriers is taken to be (12 + 2 × 4 =) 20 $/hour.

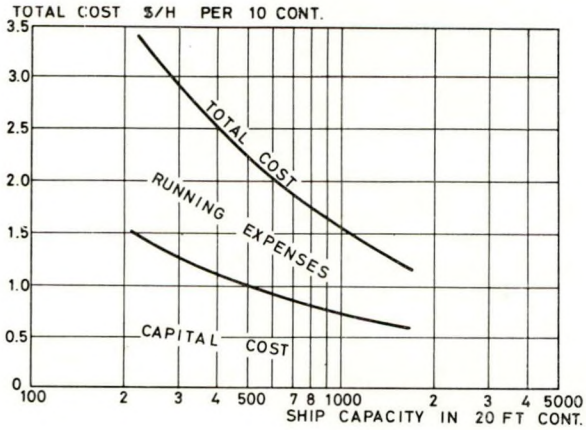

Fig. A1.

Cost of ships stay in port.

Cost of ships stay in port.

The cost of the ships stay in port should for the purpose of this study be based on a marginal analysis of receipts. However, to the knowledge of the author, no such analysis is published and the figures are replaced here by the average cost figures given by GETZ and others(1). The cost is taken as capital cost and operating expenses (excluding fuel) for a medium cost country vessel (1) but assuming a bale capacity of 1650 cuft per 20 ft con-

(1) GETZ, ERICHSEN and HEIRUNG : Design of a Cargo Liner in Light of the Development of General Cargo Transportation. Paper no. 6 presented at the International Meeting June 1968 of the Society of Naval Architects and Marine Engineers. New York 1968.

tainer. The costs of ships of different sizes are given in Figure A1, and for any particular terminal the cost per hour per container for the mean ships size is applied for all ships using the terminal.

RÉSUMÉ

Les dimensions optimales d'un port terminus pour containers sont déterminées par un grand nombre de données. Le rapport présenté ici ne tient compte que des opérations au quai, ce qui fait que les dimensions optimales du port sont déterminées surtout par deux données : 1° la longueur du quai et 2° le nombre de grues de containers et de chariots cavaliers connexes.

En ce qui concerne les grands ports terminus pour containers, normalement en service 24 heures sur 24 tous les jours de la semaine, la méthode de simulation suggérée dans ce rapport servira à déterminer les dimensions physiques optimales du port terminus.

En ce qui concerne les ports terminus plus petits la méthode servira en outre à déterminer le nombre optimal de roulements ou d'heures de travail par semaine pour les différentes intensités de trafic et, en conséquence, à fournir un plan complet pour le développement de la capacité de chargement/déchargement du port terminus.

Dans la plupart des ports les navires arrivent suivant un tableau de service, et pour assurer la formation de la file d'attente des navires attendant d'accoster il est d'importance que les heures d'arrivée fixées soient respectées. Dans cette hypothèse les arrivages seront généralement répartis autour des heures fixées, et dans les ports terminus d'un taux d'utilisation raisonnable (0.3 - 0.5) l'attente sera réduite par un taux de 2.5 - 3, si l'écart standard de l'heure d'arrivée est réduit à moitié.

Des changements dans la composition du trafic effectués par de différentes combinaisons de navires « secondaires » (feeders) et de navires transocéaniques n'ont pas de grande influence sur les dimensions optimales du port terminus, si le nombre d'expéditions de containers par an reste constant. Or, les frais totaux par container diminuent quand la grandeur moyenne des navires augmente, et dans ce cas il sera possible de réduire aussi la longueur des quais.

Les heures d'ouverture par semaine ont une influence déterminante non seulement sur les dimensions optimales du port terminus, mais aussi sur les frais totaux par container. Même les ports terminus où ne sont manutentionnés et expédiés que 30.000 containers par an dans les deux directions auront avantage à fonctionner 24 heures sur 24 tous les jours de la semaine. Dans cette hypothèse 1 poste avec 1 grue de container sera optimal jusqu'à un chiffre de passages de 70-80.000 containers par an dans les deux directions. Ces chiffres seront naturellement beaucoup influencés par le degré d'exactitude avec lequel les arrivages observent le tableau de service dressé, et les deux chiffres sont susceptibles d'augmenter, si l'exactitude est meilleure que la déviation standard donnée de 4 heures.

S. II - 5

PAPER

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LOCATION PROJECT FOR THE HARBOUR TRAFFIC OF NORTHERN FINLAND BY MEANS OF MODEL TECHNIQUES

I. AREA AND BACKGROUND OF STUDY

1. Effect of the seasonal variations on harbour traffic in the area of study.

In the west and in the south, Finland is bounded on a length of 1,100 km by the gulfs of the Baltic, the Gulf of Bothnia and the Gulf of Finland. Since the foreign trade of Finland for the most part is directed toward the west and the south, from the view point of international freight traffic Finland is comparable with an island. Because of this, communication by sea is of importance and as much as 95% of the exports and nearly 80% of the imports take place by water.

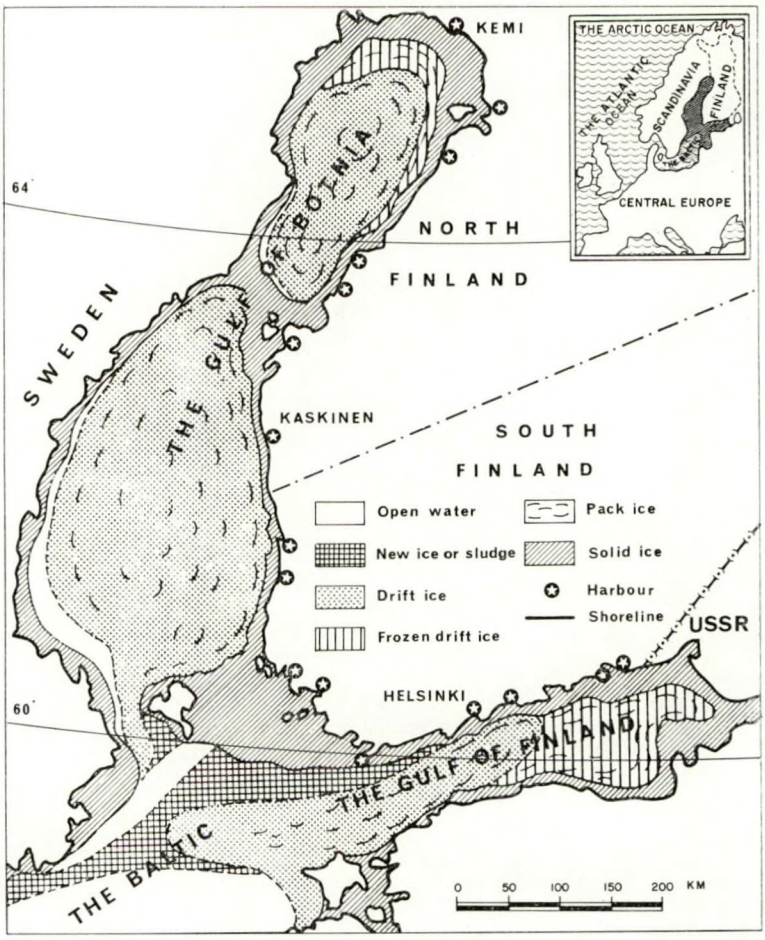


Fig. 1.1.

Gulfs of the Baltic Sea — Maximum extention of ice in an average winter (27-2-1948).

The Baltic with its gulfs (Fig. 1.1) is one of the scarcely salted inland seas of the temperate zone where ice formation occurs in the winter time. The

extension of the icy cover and the time of its duration vary according to the severity of the winter.

In the severest winters the maximum extension of the cover of ice is 420,000 sq.km. when the Baltic and the Straits of Denmark are covered with ice for a while in February. Such a hard winter occurred only 3 times in the period 1924-1970. However, on the average every tenth winter must be classified as a severe winter whereat almost the entire Baltic gets a cover of ice. In milder winters the largest extention of the icy cover is but 60,000 sq.km. Then the basin of the Baltic remains open all the winter, and only the northern part of the Gulf of Bothnia is totally covered by ice for a short time. Also in normal winters the Baltic is open, but the waters that bound Finland, the Gulf of Bothnia and the Gulf of Finland are frozen to the extent of 190,000 sq.km on the average.

The length of the freezing time in the coastal waters of Finland is on the average 70-170 days annually counted from the south to the north. The thickness of solid ice is correspondingly 30-80 cm, while the layers of pack ice may measure here and there 5-6 m.

The continuation of maritime traffic regularly throughout the year, also in the winter, between Finland and the countries with which we are trading is indispensable for the export industries and for the fuel service of the country. By means of icebreakers the winter traffic of at least some harbours in the southern and south-western coasts which are easiest to keep open have been maintained even in the most severe winters. However, also in normal winters there has not been a sufficient capacity of icebreakers for keeping the harbours of the Gulf of Bothnia open through the whole winter. In the years 1966-1970 in December-May the average time during which icebreaker assistance was required or during which the harbour was closed was the following as regards the most important ports of Northern Finland :

Harbour	Icebreaker assistance	Harbour closed	Total	Distance from Kaskinen to the north km
	Months/year			
Kemi	2.9	3.3	6.2	400
Oulu	2.8	3.5	6.3	320
Raahe	1.8	3.3	5.1	280
Kokkola	3.1	2.3	5.4	180
Pietarsaari	2.8	2.1	4.9	160
Vaasa	3.1	1.6	4.7	100
Kaskinen	3.5	0.6	4.1	0

In the years 1975-1976 the icebreaker standard will be renewed and strengthened when the oldest icebreaker of 4,500 shp, which dates 35 years back, will be replaced by 2 new 20,000 shp breakers :

Type	Engine Power shp	1972	1976
		number	
Sisu	4,500	1	0
Karhu	7,500	3	3
Voima	10,500	1	1
Tarmo	12,000	3	3
Urho	20,000	0	2
		8	9

The new icebreakers will be able to assist the ship traffic all the winter through also in the northern part of the Gulf of Bothnia in mild and normal winters, or in nine winters out of ten. Every tenth year there would be a probable break of 2 or 3 weeks in the traffic. As the number of cargo ships of the ice reinforcing classes I A Super and I A which are able to sail in ice is increasing simultaneously with the increase in the icebreaker capacity, the opinion of the Board of Navigation is that the arrangement of the winter navigation of Northern Finland seems to present no special technical navigation problem as from the middle of the current decade. Before all there is the question about a transportation economical and traffic political and area political problem. In this connection we confine ourselves to a traffic economical study.

2. **Present arrangement of transportations.**

In the area of influence of the harbours on the Gulf of Bothnia (Kaskinen-Kemi) or as the area is called here, in Northern Finland, more than 80% of the goods of the overseas traffic are produced or used in the harbour localities or in their immediate vicinity. When traffic is maintained in the harbours either during open water or assisted by icebreakers, four fifths of the exports and imports of the area can easily be managed through « own » harbours practically without any inland transportation and therewith connected costs.

Up to now, due to the lack of capacity, the icebreaker assistance of the harbours in Northern Finland has been gradually discontinued according to the advancement of the winter from the north to the south, and therefore there have remained for the exporters and importers during the winter season of 1-3 months two possibilities :

— Storing of goods.

— Land transportation of goods and shipping through the open harbours situated farther to the south.

The transportation distances by land from Northern Finland to the South-Finland harbours are comparatively long, 500-800 km, and the land transportation costs high as compared to the sea freights. Because of this, there have arisen as the result of the minimization of the sum of the business economical storing and the land and sea transportation costs, three traffic seasons in practice. These are per commodity groups :

Traffic seasons	Loading port or Discharging port	Commodity group
1. Open water season	Nearest port in Northern Finland.	Liquid fuels, mass goods, processed products.
2. Intervening season	Southern ports in Northern Finland.	Slightly processed and far processed products.
3. Winter season	South-Finland ports.	Far processed products.

The open water season (1) means here in addition to the iceless period that period of icy cover in early winter and in early spring during which ships are assisted to all harbours.

During the intervening season (2) again, the icebreaker assistance is limited, decreasing in the beginning of the winter from the north to the south and increasing at the end of the winter from the south back to the north. Thus, there is an intervening season both before and after the winter season (3) when only the traffic of the South-Finland harbours is assisted.

When proceeding in the above mentioned manner, the use of the icebreaker capacity truly is even, but the sea traffic and the land traffic moving from one route to another according to the variation of seasons cause a need for an excessive measurement of their resources, such as the capacities of the harbours, railways, local lorries and storages (Fig. 2.1). Therein must also be included different permanent employees (i.a. pilots, customs house officials, harbour board officials, etc.).

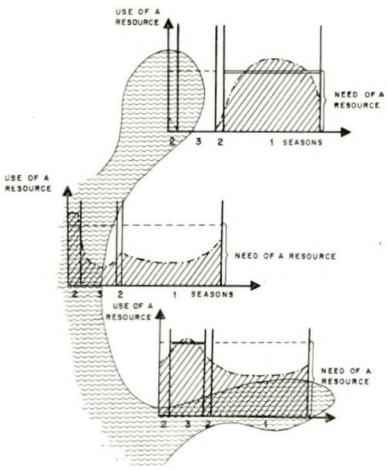


Fig. 2.1.

Scheme of seasonal variations in harbours situated in different locations.

Seasons : 1 = open water;
2 = intervening season;
3 = winter season
use of a resource.
–.–.–.–.–.–.– imagined usage.
- - - - - - - - - - - maintained resource.

3. **Goal of the study.**

As even traffic as possible throughout the year, in extreme cases either through the ports in Northern Finland or through the South-Finland ports would level

the need of resources and decrease the costs for their acquisition and maintenance. The capital costs would then decrease whereas the costs of operation would increase. The question about the fact which degree in the smoothing of the seasonal variation is most profitable in view of the total costs of the transportation chain, forms one starting point for the setting up of the goal of the study.

If the flow of goods is centralized in a few harbours, it will create economic possibilities for the use of larger vessels and larger cargoes and even at that for a sufficiently frequent line traffic and more efficient harbour technique. Then the harbour costs and the sea transportation costs per unit decrease but the sea and land transportation costs are in substitutional proportion. Thus there is as the second starting point of the goal of the study the question about how far (in view of the minimization of the total costs) it is advantageous to proceed with the division of labour and with the centralization of traffic in the harbours.

The calculation on which the present traffic solutions are based and which are used by the buyers of transportation services, lack partly or totally the share of the public power in harbours, in inland and deep water channels, in icebreaker assistance activity, etc. Because of this, transportations are not automatically guided in the best possible manner in respect of the use of the resources of the entire society. If one aims at arranging the winter traffic of Northern Finland in a manner which is most advantageous to the national economy and at the optimum centralization of the flow of goods, this can be rational only if it is possible to create a logistic picture of the operation area covering the most essential transportation and terminal activities in the different seasons.

Starting from the above mentioned view, it is the goal of the study to clarify the costs of the most important part phases in the overseas traffic of Northern Finland in respect of the different arrangements and location alternatives of the traffic and to find thus the transportation routes by the use of which the total national economical costs of transportation between the places of production and the places of consumption would become at long sight as low as possible.

4. **Cost determination principles.**

Endeavours are made to determine the costs on the basis of causing, applying the so called substitutional national economical costs.

The principle of causing means that of the costs of each location alternative of the traffic. Only the costs are included which the form of traffic in question will cause during a long time interval, 10-30 years, if the alternative concerned should materialize. This means that the harbour, railway network, etc., infrastructural investments already irrevocably made are not included. On the other hand, as a cross section observation the necessary long-range additional investments (investments in replacement, improvement and extension of channels, terminals, facilities and transportation equipment) are determined as well as the costs incurred by the maintenance and the performance of transportations during a long time interval.

Substitutional national economical costs mean costs caused to the entire society irrespective of who does bear the costs. They are pictured by the market price (business economical) costs after deviations caused by possible over- or underratings have been corrected. The correction is made so that :

— From the business economical costs are deducted the indirect taxes (turnover tax, customs duty, import tax, excise tax, etc.).

— To the business economical costs are added the costs incurring to the public power, such as costs concerning construction, renovation, improvement and maintenance of the routes of traffic, icebreaking operations, etc. (without indirect taxes).

— As the rate of interest in calculations, 6% has been applied in all traffic forms and cost groups.

The so-called non-substitutional national economical costs on which the market mechanism does not presently set a price are not included in the calculations. Such factors are, among others, independent area political goals, labour power political goals, etc.

In the determination of costs the price level of the year 1970 is used as the basis. The changes in costs by the project year 1980 are taken into consideration by increasing the salary and wage costs and the social and pension protection costs as much as their real value is assumed to grow or by 4%/year.

The growth of the productivity is taken into consideration so that in the traffic centralizing alternatives the capacity of transportation equipment and the degree of its utilization increase from what they are in the traffic decentralizing the flow of goods. These assumptions about the development up to the year 1980 concern :

— The size of the vessels and the travel speed of the vessels.

— The degree of the filling of the vessels (cargo/tonnage).

— The possibility of using whole trains.

— The train weight.

— The amount of goods assisted by the icebreakers at a time.

The goods to be transported have been divided into three groups which are : cellulose, other unit goods (sawn goods, paper, plates, etc.) and mass goods (ore, mineral fuels, industrial chemicals, etc.). The present vessel sizes and the sizes of vessels in 1980 have been determined for vessels carrying cellulose and other unit goods and on the other hand for vessels carrying mass goods in the Baltic, North Sea, Mediterranean and ocean traffic.

In the costs of the transportation chains have been included in addition to the handling and transportation costs (terminal costs in the factories and in harbours, land transportation costs, sea transportation costs) the possibly needed costs of the investments in harbour extensions and costs of reserve capacities.

Among the sea transportation costs are counted in addition to the daily costs arising in the harbour and on sea as so called winter costs :

— Costs for icebreaker assistance.

— Costs for damages caused to vessels by ice.

— Additional time costs of the vessels caused by the slow moving in ice.

5. Demand for transportation and its future development.

The starting point of the project concerning the future is naturally the transportation demand and its future development. In the development of the demand for transportation services changes can be expected regarding both the quantity and the quality.

Quantitatively the overseas exports and imports of the influence area of the harbours of Northern Finland (excluding the importation of piece goods which takes place through central terminals of South-Finland and without the deliveries of liquid fuels the main part of which arrive from domestic refineries as coastal transportation) are expected to develop as follows :

Direction of the traffic and the group of goods	1969	1980
	millions of tons	
Exports :		
— Cellulose	1.2	0.8
— Other unit goods	1.4	2.5
— Mass goods	0.5	0.5
Imports :		
— Mass goods	1.3	1.7
Total	4.4	5.5

Qualitatively the need of transportation will change so that the processing degree of the export goods will increase strongly. For example the export of paper and cardboard which in the year 1969 was 0.5 million tons will be 1.3 million tons in the year 1980. This direction of development increases the need of a sufficiently frequent and regular sea transportation throughout the whole year.

In the event that the traffic of the harbours of Northern Finland should be interrupted in winters, a continually increasing quantity of goods will be transferred by railway to the harbours of South-Finland (so called winter transition), and in case the vessel traffic will not be centralized in lines in rather few harbours

in Northern Finland, and increasingly greater part of the exports will be transferred throughout the year to the South-Finland harbours (so called normal transition) which offer a serviceable line connection abroad. It has been estimated that the transitions concerned, provided that the present decentralized traffic will continue, will amount to nearly 1 million tons in the year 1980. This would mean a corresponding shortage in the use of the harbours of Northern Finland and an increase in the railway traffic and in the traffic peak of the harbours of South-Finland.

6. **Methods of study.**

Concerning the need of transportation the goods have been divided into two parts which are the goods to be transported throughout the year (cellulose, etc., unit goods) and goods to be stored during the winter season (mass goods).

A year has been divided schematically into three seasons so that within each of the areas the demand for transportation, the use of ressources and the costs would be as even as possible.

Season	Point of time	Duration Months
1. Open water season	01.05. – 31.12.	8
2. Intervening season	01.01. – 15.01. and 16.04. – 30.04.	1
3. Winter season	16.01. – 15.04.	3

The transportation calculations have been made in the first place applying the usual alternative calculations at which the costs of the part phases of each alternative transportation chain are calculated separately and summed up. As the zero alternative is the present decentralized traffic (Fig. 6.1) when all the harbours of Northern Finland are in use during the open water season and in the winter

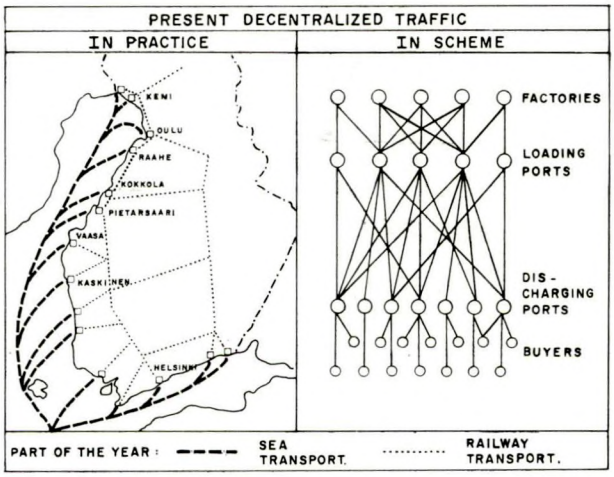


Fig. 6.1.
Zero alternative of the alternative calculations.

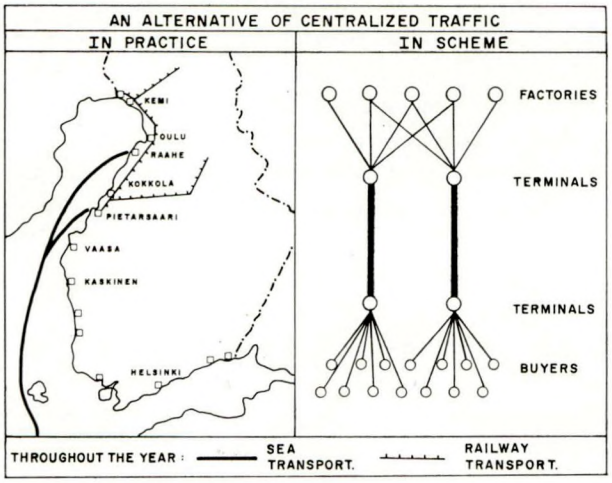


Fig. 6.2.

A project alternative of the alternative calculations.

season the traffic runs through many South-Finland harbours. Moreover, several alternatives have been chosen, the extremest cases of which are represented by the management of the traffic of Northern Finland throughout the year centralized either through the harbours of Northern Finland (Fig. 6.2) or through the harbours of South-Finland.

In the easiest and surest manner optimization problems of the kind concerned here can be solved by means of a linear programming. The model based on a linear programming finds the best traffic solution complying with the goal, measures the necessary traffic resources and sums up the required information by season or for the whole year.

The method has been widely applied besides to the project problems of the trade and industry also among others to the project problems of the traffic. In spite of and although the quantities of goods to be studied here, 4-5 million tons annually, are minimal according to the international standards, the problem is so versatile and of national level as to its extent that there was reason to get experience about the applicability of the model before its final approval. Therefore the model method has been applied to the study as a parallel method in the calculations of the alternatives. Thus it has also been possible to improve the model and to test its reliability.

II. SEAPORT LOCATION MODELS

7. The Problem.

7.1. *The problem and the models.*

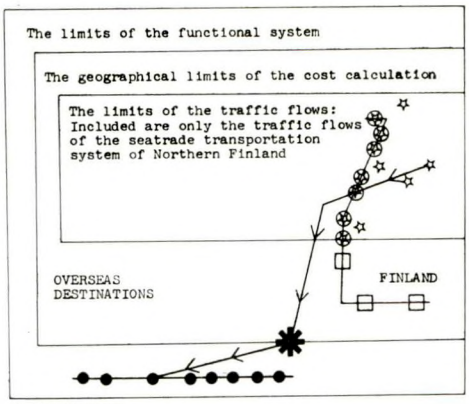
Figure 7.1 represents the geographical structure of the simplified maritime transportation network of Northern Finland such as the system will be described here.

The network is analogical to that of a complicated warehouse problem. The main functional problems in the developing of this system as a whole can be recapitulated as follows.

Due to the ice cover the cargoes go through the Nothern ports in summer and the Southern ones in winter. The present traffic practice like this causes double systems in the annual maintenance of the transportation facilities by loading, especially the railways and the harbours, unevenly during the year.

The centralization and coordination of labour in harbours and cargo lines make the use of modern techniques and larger ship sizes possible thus lowering the unit costs of traffic and shortening the transport times.

The goal is to minimize the costs of the whole transportation system by locating the traffic flows known beforehand.



Explanations:
The inland and overseas points of production and consumption
☆ - inland point
● - overseas destination
Ports
○ = port in Northern Finland
□ - port in Southern Finland
Further explanations
— - the shoreline of Finland
<< - one typical route
✱ = the point in the Baltic Sea, beyond which the voyage is independent of the state of the Finnish harbours. Nevertheless the shipsizes used and cargo lines are dependent on the overseas destinations.

Fig. 7.1.

The levels of description of the maritime transportation network of Northern Finland.

Three mathematical models have been built to describe the system and its parts. The main model is the location model, which on a coarse level covers all of the functions of the seaport transportation system. Two assisting models, the seaport simulator and the model of ship delays, have been built to cultivate the data of the most complicated partial system for the location model. The hierarchy and the connections between these models can be seen in figure 8.4. The paper mainly discusses the location model but the submodels are superficially represented in paragraph 8.6. Thus the reference model without more qualifying words means the location model in this paper.

7.2 *The assumptions and the limitations made.*

Listed below are the main features of the mentioned system and its cost minimization problem :

a) The location of the ports are known beforehand as well as the traffic flows between inland and overseas destinations. The question remains which of the ports should be selected for development.

b) Due to the ice cover on the Baltic gulfs the transportation costs on the sea strongly depend on the time of the year. The problem becomes harder in proportion as the port is situated further north. This state of affairs has traditionally caused seasonal variation in the traffic volumes of the railways and harbours though the traffic demand would otherwise be relatively steady through the year.

c) The point of view is one of national economics though only the first hand costs of transportation have been included. Thus the whole system must be handled as an entity counting all the facilities needed in the transportation in question; inland and deep water channels, rolling stock, harbours, stores, etc.

d) The cost functions (cost/transported amount) of the ports and the cargo lines are concave and have a fixed charge. In the railways the unit costs depend both on tons and ton kilometers.

The features *a* and *d*, at least to some extent, are common to and the features *b* and *c* different from the warehouse location problems described in literature. The above list is continued by the further assumptions and practical limitations used in constructing the location model of the Northern Finland maritime transportation system.

e) The model is used in long-term planning, the time dimension being 10 years, ranging from 1970 to 1980. During this time interval the necessary railway and deep water channel networks are assumed to be existent. These simplifications, which could be removed by fixed charge cost functions, are due to the following facts. In the case of the railways the system under study is only a part of the whole railway system. The present deep water channels are sufficient for ten years because of the present double transportation system. On the other hand the amount of the rolling stock and harbour resources can be influenced in the planning period.

f) The model describes the traffic of one period, a year, as a cross section of this periodical system.

g) The problem is considered to be the allocation of the transportation resources. This means that we do not state the costs routewise, but have on an annual basis a unit cost both for the maintenance and the running of a transportation resource. Besides the harbours, which are handled in this way in some warehouse problems too, this handling is extended to concern the railway and the icebreaker resources as well. The cargo lines are handled routewise.

The limitations *f* and *g*, based on the assumptions *b*, *c* and *e*, strongly affect the formulation of the model. The following two limitations are based on the present state of the research : We try to find the main lines of the system and an automatic way to collect the data needed.

h) In the allocation of traffic resources the main interest is in the economical smoothing of the seasonal variation. This feature is described explicitely in the model.

i) The main interest being in the problem of seasonal variation, the problems of centralization and coordination of labour in harbours and cargo lines have remained secondary. Thus the non linear cost functions were not built in the model, one reason being also the present coarse data base. Moreover some studies on non linearity were accomplished by simulation with the linear model.

The location model is a linear programming (LP) model by the limitation *i*. The assumption *g* makes a big difference between this location model and the customary transportation or warehouse location models.

Based on the assumptions and limitations listed above, the goal used as the objective function in the location model can be crystallized as follows :

j) We want to define and to locate such an amount of inland, harbour and maritime transportation resources that the totalled national economic costs of maintaining and running the above mentioned transportation facilities are minimum over the period of a year.

The special feature of the location model is its objective function. The division of the unit costs into the maintaining and running parts as described in the limitation *g* above, is familiar when dealing with the costs of a single machine, production line, etc. The question remains whether it is possible to apply the same principle in the case of a large transportation system. The application, described here, showed that most items of the costs could easily be classified in this way on an annual basis. In the railways, for example, the costs of manpower, the interests of capital, etc., are typical costs of maintaining the railway resources.

8. **The mathematical models.**

8.1 *The location model.*

The location model is a linear programming model describing on a coarse level all of the main functions of the seaport transportation system of Northern Finland. The limitations used in building the model are defined by the statements *a-j* made in 7.2. The seasonally varying transportation costs on the sea (statement *b*) form the special feature of the system. This feature combined with the national economic point of view and the intended use of the model (statements *c* and *e*) has phrased the formulation of the model; the allocation of the transportation resources (statements *g* and *j*).

There are two types of variables in the model. The only independent variables represent the seasonally (open water, winter and intervening season) known traffic flows through every possible port. The resource variables represent the seasonal use and the annual maintenance of the transportation facilities. The resource variables are direct or weighted sums of the traffic flow variables, the weights being distances and delays in different ice circumstances.

Further the actual model is structural consisting of three hierarchical levels (blocks). The seasonal model describes the transportation system of one product in one season. The annual model consists of the three seasonal blocks of the product in question. The last level, the model itself, combines the annual blocks of all products in the model. The location model, described in the paragraphs 8.2-8.5, is the annual model thus consisting of only one product. This simplification is justified by the following facts :

— The cost function, which is the special feature of the location model is just of the same kind also in the annual model.

— The products are so aggregated and are so few, differing from each other so much, that only the icebreaker resource is common for them all.

The seasons have been chosen in such a way that the transportation costs on the sea can be assumed to be the same during the whole season.

8.2 *The variables of the location model.*

The variables of different types and levels of hierarchy as well as the indices used can be seen in figure 8.1.

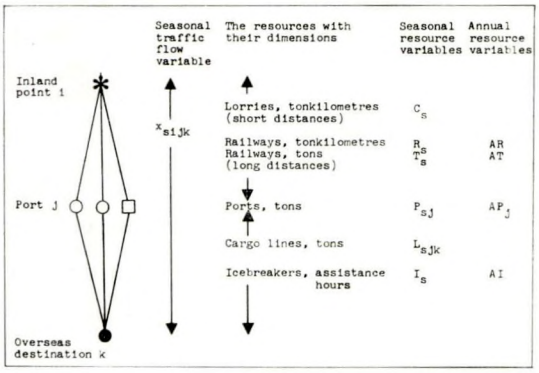


Fig. 8.1.

A known traffic flow from inland point to overseas destination divided into the routes through different ports and the transportation facilities required. (Index s = season).

Figure 8.1 shows that there are annual resource variables describing the maintenance of the railway, port and icebreaker resources. The amounts of the ships and lorries needed in the maritime traffic system of Northern Finland are not so interesting because these means of conveyance are assumed to have compensating use in other systems. Thus there are no annual resource variables in these cases. The use of the resources are represented by the seasonal resource variables in all cases.

8.3 *The constraints of the location model.*

The traffic flow equations are the following :

$$f_{sik} = \sum_{j} X_{sijk} \qquad \text{(I)}$$

Parameters f are the seasonally known traffic flows from inland points to overseas destinations.

The seasonal resource variables represent the use of the transportation facilities (Fig. 8.1).

The calculation equations of the variables are the following :

$$C_s = \sum_{i,\,j,\,k} d_{ij} \,.\, X_{sijk} \text{ (short distances)} \qquad \text{(II)}$$

$$R_s = \sum_{i,\,j,\,k} d_{ij} \,.\, X_{sijk} \text{ (long distances)} \qquad \text{(III)}$$

$$T_s = \sum_{i,\,j,\,k} X_{sijk} \text{ (long distances)} \qquad \text{(IV)}$$

$$L_{sjk} = \sum_{i} X_{sijk} \qquad \text{(V)}$$

$$P_{sj} = \sum_{k} L_{sjk} \qquad \text{(VI)}$$

$$I_s = \sum_{j} a_{sj} \cdot P_{sj} \qquad \text{(VII)}$$

Parameters d are the inland distances between the harbours and the inland points.

Parameters a are the seasonally know icebreaker assistance hours/ton transported from the harbour.

The calculation of the annual resource variables is simplified by the notation

$$\max Z_s = \max \left\{ \begin{array}{l} 12/8 \cdot Z_{openwater}, \\ 12/1 \cdot Z_{intervening\ season}, \\ 12/3 \cdot Z_{winter} \end{array} \right\}$$

where the numbers 8, 1 and 3 are the lengths of the seasons expressed in months. The non linear variable max Z_s can be calculated by three linear inequalities in the common case where the variable is burdened by costs. Thus the annual resource variables, giving the amount of the transportation facilities maintained all over the year, are calculated by the equations :

$$AR = \max (R_s) \qquad \text{(VIII)}$$

$$AT = \max (T_s) \qquad \text{(IX)}$$

$$AP_j = \max (P_{sj}) \qquad \text{(X)}$$

$$AI = \max (I_s) \qquad \text{(XI)}$$

The scrutiny of this paragraph reveals that the traffic flow equalities (I) are the only restrictive ones the others being only for the calculation of the dependent resource variables.

8.4 *The objective function of the location model.*

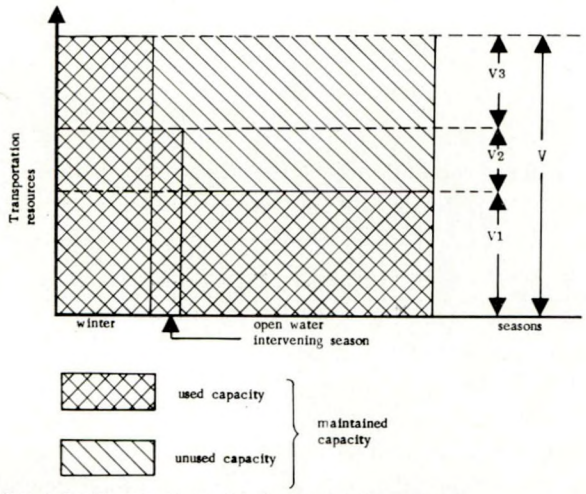
In the case of seasonal variation the unit costs of transportation are dependent on the traffic volumes of the seasons. Conventionally the seasonal unit costs were calculated as averages from the existing system.

$$a = \text{average unit cost of resource} = \frac{\text{total costs}}{\text{transported units}}$$

These unit costs, however, apply only in the traffic solution they are derived from and fail when changing the volumes of traffic. In an LP-model we must have a means to calculate the actual unit costs automatically in all levels of the traffic volumes. The way of handling the unit costs like this is stated in item g of 7.2. The mathematical realization is as follows. On an annual basis the average unit costs of the railways, harbours and icebreakers consist in two parts; one part depending on the amount of the resource maintained and the other part burdening the use of the resource. We call the former maintainance costs and the latter running costs. All of the costs of ships and lorries are handled as running costs.

Every unit of transportation used in some season must be maintained all over the year. In accordance to the linear principle the costs of the maintained units of resource are shared equally among the traffic using it. The principle states, that the annual maintenance costs of the transportation resources must be divided by the sum of the unused as well as the used capacities when calculating the corresponding unit costs.

$$b = \text{unit cost of the annual maintenance of resource} = \frac{\text{total costs of maintenance}}{\text{transported units plus unused units of resource}}$$



Summary of maintenance and operation of a transportation resource

Capacity 'maintained by the season'				Usage of the maintained capacity			
open water	intervening season	winter	total	open water	intervening season	winter	total
8/12 • V1	1/12 • V1 3/12 • V2	3/12 • V1 9/12 • V2 V3	V1 V2 V3	8/12 • V1	1/12 • V1 1/12 • V2	3/12 • V1 3/12 • V2 3/12 • V3	V1 4/12 • V2 3/12 • V3
Total annual maintaining: V				Total annual running: V1 + 4/12 • V2 + 3/12 • V3			

Fig. 8.2.

The linear principle of the cost function of a transportation resource.

The linear principle can be seen in figure 8.2, the summary of which shows that the amount of the transportation resources maintained throughout the year is defined by the season, when the resource is in greatest demand.

Figure 8.2 shows that the use of the resource is represented by the seasonal resource variables (V1, V1+V2 and V1 + V2 + V3), which are burdened by the running costs. The annual resource variable (V) is burdened by the costs of maintenance.

The mathematical form of the objective function to be minimized is illustrated in table 8.1.

The coefficients in the cost function (table 8.1) are the unit costs of the different means of conveyance. The parameters *i* and *ai* for example are the unit costs of the operation and maintenance of the icebreaker resources. Listed hereafter are some further notes of the items included in the port parameters.

— There is an extra phase in cargo handling in the case a traffic flow originating from a port is transported through another one. The costs of this phase are added to the unit costs of railway tons, parameter *t*.

TABLE 8.1 — *The objective function of the location model.*

Activity	Running costs	Costs of maintenance
	COST =	
Inland traffic . .	$c. \sum_s C_s + r. \sum_s R_s + t. \sum_s T_s$	$+ ar. AR + at. AT$
Ports	$+ \sum_{s,j} p_j . P_{sj}$	$+ ap_j . AP_j$
Cargo lines . . .	$+ \sum_{s,j,k} l_{sjk} . L_{sjk}$	
Icebreakers . . .	$+ i. \sum_s I_s$	$+ ai. AI$

— In the present model the unit costs of running the port resources, parameters *p*, have no influence on the solution, for these costs are assumed to be the same in all ports. In the future more precise data would cause the use of the non linear cost function, represented by figure 8.5.

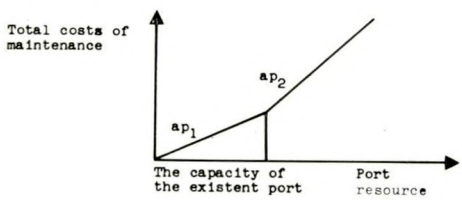


Fig. 8.3.

The costs of maintenance in ports with restrictive capacity.

EXPLANATION.

The unit cost ap_1 contains the maintenance of the existent port facilities whereas the unit cost ap_2 contains the maintenance and the annuity of the investment made in building the new resources.

— The cost coefficient *ap* contains the costs of the maintenance of the existing port. The cost function is assumed to be linear if the capacity of the port is not restrictive, which is the common case in Northern Finland. In two exceptional cases the costs of the annual port resources were convex as shown in figure 8.3. It is remarkable that the convex cost functions do not disturb the linear features of the location model.

— The parameters *l* include the unit costs of the sea voyages and the damages to ships due to the ice. The overseas destinations affect these costs by defining the ship sizes used and the amount of cargo needed to form a cargo line. If there is a cargo line in every port, the assumption by which we start calculations, the delays for ships are the same in all ports and the corresponding costs can be left outside the model. When this is not the case the costs of

skirting the coast are added to the unit costs of the scanty or missing cargo lines. This has been done stepwise by simulating with the location model after having got the optimal linear solution. This sub-optimizing method agrees with the present coarse data. Figure 10.1 shows the nonlinear cost function of the cargo lines, which would have the same effect represented explicitely in the location model in the future. The simulating method has shown that the unsolved cargo lines needing nonlinear handling are few.

8.5 *Some technical notes concerning the location model.*

The dimensions of the model were :

— 10 ports (7 Northern and 3 Southern ones),
— 11 inland points,
— 8 destination countries,
— 3 seasons and
— 4 commodities (3 exports and 1 import)

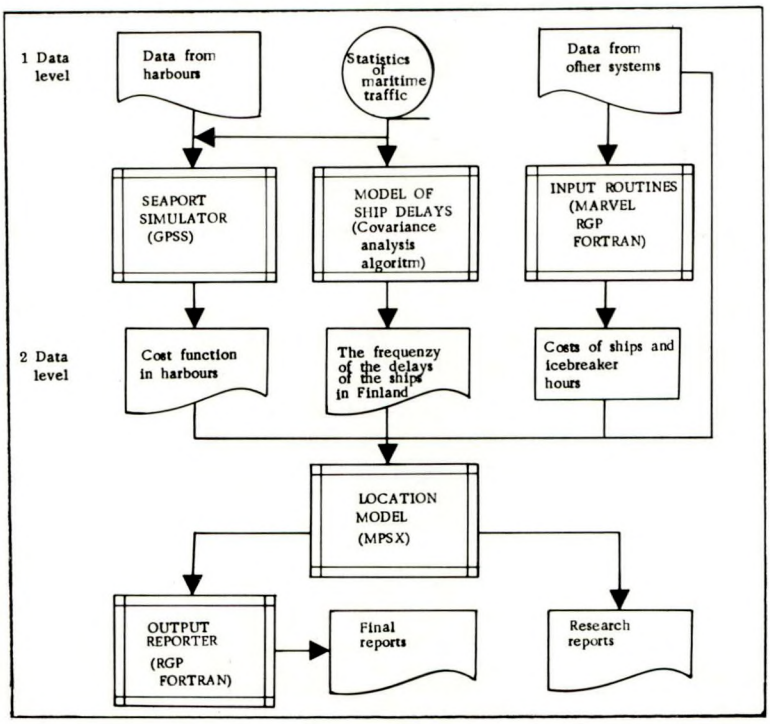


Fig. 8.4.

The data processing system of the seaport location models.

EXPLANATIONS.

The two levels of the data are :

1. The detailed data from the partial systems.
2. The aggregated data for the location model, the unit costs and performances of each participating transportation sector.

The ADP-systems, referenced in brackets belong to the program library of IBM 360/370.

making about 4,000 variables (only a part of the combinations : inland point, port, overseas destination were sensible) and 1,500 equalities.

The structural part of the model, consisting of the sums and the distances only, was built by the matrix generator language MARVEL. Some uncertain and laborious coefficients, the costs of ships and icebreaker assistance hours, calculated by evaluating the different open water and ice circumstances on the gulfs (4), were produced by FORTRAN-programs. Otherwise the input data was very aggregated when dealing with the resources only.

The LP-system used was MPSX360 and the computer IBM 360/50. Because of the large uncertainty a coarse sensitivity, analysis was fulfilled by using large intervals of data. Thus the running times ranged from 10 minutes to 1 1/2 hours. The sensitivity analysis of the LP-method itself was of minor significance in this case.

The results of the model were reported using the program RGP/MPSX360. The input/output processing system of the location model can be seen in figure 8.4.

8.6 *The seaport simulator and the model of the ship delays.*

These two assisting models are used in the aggregation of the data of ports and cargo lines for the location model.

The seaport simulator was built to produce the cost function FO for the location model. To produce one of the curves F1-F3, the port facilities were assumed to be known beforehand and different traffic volumes were simulated through the port. When some of the port facilities (quays, harbour stores, men, loading machinery) become overloaded then the costs become indefinite, because of the costs of the ship delays. The model tells also, which was the overloaded resource thus guiding the investments.

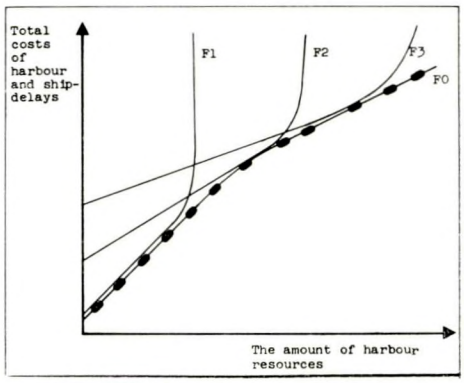


Fig. 8.5.

The cost function of a port.

EXPLANATIONS.
Function F1 represents the costs of the existent port.
Function F2 and F3 represent the costs in different investment choices.
Function FO is the envelope of the functions F1-F3.

The function F0 includes both of the cost coefficients p and ap, (explained in 8.4). These components can be derived directly from the results of the seaport simulator.

The seaport simulator describes a port in a very rough level and is by no means intended to be a device for the planning of a selected port, as the simulator

in reference (1) is. The function F1 was produced for every port in Northern Finland, but the missing investment data made the producing of the functions F2-F3 and accordingly F0 impossible. Consequently the cost function was assumed to be linear.

The cost function of a cargo line, which depends on the ship size used, is described in figure 10.1. The model of the ship delays was built to give the cost difference due to the excess time caused by going to another port, cost d. The method used was co-variance analysis and the data came from maritime traffic register, which includes the ship manifests. Unfortunately the only identification to combine the data of one ship was the name of the ship, data not inspected for the portwise statistics.

9. **The validation and the use of the location model.**

9.1 *The validation.*

The basis of the cost calculations of the location model differs essentially from the conventional calculations. Thus the model can be expected to give solutions different from the existent system. Consequently the demand to validate the system is obvious. But the validation of the model concerns the cost function itself, because the restriction equalities are almost trivial. The point is : How to validate a model against the state of the system, which results in the different basis of calculations.

Instead of validating the model we could control the model by the carefully selected set of indicators of the system. For example the unit costs a and b, explained in 8.4 and derived from the existent solution in practice, are good indicators. The unit costs b are those used in the location model and the average unit costs a in conventional calculations. Now we can simulate the existent practice by the location model (which is not allowed to optimize in this case) by using the unit costs b. After the calculation we can compare the average unit costs a derived from the model and the system itself. The possible differences show that the systems are not analogical as they should be. Besides the costs, the average performances of the transportation facilities form a good set of indicators. Such are for example the average number of ships in a harbour, the average tonnage per ships and so on. The examination of the differences in the indicators conducts to a controlling system, which makes the model realistic step by step and keeps it up-to-date.

9.2 *The use of the location model.*

The calculations of the sensitivity analysis formed the main task of the location model in the project it was done for. This was an important task too, for it revealed in a concrete way the state of the present data and led to the development of data processing routines. Some of the numerical results obtained by the location model, are represented in part 3.

In planning the future use of the location model or a system similar to it (perhaps different inland points, harbours, overseas destinations etc.), the limitations made in a-i in 7.2 must be kept in mind. Especially the costs of national economy interpreted to cover only the direct costs of transportation mean that the location model does not handle the questions of regional planning or other questions of national economy, which the planners are interested in. However the location model can be used side by side with other planning devices to calculate the transportation costs of the different choices in regional planning for example. Another point is that the model does not belong to the class of the investment models but gives just an annual cross section.

10. **Further development of the location model.**

10.1 *The data development.*

The main point in developing the use of the seaport location models is in the improvement of the input data. There are two aspects in doing that :

— It is difficult to define the national economic costs practically enough to be used in a quantitative model like this. Further, the many organizations participating in this transportation system have a basis of calculations of their own. However, it is not difficult to find a basis of calculations better than the conventional ones, where the majority of the costs of maintenance, paid by the public administrations, were left outside the economic calculations. The progress made in the defining of the basis of calculations is explained in paragraph 4, but a lot of questions remain to be solved.

— The planning of the extensive maritime systems must be founded on trustworthy time serials and actual data, which cannot be collected just for the case. The planning using the models revealed clearly the most serious insufficiencies in the existing data registers. Especially the operations and delays of the ships and icebreakers were not known enough, though these questions are essential to the problem. Some concrete recommendations on the field of data processing were made. A new icebreaker register, small in volume, would give all of the data needed in the location model. The necessary data of navigation already exists in the maritime traffic registers, but the statistics are prepared portwise. Consequently the access to the data concerning the movements of single ships is complicated and uncertain, though existing in principle. Minor revisions in the registers would improve the maritime data substantially.

10.2 *The development of the model.*

The cost functions with concave and fixed charge parts become actual after developing the data. The well known shape of the cost function in ports was discussed in 8.6.

The principle and the shape of the non linear cost function of a cargo line is described in figure 10.1. At present this cost function is not represented

explicitely in the location model but the effects of it have been simulated in the way discussed in 8.4.

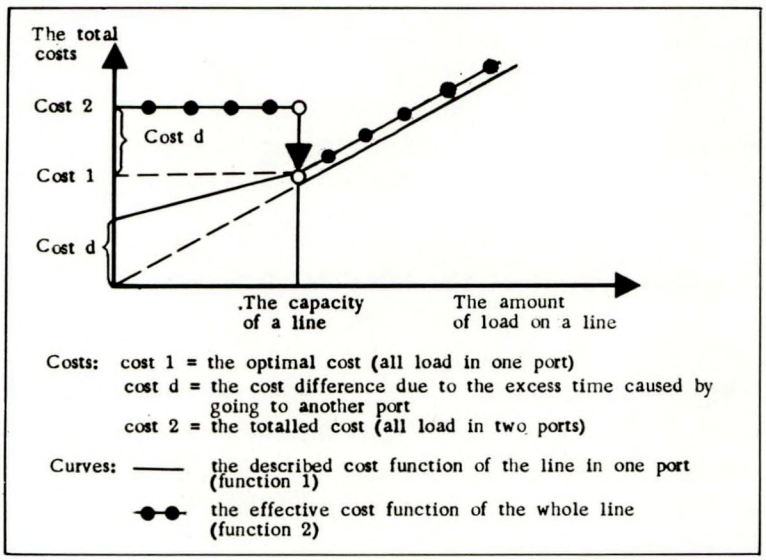


Fig. 10.1.

The costs due to a line divided between two ports.

Figure 10.1 shows that the cost of the whole line (function 2) is cost 2 in so far as the ship must go to two ports and suddenly becomes cost 1 if all of the cargo needed to form a line is in one port. The small items of cargo are critical especially in Northern Finland whereas the larger cargoes make the problem easier. That is why the function 2 is continued by linear part after the point of line capacity. Function 1 represented in the model causes the effect of function 2.

11. Summary.

The problem described by the location model is of the type of a complicated warehouse location problem with seasonally varying transportation costs. The location model allocates the transportation and harbour resources by locating the known traffic flows through the known harbours. The main parts of this LP-model are the following :

— The restriction equations take care of the continuity of the traffic flows and register the transportation resources maintained and used by the flows.
— The cost function guides the alternative choices of the routes.

When selecting a new route for some seasonal traffic flow the cost function makes the model operate in the following way :

— If the flow uses the resource maintained by the traffic of other seasons, then the total costs are added by the running costs only.

— If the flow adds the maintenance of the resources, then the annual costs of maintenance must be added to the total costs.

The location model represents the zero level in the development of advanced systems for maritime transportation planning. The defects in the data have influenced on the formulation of the model. Thus the best results, accomplished by the cooperation of the participating organizations, have been the concrete impulses to develop and automatize the routines of the data processing in field. Sub models such as described in 8.6 will be needed to aggregate the data of the sub systems to the location model also in the future.

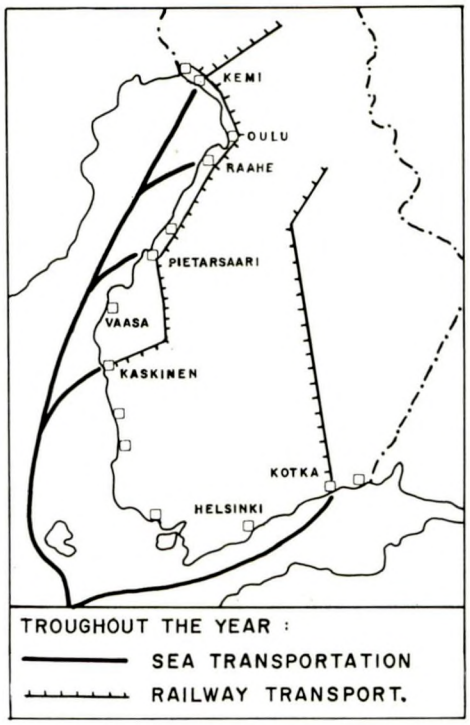


Fig. 12-1.

Optimum solution.

III. RESULTS

12. Optimum transportation routes.

The optimum solution of the model for the year 1980 places more than 90% of the total traffic throughout the year in four harbours in Northern Finland, or in Kemi, Raahe, Pietarsaari and Kaskinen (Fig. 12.1). The traffic of Vaasa is ferry traffic to Sweden and thus it would remain unchanged. According to the model, the distribution of traffic will be :

Harbour through which the traffic is carried on	Open water season (8 mos.)	Intervening season (1 mo.)	Winter season (3 mos.)
	Millions of tons per year		
Kemi	1.39	0.10	0.24
Raahe	1.28	0.06	0.16
Pietarsaari	0.97	0.08	0.16
Vaasa (ferry traffic)	0.09	0	0
Kaskinen	0.34	0.05	0.16
Kotka (in South Finland)	0.27	0.03	0.10
Total	4.34	0.32	0.82

The solution involves the reservation of 2.8 icebreakers on the average in a normal winter for the traffic of Northern Finland in the year 1980.

In the alternative calculations 9 different solutions of the location of traffic had been chosen in advance, a part of which minimized the need of land transportation in the whole year or in the winter season. The study made afterwards showed that the total costs of the optimum solution summed up by the model was somewhat lower than the most advantageous of the alternatives chosen in advance. Accordingly, the most advantageous solution would not have been found without the model, even if the difference in this case was trivial.

The zero alternative (present situation) of the alternative calculation and the corresponding alternative found by the model (the export of cellulose etc. unit goods to the destination port abroad) were as to their structure the following :

Cost group	Zero alternative	Optimum alternative
	Share %	
Land transportation	12.1	5.4
Terminals	30.2	31.3
Sea transportation	51.7	52.1
Icebreaker operation	4.3	5.9
Ice damages to vessels	1.7	2.7
Reserve capacity	—	2.6
Total	100.0	100.0
Costs, million marks/year	248.0	233.0

The national economical saving in costs would be, according to the result, 15 million marks per year which is only 6% of the costs of the present method, in other words : in consideration of the accuracy of calculation the difference is well-nigh insignificant.

13. **Conclusions.**

There is no reason, however, to pay attention to the numerical result. The reason thereto are the deficiences which have been discovered in the course of the study and which concern the starting data. Several basic statements, indispensable in respect of the reliability of the results, such as i.a. appropriate statistics concerning the assistance activity of the icebreakers and ice damages could not be found. In addition, difficulties were encountered in the determination of the national economical costs incurring in long range in the different forms of traffic, applying uniform bases. This for its part is caused by the different organizational and operational structures of the individual forms of traffic. Among others, in railway traffic the same railroad network, equipment and organization serve the passenger traffic as well as the goods traffic, and partly

the goods traffic of both Northern and Southern Finland, which causes problems regarding the distribution of costs. Similary, the icebreaker equipment of Finland serves the whole country in respect of the peak demand of the winter traffic in the rarely occurring very severe winters, etc.

The results are furthermore affected by certain simplifications, such as the same seasonal division in all alternatives, the capacity of vessels, irrespective of the degree of centralization of the traffic, etc.

The main result of the study was that the national economical examination forced one to pay attention to all essential cost factors, the deficiencies in the preparation of statistics and in the basic data became known and the reliability of the model in the work for which it is now intended was established. In the autumn of 1972 a research covering the location project for the harbour traffic of the whole of Finland was launched on the basis of the experience gained in this study. The said research will be ready in the year 1974 and on the basis of it, concrete proposals for actions will be made regarding the development of the harbours of the country at a long range.

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RÉSUMÉ

Les eaux du littoral finlandais sont prises par les glaces en hiver (fig. 1-1) et la solution actuelle, variable avec les saisons, adoptée pour le trafic étranger de la Finlande septentrionale pèse inégalement sur les ressources portuaires et routières (fig. 2-1). L'optimalisation des frais commerciaux, plus ou moins subventionnés, disperse le trafic (fig. 6-1) et s'oppose en même temps au développement rationnel des ports et, entre autres, à l'emploi de bateaux de dimensions économiques.

En concentrant le trafic sur quelques ports d'une façon égale d'un bout de l'année à l'autre (fig. 6-2), on pourrait épargner, en termes d'économie politique, sur l'ensemble des frais de transport. La question de savoir quel est, d'un point de vue économique général, le degré le plus avantageux du développement du trafic et de l'organisation du trafic hivernal de la Finlande septentrionale, sert de point de départ à la mise en place des objectifs de l'étude.

Le système de transport du commerce maritime de la Finlande septentrionale est en analogie avec les problèmes complexes de localisation des entrepôts. Ce qui fait la particularité du système est la variabilité saisonnière des frais de transport en mer par suite de la prise des eaux par la glace. Pour représenter le trafic d'une période, un an, de ce système périodique de transport, on a réalisé un modèle de localisation en utilisant une programmation linéaire. Les parties principales de ce modèle sont les suivantes :

— A l'aide de contraintes on veille à la continuité des flux de trafic et on enregistre l'emploi des ressources en trafic occasionné par les flux.

— La minimalisation, en termes d'économie politique, de l'ensemble des frais directs du système représentés dans la fonction objective commande le choix des trajets.

Dans le modèle, l'année est divisée en périodes qui diffèrent en fonction du trafic. La caractéristique la plus particulière de ce modèle est que les frais n'y sont pas déterminés selon les trajets mais en tant que frais d'utilisation mensuels et frais d'entretien annuels des ressources de trafic.

Deux sous-modèles, le simulateur de port et le modèle des retards des navires, ont été construits pour fournir des connaissances globales sur les parties les plus difficiles du système comme l'exige le modèle de localisation.

S. II - 5

RAPPORT

par

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L'INFORMATIQUE PORTUAIRE EN FRANCE

SOMMAIRE

INTRODUCTION

Il y a sans doute peu de domaines de l'activité économique qui fassent appel à des techniques aussi variées que l'activité portuaire; il y a peu de sciences qui ne soient, peu ou prou, utilisées lors de la conception, de la réalisation, de la gestion ou de l'exploitation des ports. De la biologie à la statistique, de la mécanique à l'acoustique, de l'hydraulique à la chimie, du droit à l'économie, la plupart des sciences appliquées sont mises en œuvre dans les innombrables problèmes qui se posent à l'ingénieur ou au responsable portuaire.

C'est que les conditions de l'activité portuaire sont en elles-mêmes extrêmement complexes :

— le milieu physique est le milieu marin, ou plus exactement le milieu côtier, dont on connaît la complexité sur le plan scientifique;
— le milieu économique est celui du transport international, qui fait intervenir tous les secteurs de l'économie mondiale;
— le milieu juridique est celui des transports maritimes dans lesquels interviennent des catégories très nombreuses de professions.

Enfin, il faut noter que l'activité portuaire donne lieu à de grandes concentrations : quelques ports se partagent l'activité d'un pays entier, quelquefois de plusieurs pays.

Il n'est pas étonnant dans ces conditions que l'informatique joue un grand rôle dans les divers aspects de la naissance et de la vie d'un port. Par son apti-

tude à permettre des calculs volumineux, à faciliter l'utilisation et la transmission de l'information, l'ordinateur est de fait très utile aux ports.

Toutefois, l'ordinateur ne se développe bien que lorsqu'il ne se heurte pas trop souvent à certaines limites, dont les plus difficiles à franchir sont, sans aucun doute, celles de l'entreprise où il est établi.

La dispersion des centres de décision paraît ainsi être un frein aux progrès de l'informatique dans l'activité portuaire.

Nous allons voir comment les ports français ont, néanmoins, eu recours aux ressources de cette technique sans laquelle désormais il n'est plus possible de travailler vite et économiquement ni de faire de la bonne gestion.

A. L'INFORMATIQUE DANS LA CONCEPTION DES PORTS

1. Etudes hydrauliques.

L'exécution et l'exploitation de mesures *in situ* préalables à l'établissement d'un projet de port ont été grandement facilitées par l'informatique. En effet, le grand nombre de données numériques à collecter et à traiter bénéficie de la rapidité et de l'automatisme de l'ordinateur.

Au Laboratoire National d'Hydraulique comme aux laboratoires de SOGREAH (1), les données d'observation des phénomènes naturels (houle, vent, salinité, température) sont relevées sur les enregistrements graphiques des appareils de mesure et mises sur cartes perforées.

L'ordinateur permet alors une analyse de la fréquence des phénomènes enregistrés. Dans le cas de la houle, l'utilisation des méthodes de Fourier ou de Tuckey permet une description très fine du phénomène.

L'analyse peut être également spatiale. Tel est le cas en particulier du sondage des profondeurs où l'ordinateur permet un report rapide des points de mesure sur une carte.

De même, la propagation de la marée dans l'embouchure de la Loire est étudiée par les Services du Port Autonome de Nantes-Saint-Nazaire au moyen d'un ordinateur qui calcule en fonction des données d'observation les grandeurs utiles à la navigation (hauteur d'eau, lieu géométrique des hautes mers).

Toutes ces analyses débouchent sur des calculs théoriques, ou permettent l'extrapolation des mesures au moyen de simulations.

Le Service des Phares et Balises a mis au point une application complètement automatique pour la mesure de la houle.

L'enregistreur de houle émet en permanence un signal traduisant la hauteur instantanée de l'eau. Ce signal est enregistré directement sur bande magnétique,

(1) Société Grenobloise d'Etudes et Applications Hydrauliques.

et c'est cette bande qui sert au dépouillement par l'ordinateur, qui restitue le creux de la houle et effectue les analyses statistiques.

Le relevé manuel sur les enregistrements graphiques, long et générateur d'erreurs, ainsi que le report sur cartes perforées, sont ainsi supprimés ce qui rend les résultats très fiables, et réduit leur délai de production.

En matière de prédiction de la propagation de la houle, il n'y avait naguère d'autre solution devant la complexité ou le volume des calculs qui auraient été nécessaires, ou bien de se contenter d'approximations ou de schématisations, ou bien de recourir à la simulation sur modèle réduit.

L'ordinateur permet maintenant d'effectuer ces calculs jusqu'ici inabordables.

C'est ainsi que le laboratoire de SOGREAH à Grenoble établit automatiquement les plans de réfraction de la houle par application de la théorie linéaire ou de la théorie au troisième ordre d'approximation. De même, les plans de diffraction de la houle en profondeur constante par la méthode de l'intégrale de Green et la diffraction de la houle en profondeur variable par une méthode analogue sont calculés à l'aide de l'ordinateur.

Le Laboratoire de Chatou utilise des méthodes analogues.

L'étude de la marée donne lieu à une évolution semblable : calcul à une dimension de la propagation de l'onde de marée par intégration numérique des équations de Saint-Venant, dans le cas d'un lit unique, ou par une méthode analogue dans le cas de lits multiples, calcul à deux dimensions avec variation des limites en fonction du niveau (SOGREAH).

A Nantes-Saint-Nazaire, l'ordinateur calcule, à partir des enregistrements marégraphiques, les lieux géométriques des hautes et basses mers et les profils instantanés de l'onde de marée. A partir d'un fichier des profils en travers, on peut alors calculer les débits et les vitesses moyennes instantanées. Outre leur utilisation comme aide à la navigation, ces calculs permettent d'améliorer la connaissance des lois de frottement et rendent possible l'établissement de modèles mathématiques sur lesquels on étudie les aménagements de la Loire (Port Autonome de Nantes-Saint-Nazaire).

Mais l'ordinateur ne remplace pas encore les modèles réduits qui demeurent des instruments irremplaçables pour l'étude des projets de port. Au contraire même, l'informatique a fait faire aux modèles réduits des progrès décisifs, principalement dans deux domaines : automatisation et gain de temps. Nous donnerons deux exemples empruntés à des réalisations du Laboratoire National d'Hydraulique de Chatou : ceux des deux modèles des extensions du port de Dunkerque.

Sur un modèle d'agitation de 900 m² au 1/150, la surface du modèle est explorée par un capteur électrique dont la mesure est digitalisée, pré-traitée et enregistrée sur bande. L'enregistrement est ensuite traduit en carte d'agitation.

Pour obtenir ce résultat, le modèle a été équipé d'un chariot de mesure mobile sur une poutre elle-même mobile sur deux rails. La position de la poutre et du chariot peut être repérée automatiquement par lecture de perforations centimétriques.

Le chariot porte un capteur à jauge de résistivité, associé à un détecteur délivrant une tension proportionnelle à la hauteur. Un second capteur mesure la houle de référence incidente.

Un appareillage électronique numérise les hauteurs mesurées et effectue la sélection de ses extréma. La position et la mesure sont alors enregistrées automatiquement sur bande magnétique.

La commande du modèle est centralisée dans une cabine qui abrite également le dispositif de pilotage qui permet au modèle de reproduire fidèlement les conditions de marée et de courant.

Le traitement des données de mesure comprend le lissage, l'établissement d'une liste imprimée et d'une carte figurant :

— les limites caractéristiques (ouvrages, etc.);
— les courbes d'égale agitation;
— le hachurage selon un code figuré en légende;
— les données de base (direction et amplitude, période de la houle incidente).

Le relevé des fonds sur un modèle sédimentologique de 1800 m² au 1/400-1/150 est assuré selon une méthode comparable. La jauge de niveau est remplacée par un ensemble de deux jauges mesurant l'une le niveau de l'eau, l'autre celui du fond (jauge à champ électrique).

L'ordinateur restitue la carte des fonds, ainsi que des cartes différentielles permettant de visualiser les érosions et les apports. Des cubatures précisent ces indications.

Par rapport à la méthode utilisée auparavant qui consistait à relever les fonds isobathe par isobathe en faisant baisser progressivement le niveau et en soulignant la limite de l'eau par un fil pour permettre la photographie, cette méthode, qui permet la mesure en cours d'exploitation, est incomparablement plus rapide. Elle permet des relevés d'une grande richesse, et rend possible la multiplication des essais.

Nous terminerons avec les études hydrauliques en citant quelques exemples d'études diverses effectuées grâce à l'ordinateur.

Les mouvements d'accostage d'un navire soumis aux vents, aux courants et à l'action des remorqueurs, ont été simulés sur un modèle numérique qui permet de juger à l'avance la difficulté des manœuvres et de déterminer les limites au-delà desquelles la manœuvre ne peut être réussie (Port Autonome du Havre).

Les écoulements dans les circuits hydrauliques d'une écluse sont calculés pour tous les cas de niveaux possibles à partir de mesures faites sur quelques cas, et les consignes d'exploitation fixées en conséquence (écluse de Mardyck, SOGREAH).

2. Calculs de génie civil.

Nous ne citerons que pour mémoire les applications de l'informatique dans les calculs des ouvrages portuaires. Quoique très nombreuses, ces applications ne sont pas, en effet, spécifiques des ports, mais communes à tous les calculs de génie civil où, grâce à la multitude de programmes disponibles dans les bibliothèques des fournisseurs de matériels, les sociétés de software ou les bureaux d'études, grâce à la gamme étendue des matériels offerts par les constructeurs, l'informatique rend d'appréciables services. Les équipements les plus légers ne sont d'ailleurs pas les moins utiles : le calcul des cercles de grand glissement ou les calculs topographiques sont par exemple grandement facilités par les machines de bureau programmables.

En outre, c'est quelquefois à partir d'applications de génie civil que l'informatique a fait son entrée dans les organismes portuaires.

3. Etudes économiques.

Quoique également communes à tous les domaines de l'activité économique, les applications de l'informatique en matière d'études économiques portuaires sont toutefois suffisamment originales pour mériter une étude particulière.

Aussi bien l'analyse statistique que la programmation linéaire et la simulation sont en effet très largement utilisées dans les ports français lors de la mise au point des projets d'équipements ou dans les études financières faites en vue de la prise des décisions.

Grâce à la puissance des machines, l'informatique permet l'établissement de modèles d'hinterland, bâtis à partir des informations fournies par les statistiques et dans lesquels sont représentés les flux de marchandises décrites selon leur nature, leur origine, leur destination. Des procédures de calcul permettent de déterminer, en fonction des données tarifaires ou géographiques introduites également dans le modèle, la répartition de ce flux de marchandises.

Parmi les modèles de cette nature, nous relèverons un modèle de transport pétrolier de l'Europe Continentale de l'Ouest qui permet de comparer l'intérêt économique des diverses solutions possibles pour l'établissement d'une nouvelle liaison internationale par pipe-line (Port Autonome de Dunkerque).

A partir des besoins en pétrole brut des divers centres de raffinage européens et des productions des champs pétrolifères, le modèle calcule la répartition optimale des tonnages entre les divers ports de déchargement. Le modèle tient compte des coûts de transport (par les navires des diverses classes ou par les pipe-lines) selon les diverses routes possibles (canal de Suez, pipe-line du Moyen Orient, tour du Cap de Bonne Espérance) de la flotte existante de navires, du coût de construction des navires à construire, des capacités de réception des ports et des pipe-lines. Il calcule également en fonction de la croissance de la consommation, le nombre des navires des diverses classes qui sont nécessaires.

Ce genre de modèle nécessite l'utilisation de machines très puissantes et le recours à des techniques de programmation très élaborées.

La simulation est incontestablement le domaine dans lequel les ports français ont effectué les applications les plus intéressantes. La cause doit sans doute en être recherchée dans le fait que les phénomènes à étudier font en général intervenir un grand nombre de facteurs et que les problèmes qui se posent peuvent difficilement de ce fait être abordés par des études théoriques de recherche opérationnelle.

L'informatique, en apportant la possibilité de :

— tirages au sort superposés,
— mélanges de séquences réelles et fictives,

permet des représentations parfaitement réalistes. Aussi, les modèles de simulation sont-ils très nombreux.

L'attente des navires devant le terminal pétrolier de la Baie de Seine, dans plusieurs solutions envisagées, a été étudiée par le Port Autonome du Havre à l'aide d'un tel modèle.

Le Port Autonome de Dunkerque a de son côté mis au point plusieurs modèles de simulation. Un modèle général permet d'évaluer la charge de trafic des accès du port en fonction des hypothèses de développement. Ce modèle engendre automatiquement des séquences d'arrivée des navires qui peuvent être répartis en plusieurs flottes caractérisées par leur loi d'arrivée et leur histogramme de tonnage. Il représente les conditions de marée et le cycle diurne/nocturne qui règlent l'entrée des navires. Il simule à partir de là le fonctionnement des écluses du port et calcule les temps d'attente.

Ce même port a également mis au point un programme de simulation du fonctionnement des postes à quai permettant de prévoir les attentes des navires en fonction du trafic, du nombre des postes disponibles, de leur équipement.

Le Service Technique des Ports Maritimes au Ministère de l'Equipement a de même mis au point un modèle de simulation du fonctionnement global d'un poste pour navires porte-containers, dans lequel (comme dans le modèle précédent) l'instant de l'arrivée du navire, sa charge et la durée du service, sont tous trois aléatoires.

Citons également un modèle de simulation permettant d'étudier les besoins du port du Havre en remorqueurs (Port Autonome du Havre) et un modèle d'optimisation du fonctionnement d'un groupe de postes à quai (Port Autonome de Marseille).

B. L'INFORMATIQUE DANS L'EXPLOITATION ET LA GESTION DES PORTS

Il ne nous paraît pas utile ici de décrire les utilisations de l'ordinateur à la gestion interne des entreprises portuaires. Il s'agit en effet là d'applications banales qui ne se différencient guère d'applications semblables faites par la plupart des organismes industriels du secteur public et privé. Comptabilité générale, comptabilité analytique, gestion des stocks, gestion du personnel,

sont de plus en plus opérées de manière automatique, et en général d'autant plus que le volume des opérations est plus élevé.

Nous examinerons par contre les applications d'exploitation ou de gestion spécifiquement portuaires, qu'elles soient le fait des administrations portuaires elles-mêmes ou celui des usagers des ports dont l'activité économique ne peut pas être dissociée de celle de l'établissement portuaire dans son ensemble.

1. Applications des administrations portuaires.

Parmi ces applications, la plus généralisée est sans aucun doute le traitement des statistiques portuaires.

Ces statistiques sont généralement faites à partir d'informations recueillies localement soit par le port lui-même, soit par les Douanes.

Les statistiques « marchandises » sont faites à partir de déclarations douanières D.1 (manifeste douanier) et D.35 (déclaration de droit de port) qui décrivent, navire par navire, les marchandises chargées ou déchargées par le port, et les caractéristiques du navire lui-même. Les informations fournies par le manifeste sont chiffrées selon la nomenclature NST (1) à 4 chiffres, soit par le port lui-même (Dunkerque, le Havre), soit en commun avec la Douane (Marseille).

Les relevés des prestations du service public (passage à quai, outillage, etc.) fournissent également des informations qui sont recueillies et traitées.

Quelquefois, on exploite des renseignements sur les activités de manutention fournis par les usagers eux-mêmes (Dunkerque). Dans la plupart des cas, les renseignements recueillis et chiffrés sont reportés sur cartes perforées. Selon le volume des informations à traiter, le traitement se fait directement ou après transfert sur bande magnétique.

Les informations recueillies au port lui-même ne sont pas les seules utilisées. La Douane possède en effet une information extrêmement riche que certains ports utilisent. C'est ainsi que le port de Dunkerque traite les informations concernant l'ensemble des marchandises de son hinterland quel que soit leur port de passage. Des condensations ou des listes sont fournies à la demande aux usagers qui sont intéressés.

Certaines études complexes de tarification donnent également lieu à des applications de l'informatique, qu'elles soient effectuées pour des associations professionnelles (ex. refonte du système de tarification des manutentions) ou pour l'établissement lui-même (refonte du système des droits de port). Ces études mettent en général en jeu les techniques de la programmation linéaire.

Les méthodes de corrélation sont également utilisées dans les études de nouvelles bases de tarification des services de remorquage ou de pilotage (Marseille, Dunkerque).

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(1) Nomenclature Statistique des Transports.

2. Application dans le domaine de la consignation.

La plupart des compagnies maritimes françaises utilisent les moyens de l'informatique pour l'exécution des opérations de consignation de leurs agences portuaires.

Le développement des conteneurs va de pair avec celui de l'automatisme.

Plusieurs réalisations peuvent être citées parmi lesquelles celle de la Société Commerciale Transocéanique des Conteneurs (Messageries Maritimes) et celle développée par la Compagnie Générale Transatlantique dans le cadre du Consortium Atlantic Container Line (A.C.L.).

Dans la première application, les activités portuaires se limitent aux opérations de groupage et dégroupage des conteneurs et à leur chargement ou déchargement. Le système mis en place comporte un centre de traitement d'origine et un centre de destination qui échangent chacun à leur tour des informations sur les containers traités. Cette transmission se fait sur bande magnétique ou ruban perforé. L'information recueillie sert à l'établissement des documents commerciaux et administratifs.

Le système mis en œuvre au terminal A.C.L. du port du Havre est comparable. Il s'agit d'un système informatique d'établissement et de transmission des documents de fret qui couvre le transport des conteneurs entre l'Europe et les Etats-Unis. Le terminal du Havre est équipé pour établir, à partir des connaissements, l'ensemble des documents de fret qui sont nécessaires à l'exécution du transport et pour les transmettre au port de destination (ou pour les recevoir du port de chargement). Le système couvre plusieurs pays de part et d'autre de l'Atlantique et il est commun à plusieurs compagnies (6 entreprises, 4 nationalités). Il met en œuvre quatre ordinateurs et un système de transmission de données entre les divers ports de la ligne. Le système de transmission et les ordinateurs ne sont cependant pas connectés, et l'introduction des informations dans les machines se fait par une bande magnétique.

3. Applications dans le domaine des transports terrestres.

Les opérations portuaires des transports routiers ne donnent lieu en France, à notre connaissance, à aucune application particulière de l'informatique.

Les Chemins de Fer Français n'ont pas mis en place de système propre aux ports, mais dans la mesure où les gares de triage portuaires sont intégrées dans le système de gestion centralisée du trafic de marchandises de la S.N.C.F. (1), on peut considérer que l'informatique est largement utilisée par les opérations portuaires des Chemins de Fer. Plusieurs ordinateurs et un réseau très étendu de transmissions assurent sur l'ensemble du territoire, et dans les gares portuaires en particulier, l'exploitation et la gestion du parc de wagons.

Ce système s'arrête toutefois aux gares elles-mêmes, et les contacts S.N.C.F.-destinataires ne sont pas automatisés.

(1) Société Nationale des Chemins de Fer Français.

C. PERSPECTIVES

L'informatique est déjà largement utilisée dans les ports français où elle représente entre 1 et 1,5 % des dépenses de fonctionnement des établissements portuaires.

Mais il ne fait aucun doute qu'elle continuera à se développer rapidement.

Du point de vue interne aux entreprises, les ports qui ont commencé par recourir aux traitements à façon dans des centres de calcul, s'équiperont d'abord de terminaux reliés à des machines mises en commun, ensuite de machines à usage privatif.

Le télé-traitement interne à l'entreprise devrait bientôt faire son apparition : cette méthode de saisie de l'information est envisagée par plusieurs établissements portuaires.

Simultanément, l'intégration verticale devrait se généraliser jusqu'à couvrir tous les secteurs de l'activité de l'établissement dont le fonctionnement pourrait alors être simulé par des modèles complets.

Des systèmes d'exploitation de plus en plus sophistiqués devraient apparaître, notamment dans le domaine du contrôle du trafic, où l'électronique n'a pas encore épuisé toutes ses ressources.

Du point de vue externe, la tendance devrait être à l'intégration horizontale, par l'interconnexion des systèmes particuliers à chaque agent économique. Le progrès se heurtera sans doute là à plusieurs obstacles.

D'abord, la dispersion des centres de décision sera un frein à la circulation de l'information et par conséquent à l'établissement d'un réseau de transmission. Mais c'est là un facteur de retard qu'il faudra dominer car il est clair que l'efficacité en dépend.

Ensuite, se poseront des questions de langage. Les machines ne parlent que chiffres et le codage de l'information suppose l'établissement de nomenclatures. Plusieurs sont utilisées en France : N.D.B. (1), C.T.C.I. (2), N.S.T. (3), etc., et le passage de l'une à l'autre ne se fait pas sans difficulté. A l'intérieur même d'une même nomenclature, les informations recueillies par deux agents économiques de fonction différente n'ont pas toujours le même contenu. Là encore, il faudra surmonter la difficulté sous peine de gaspillage.

Il est difficile de prévoir jusqu'à quel degré sera poussé l'intégration horizontale. Plusieurs voies sont d'ailleurs possibles comme la création de banques de données ou la mise en œuvre d'un système unique de documentation du fret comme cela est envisagé dans le projet S.O.F.I.M. (4), étudié par la Direction Générale des Douanes). Une expérience de ce genre est en cours d'expérimentation au port de Marseille entre la Douane, l'administration portuaire et les usagers du port.

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(1) N.D.B. : Nomenclature de Bruxelles.
(2) C.T.C.I. : Classification Type Commerce International.
(3) N.S.T. : Nomenclature Statistique des Transports.
(4) S.O.F.I.M. : Système d'Organisation du Fret International Maritime.

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SUMMARY

Uses of computers in planning, design and operation of French ports

Computers are widely used by French ports, as well in technical studies as in economic surveys or in operating the ports.

As far as technical studies are concerned, wave records counting up and swell propagation maps are done by computers. The computer is also used to control the working of models.

In the field of economic surveys, mathematic models are operated automatically.

Finally, the electronic calculating machines play a greater and greater part in producing statistics of the port authorities and in the activity of shipping agents.

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PAPER

by

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1.0. HAMBURG PORT DATA BANK — COMPUTERIZED DATA & DOCUMENTATION SYSTEM

1.1. It is now some two years since the Port of Hamburg has been equipped with a data system which, from the outset, with the help of a central computer and, up to the present, some 35 directly connected data feeding terminals, has successfully completed almost 30,000 export operations per month. The reason for the development of this Hamburg project lies in the fact that between-times it has been realized that owing to the increase in the number of goods movements as well as the higher speed for their handling, the processing of these goods as far as paper-work is concerned, has become a tedious problem.

— the increasing quantity of goods proportionally increases the « paper war »;

— the shorter staying time of goods in the port requires a quicker production and better arrangement of paper work;

— a labour force constantly on the decrease easily leads to faulty form filling, failure to comply with final loading conditions and often also to results that the loading documents arrive at the port later than the goods themwelves.

With a view to supervising all transport operations from the sender to the consignee by means of computer, major forwarding agents in particular have expressed the wish to accumulate data on data packs which can be read on the machine. This is not possible in a sea port today, at least not for classically packed goods.

All these reasons lead up to the fact that methods must be found in order to meet with the requirements mentioned while employing vast rational methods. Hamburg has taken the first step in this direction : the following applications

will give a general idea of present-day activities and future projects will show the possibilities of essential solutions to a problem with which all sea ports are at grips.

1.2. **Details.**

Since each port possesses its own particular working methods as regards documentation handling, and to permit a better comprehension, a brief description of conditions and operations at Hamburg will be given.

1.2.1. *Loader — Forwarding Agent.*

As regards documentation, the forwarding agent and loader in Hamburg is the first and the most important link in the export chain. It is he who first receives the data concerning the goods, this in the form of documents accompanying the goods (letters of advice, freight bills, customs declarations, etc...), informs the port loading service by means of the shipping documents, shipping note and other forms concerning the measures to be taken, advises, if necessary, the line agent about loading details, hands over the necessary information for completing the bills of lading, issues stuffing instructions when the consignment is containerized and hands over to his client a number of different forms containing the required information and details.

1.2.2. *Port Loading Service.*

The port loading services, particularly for re-shipment and warehousing, receive their operating instructions from the forwarder and generally do not supply information to others.

1.2.3. *Ship Broker.*

The ship broker who is informed by the forwarder and others acting on his behalf (consignment control) forwards all the information concerning the goods and shipping to his client in the form of bills of lading which have been handed over to him by the forwarder along with other special lists and then proceeds with calculation of shipping charges indicated in the shipping manifest.

1.2.4. *Tally.*

The line agent proceeds with a strict control in collaboration with the loading control service (tallyman). The latter and the dock loading service are also informed by the loader with the help of the shipping note and he arranges and classifies the numerous and important data concerning the goods and the consignment according to criteria, in several total, individual and special lists. Data are then given to the line agent and to the vessel itself and in many instances to the port loading service.

1.3. **Preparation of the E.D.V. programme.**

The data through-flow described will have already given to understand that a substantial part of the information contained in the individual forms is identical.

This means that these details must again be entered by all parties concerned. The slowness and difficulty of such a manual documentation as well as the too large a number of persons mentioned have now led to acknowledge that the profusion of documentation must be transmitted to a data assimilation centre which will supply directly to the firms concerned, by direct connections, the required information thus considerably reducing personnel requirements and time spent on preparing documents. This is in fact the typical case covering the use of the application of computer science and can be called a Data Bank.

DATENBANK HAFEN HAMBURG

Available to branches	Allen branchen verfügbar
Bills of lading	Konnossemente
Complete data of a consignment	Komplette Daten einer Ladung
Container stuffing instructions	Containerpackanweisung
Data for accounting and statistics	Daten für Buchhaltung & Statistik
Data for tally invoice	Daten für Tallyrechnung
Data for terminal invoice	Daten für Terminalrechnung
Dock receipt	Kaiquittung
Forwarder forms	Spediteurformulare
Forwarder house bill of lading	Spediteur Haus-zu-Haus-Konnossement
Forwarder input	Spediteur Eingabe
Information report	Informationsbericht
Invoices	Rechnungen
Line agent data	Makler-daten
List of remarks	Hinweise & Anmerkungen
Tally data	Tally-daten
Tally manifest	Tallymanifest
Terminal data	Terminal-daten
Terminal forwarding agent	Ausgabe Spediteur
Terminal tally firm	Ausgabe Tallyfirma
Terminal terminal operator	Ausgabe Terminaloperator
Terminal line agent	Ausgabe Makler
Transportation order and export documents	Transportanweisung & Exportdokumente
Vessel freight manifest	Ladungsverzeichnis des Schiffes
Waybill	Frachtbrief
Manifest	Manifest

The Data Bank at the Port of Hamburg must therefore resolve the problem of sending all documents and papers of the transport chain from the forwarding of the goods up to receipt to a central data processing unit working for all the firms, this by means of remote data processing units.

1.3.1. *Supporters of the project.*

The project enjoys the support of a large section of Hamburg's forwarding agents, all handling and tally firms as well as the line agents in general. They are now forming development companies which, working in collaboration with each other, have set up the Port of Hamburg Data Bank GmbH. This company has taken on the task of coordination, development and administration of the accountancy department.

1.4. **Method of procedure of the E.D.V. unit.**

In this so-called remote data processing network which connects all the firms concerned in the consignment, a central computer handles all the data. While at present the installation of a producer data processing unit is still necessary, a large installation operating in duplex will later be installed. Terminals are installed by the firms involved. These data input/data output terminals are connected to the central system via telephone channels. Although at present operations are effected at typewriter terminals, equipment such as television, printing units and telex will be supplied at a later stage. The procedure described below is also illustrated in Fig. 1.

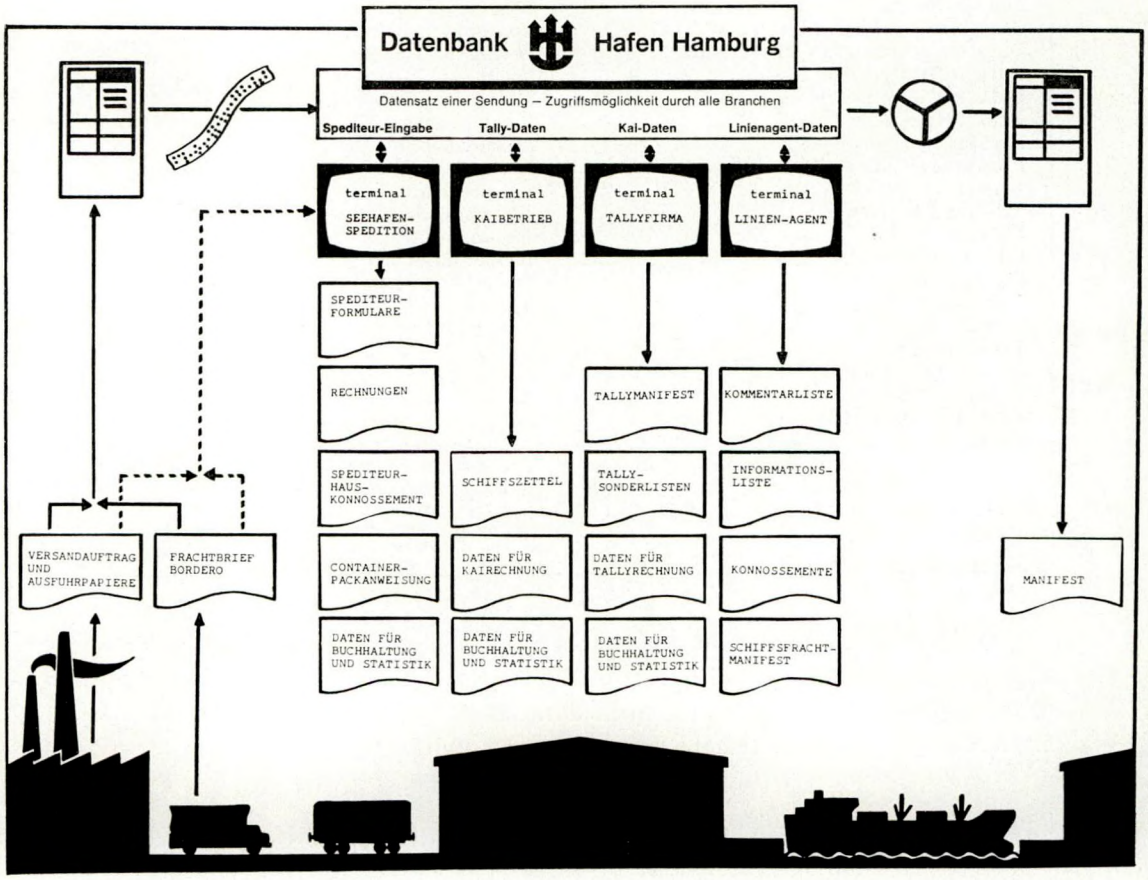

Fig. 1.

1.4.1. *Forwarding agent.*

The forwarding agent as first member in the export chain provides all data relating to despatch through the terminal installed in his premises to the central data processing system. Considerable work simplification is obtained by the

use of codes for a number of frequently used data items such as address, names of ships and ports, and description of goods. After checking and making any corrections to the information, the system processes the corrected data at once in the form desired by the firm, i.e. forms for ships, and/or proposals for delivery, clichés for forms specific to the forwarder, information lists and bills of lading are printed according to needs. This can be done at the firm's premises, at the quay or in the agent's office.

Special programmes considerably facilitate the procedure with respect to collective containers and also give the possibility for different firms to take mutual advantage of a common transport/handling pool without additional work. Obviously, other programmes namely for billing, accounting and statistics are being planned.

1.4.2. *Port services.*

In the port itself terminals are provided in the quay sheds through which the data and instructions given to the port services by the forwarders are expressed in the form of orders concerning shipping notes covering goods and ships movements. Depending on the space available, these terminals can be used by one or several quays.

As codifications should be given for all goods handled, it is possible to establish a connection between goods codes and related handling rates and deduct billing procedure therefrom. For many quay services, this means a substantial simplification in calculation tasks.

The most important supplier of information in the port is the Tallyman. He feeds into the system through the quay terminal used jointly by the quayside services, all basic information (such as dimensions of goods, indications regarding specific properties of goods, tide, etc...). This terminal in fact prepares the data later issued through the agent's terminal and also enables the tallyman to prepare and release the large number of manifests, container packing lists, port lists, special lists, etc...

1.4.3. *Line agents.*

The main advantage of a data bank for the line agent consists in the more rapid availability of loading information permitting to accelerate calculations and document preparation methods. He therefore regularly receives during delivery of the consignment to a particular vessel, information lists which, somewhat in the same way as the inscription lists, provide details on the latest arrivals of goods intended for a particular ship.

For final freight calculations, the line agent also needs, in addition to the bill of lading details, information from the forwarder (telex news) together with data provided by the tallyman before or during shipment. In the normal process, both items are completed so that a particularly wide form is issued at the agent's

terminal and which contains on one side the B/L used as a master copy and on the other the additional B/L comments of the forwarding agent and the tally man. In special cases, and firstly for collective bills of lading, the list of comments should however be printed as an appendix to the collective Bill of Lading matrices. It is of course also possible to produce shipping manifests which can be divided or prepared completely for a complete vessel or according to parts or other criteria.

1.4.4. *Miscellaneous.*

Thought has also been given to a close collaboration with institutions such as official authorities, this in addition to the basic duty of goods handling. A considerable advantage for the hinterland is provided by the Hamburg Data Bank in the possibility of off-line : Some important forwarding agents with their own export department in the port, or inland forwarders with a branch office in Hamburg or having close relations with a seaport forwarder, give their export documents for feeding into a special recording medium (paper tape) located in the port. The Hamburg office completes the data made visible on a TV screen and feeds them by terminal to the computer which, after loading, returns the tape to the inland forwarder for his own needs.

1.4.5. *Conclusion.*

At present, 35 equipments operate in various forwarding agents' offices, while two to four hundred terminals are expected to be needed at the final stage. Forwarding matrices, shipping documents and bills of lading are already printed. Direct connection with quay handling services and ships agents has not yet been finalized. Hamburg expects the implementation of the final Data Bank concept to be achieved for the middle of 1974.

2.0. CONTAINER OPERATING CONTROL SYSTEM (COCS)

The HHLA (Hamburg Port and Warehousing C°) has started developing the COCS for the service of their container terminals in Hamburg as a sub-system of an integrated and complete information system with a central Data Bank. Important parts have already been set up. Introduction of partial operation areas has followed and will follow gradually, depending on its development on the Systemlogic. Figure 2 shows the scheme of this system.

2.1. **Purpose setup.**

The basic points of this system are :

— Supervision and direction of all container movements;

— Actual information by request for data concerning container and chassis;

GENERAL FLOW „COCS"

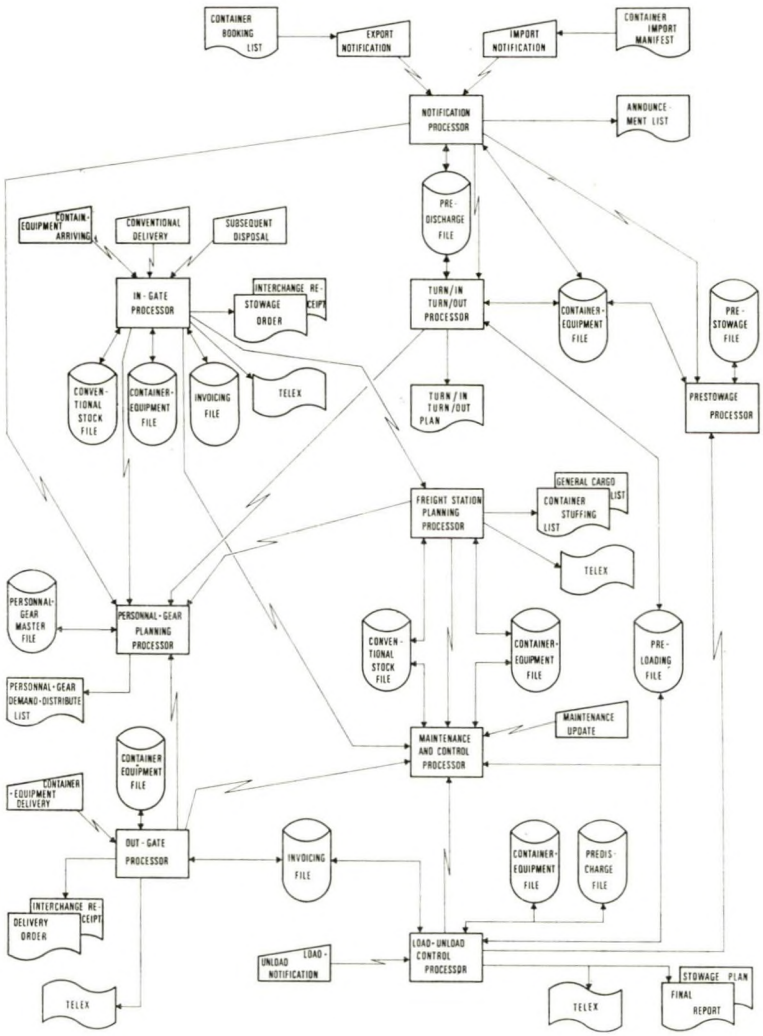

Fig. 2.

— Filing of all containers located within reach of the terminal, as well as of the container chassis and of conventional goods within reach of the container/freight station;

— Write-up of all documents, accompanying papers, statistics, etc... necessary for movements;

— Liaison/connection with other sub-systems such as accounts of costs and performance.

GENERAL FLOW « COCS »	ALLGEMEINER DATENFLUSS « COCS »
Announcement list	Meldebericht
Container booking list	Container Buchungsliste
Container & equipment arriving	Container & Gerät Ankunft
Container & equipment delivery	Container & Gerät Auslieferung
Container & equipment file	Container & Gerät Bestand
Container import manifest	Container Import Manifest
Container stuffing list	Containerpackliste
Conventional delivery	Konventionelle Auslieferung
Conventional stock file	Konventioneller Bestand
Delivery order	Auslieferungsliste
Export notification	Exportanmeldung
Freight station processor	Packhallendisposition
Final report	Lade-löschbericht
General cargo list	Stückgutliste
Import notification	Importanmeldung
In - Gate processor	In - Gate Verarbeitung
Interchange receipt	Interchange Quittung
Invoicing file	Rechnungsbestand
Load & unload control processor	Be-u. Entladeverarbeitung + Kontrolle
Load & unload notification	Be-u. Entladebenachrichtigung
Maintenance and control processor	Allgemeines Wartungs-u. Kontrollprogramm
Maintenance update	Wartungsdateneingabe
Notification processor	Anmeldungsverarbeitung
Out - Gate processor	Out - Gate Verarbeitung
Personnel & gear demand & distribute list	Personal & Geräte, Bedarfsverteilungsliste
Personnel & gear master file	Personal & Gerätebestand
Personnel & gear planning processor	Personal & Gerätebestand
Predischarge file	Löschplandaten
Preloading file	Ladeplandaten
Prestowage file	Vorstaudaten
Prestowage processor	Vorstauverarbeitung
Stowage order	Stauanweisung
Stowage plan	Stauplan
Subsequent disposal	Nachverfügung
Telex	Telex
Turn in, turn out plan	Eingangs Ausgangsverarbeitung
Turn in, turn out processor	Eingangs Ausgangsplan

2.2. **Initial phase.**

In the first phase of installation a partial information system for container handling has been set up and which opens the way to the end purpose system (COCS) step by step. This partial system now works on an IBM 360/20 Model 4 with a 16 K Band/plate, batch processing. Capacity of the plate units is approximately 15 million bytes. The EDV unit is totally enclosed, integrated and operates with a container Data Bank. The system comprises inter alia at present :

— pre-discharge programme

— pre-loading programme

— rail unloading

— rail loading

— Interchange lorry/rail for delivery and collection, etc.

This system provides for the availability of data concerning a container. The data are issued by means of a pilot card.

2.3. Further development of the system.

As a next development phase, an on-line/real-time set up between the EDV equipment installed at the terminal and the calculating unit at management level is being considered. This end will be reached after several intermediate phases.

These phases include one planned to develop direct exchange of data with various external units such as navigation companies, German Railways, etc.

RÉSUMÉ

1.0. Avec le temps, il ne sera plus possible de satisfaire, par les méthodes manuelles traditionnelles, aux besoins d'information et de documentation d'un port maritime. C'est la raison pour laquelle on a créé, au port de Hambourg, une société ayant pour mission de commander, au travers de la chaîne de transport, la combinaison globale des documents et formules grâce à l'instauration d'un système central de traitement de l'information travaillant à distance pour tous les ports.

2.0. D'autre part, on a instauré pour l'exploitation du « Container-Terminals Burchardkai » un système appelé « Container-Operating-Control-System » (COCS), lequel assumera les tâches spécifiques de cette grosse entreprise.

S. II - 5

PAPER

by

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SOME EXPERIENCE, REQUIREMENTS AND CONSTRAINTS IN THE USE OF MODELS AND SIMULATION IN PORT EXTENSION AND PORT OPERATIONS PLANNING

I. INTRODUCTION

Ports are facing difficult problems in this era of rapid change in shipping and cargo handling technology. There seems to be an ever growing discrepancy between the time periods covered by the forecasts and decisions of port users and those required by port planners for proper port extension and even port operations.

This creates the need for more sophisticated approaches to the reconnaissance of the future for establishing the design criteria and the proper phasing of the actual development of port facilities and infrastructures. Not only is it required nowadays to develop a lot more and very different alternatives, but these have to be compared and evaluated in technical, economic and financial terms. The risk of investments also comes into play, as different sets of circumstances emerge :

1. The number of alternative and completely different « scenario's » for the future increases.
2. The relative certainty of the start of alternative developments (such as in packaging and shipping modes) has to be estimated.
3. Modular extension seems indicated, to avoid heavy mis-investments.
4. Macro-economic and environmental issues are to be included in the evaluations.

Identical problems in other business areas and for large semi-government projects have meanwhile lead to the development of several (often computer-

oriented) techniques, which can be used to add to the execution of the above mentioned complex evaluation processes. Usage of these techniques is not very widespread yet and their development is still going on. On the other hand the discussion about their practical and added value is continuing.

This paper describes some of these techniques and their possibilities for application in port extension and port operations planning. The usage of these techniques presupposes a certain availability of data, special know-how, and « systematizing power », specifically because the required way of thinking differs from known approaches and because we are experimenting in an area where the translation of scientific finds into practical application is still in full swing. In this paper some practical exercises in the Netherlands with the described techniques are mentioned and some major constraints are indicated. We would finally like to indicate, that the purpose of this paper is only to add to the above mentioned discussions aiming at finding a better solution for the difficult problems now emerging for those who plan and finance ports.

II. THE PROBLEMS STATED DIFFERENTLY

A. Problem categories.

For our approach in this paper we would like to distinguish the problems facing the planner of port extensions and port operations into two categories :

1. Static problems
   — those of improving the present situation, where only restricted investments are involved.
2. Dynamic problems
   — those requiring anticipating the future, with risk and uncertainty. Large investment, capital budgetting and financing is involved.

B. Static problems.

In problems of the first group, industrial engineering techniques, such as ratio-delay, workstudy, process-analyses, etc. are commonly used. In certain cases good use can be made of *queueing theory* and of certain restricted *simulation techniques* such as GPSS (General Purpose Simulation System).

This can however only be done when a proper *model*, or systematic description is available of the processes under discussion together with complete sets of input-data.

And completing the model and the input-data involves a considerable effort, while the results are restricted even after repeating « runs » in an intelligent manner, because input-data are too much hinged together. Models do not only require a fairly complete insight into the nature of the different processes, but

also into their interrelationships, influence factors, characteristics or variables. Figure 1 distinguishes these variables.

- Variables
  - Independent (a priori)
    - *decision* variables (which can be manipulated)
    - *input* variables (which cannot be manipulated)
  - Dependent
    - *state* variables (describing the behaviour of the model)
    - *output* variables (Objectives, goals)

Fig. 1.

In a port, or group of port facilities, although from the outside the different processes may look simple, their interrelationships and the factors governing performance (or the variables) are not. They are partly general partly specific and are to be gathered per port, facility-group or berth. For improvement of present operations without bringing in major changes or external influences, the restricted techniques can however be used very well.

C. **Dynamic problems.**

In problems of the second group, when starting to use more sophisticated approaches, including criteria for uncertainty, a good and *reasonably complete model* is again required.

The development of such a model is normally done via an analysis of the present situation in sufficient detail, cutting the port (facility or system) up into *modules* (building-blocks) that can be tackled separately (sub-systems). Then a description of these blocks, their interrelationships and their variables (process-characteristics) both internal and external (intra) is developed, trying to include the dynamics of these factors.

Problems appear however in appraising these dynamics of the future, say ten or fifteen years ahead.

1. The types of ships expected.
2. The types of commodity packaging expected.
3. The handling and even storage methods expected.
4. The land transport modes expected.

In other words (see Fig. 1) not only do the decision-variables require careful manipulation, also the input variables become dynamic and uncertain and they can be manipulated in a restricted sense.

This leads to the use of *decision-theory* and modern *forecasting techniques*, as well as to extended *cost-benefit analyses* and the socalled *systems approach* (1).

This latter « way of thinking » can be considered as a total framework or structure, in which the various techniques mentioned earlier can be applied. It should be noticed that for use in this approach proper model development and proper description of the dynamics of the variables generally takes a considerable amount of time. If fast results are required it often appears only possible to drop back to socalled « best guess » methods and some « variation of assumptions », applying as an additive some of the restricted techniques mentioned earlier (under B).

D. « Best guess » techniques and more sophistication.

A clarification of what this paper calls « best guess » techniques may be needed. The « best guess » approach has been used by generations of development planners and can, even today, be considered as the basis for all further development planning. In this approach, a few well-reasoned sets of assumptions (or expert opinions) about the future are brought together and selected mainly via discussions. This leads to one solution of the development planning problem : the « line » solution.

By then varying the assumptions, a « channel » solution is obtained in which the « line » solution may be considered as the most probable. Some influences on major decision-variables of the solutions in the channel, such as on costs and rates of return, may be calculated and tabulated. When investment risk is to be evaluated, variation of assumptions and the reconnaissance of influences on major decision variables is to be done more systematically over a broad area of possible values of the variables.

Probability-distributions of the main variables are inserted and a formal procedure is required to govern the decision preparation process.

III. DECISION-ANALYSIS

A. The approach.

Following Howard (2) decision-analysis is described as a formal procedure for the analysis of decision problems.

Three phases are distinguished :

1. The deterministic phase.
2. The probabilistic phase.
3. The informational phase.

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(1) J. K. O'Keefe : « An introduction to Systems Analysis », Journal of Industrial Engineering, Vol. XV, No. 4, June/August 1964.

(2) Ronald A. Howard, Institute of Engineering-Economic Systems, Stanford University, IEEE Transactions, Vol. SSC-4, No. 3, Sept. 1968, « Foundations of decision-analysis ».

In the deterministic phase a model is constructed in such a manner that the impact of shifts in value of the variables in the different alternatives can be evaluated. The model supplies an output in functional form (objectives-function, profit-function) if the state — and decision — values are swept through a possible range of values individually and jointly. Such reconnaissance or sensitivity-analysis shows for which variables uncertainty plays an important role. The crucial variables can be determined and thus directions for further research are provided.

In the probabilistic phase, probability-distributions are assigned to the state-variables. For each alternative the output of the model will then also have the form of a probability-distribution e.g. of profit, the profit-lottery.

The decision maker does now have a wider choice or rather gets a deeper insight, making it on the one hand more difficult to choose, but on the other he may feel more secure.

In the case of stochastic dominance, the choice is easy. If this is not so, the choice will depend on the decision-maker's attitude towards risk. In showing him the implications through the results of the above reconaissance-tour, his attitude can be expressed in terms of utility. The best alternative can then be considered the one with the highest expected utility. By again executing a sensitivity-analysis it can be shown how a certain utility depends on a particular state-variable, when the other state-variables are uncertain. This « selection process » may well lead to a more comfortable feeling about the environment influencing the decision. Thus the decision is easier to make as its implications or risks are better known.

In the third phase, the informational phase, the « economic sensitivity » of the model is tested, that is to say, the value is determined whereby the influence of uncertainty of crucial state-variables is eliminated. In this manner an economic information gathering program can be developed before going further with the various exercises.

After this has been done, the deterministic phase is repeated after adjustment of the ranges of possible values of the state- and decision-variables and sometimes of certain interrelationships and it is hoped that the total number of workcycles can be minimized as the calculation system converges. Of course computer support is required throughout, specifically when the number of state-variables is large.

A practical aid in visualizing the working of the above procedure, can be the development of a decision-tree (1), which combines action choices with an insight into the problem of sequencing the state- and decision-variables in the calculation process, so that realistic answers appear.

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(1) John Magee : « Decision-trees for decision-making ». Harvard Business Review 42, July-August 1964, pp. 126-138.

B. **A discussion of the method.**

Decision-analysis is regarded as a modern tool for attacking complex decision problems in a logical and systematic manner. Thereby a good insight is provided into the many factors and their relationships governing the success of a project after it has been implemented. It is not a solution method such as queueing theory, which leads to an optimum solution of a problem. Decision-analysis is rather an aid; the principles if properly applied, provide a contribution to the preparation and making of a decision as well as to evaluating the crucial factors, influencing success. The most important aspects of decision-analysis are the attachment of probability-distributions to the relevant variables (assumptions) and the selection of those variables which are of crucial importance to the decision.

A more complete reconnaissance in quantitative terms is obtained of the environment of the recommended solution(s), before a decision is to be made.

Application of decision-analysis has some typical characteristics :

1. The decision problem has to be stated and decision criteria are to be defined.
2. An appropriate model has to be constructed.
3. The boundaries of the model have to be recognized.
4. Uncertainty and probability must be common words.
5. The organizational environment in which the exercises are performed must be able to respond positively to answers that on the surface look vague.
6. It can be a costly type of reconnaissance if the converging-principle is not properly applied.

Nevertheless application of decision-analysis in complex situations, such as in port extension, has proved useful. In many port studies until now the « uncertainty-problem » has been avoided by the use of socalled conservative estimates. In complex problems, actual conservatism can however only be reached if the crucial state-variables are known and this is often not the case before a proper model is developed and tested and before probabilities are assigned to the range of possible values of these crucial variables. Il costs of such exercises are considered too high, then it would be good, as a minimum to perform certain sensitivity-analyses.

IV. TWO EXAMPLES OF THE USE OF DECISION-ANALYSIS AND SENSITIVITY-TESTING IN PORT PROBLEMS

A. **Introduction.**

The rapid development of containerization since 1965 in the port of Rotterdam has led to the development of two containerterminals which cater for deep-sea traffic as well as for short-sea and feeder services.

These terminals have been built within the existing port layout. One is in a vastly adapted and expanded area, which was originally intended for the building of conventional break bulk cargo handling facilities. The second terminal is made by adapting an existing dry bulk pier and part of its equipment.

As container traffic developed, questions arose as to the total capacity limits of these terminals and where extension could be found. Since 1967 a plan to build a new harbour area at Rijnpoort on the North side of the New Waterway was developed and put before the National Gouvernment and the public.

Since then many studies have been executed concerning the advantages and disadvantages of this development from a national economic point of view as well as from the standpoint of various local interests e.g. the present population of the area and the terminal operators running the existing container terminals.

In an attempt to examine the influence on certain economic yardsticks, such as overall return of investment, some studies have been executed or are still continuing on the effects of changes in assumptions. One study by Poeth and Arends (1) and based on the principles of decision-analysis is discussed below and some intermediate conclusions are described also in the context of intermediate results of yet another study by Nedeco/TTA (2). At the time of completion of this paper further research is going on.

B. **Towards a decision-model for container development.**

In a recent attempt to arrive at a « line »-conclusion on the national-economic benefits of the Rijnpoort development via a benefit-cost analysis it appeared that too many items had to be mentioned as «pro memoria», making the solidity of the answer rather uncertain.

In looking at it from the point of view of the terminal operator it was decided in the study by Poeth and Arends as well as by Nedeco/TTA to focus on « the investor » : Should he invest or should he not.

The decision model of Poeth and Arends, developed primarily for use in the university courses in decision-preparation, is thus an economic investment model and the prime decision criterion chosen is the net-present-value (NPV). The reader will however understand that other decision criteria could also have been chosen.

Once the decision problem was stated, factors which influence the decision were looked for, examined and judged. Many experts were questioned and existing data and studies were analysed. Then a model was constructed which could eventually calculate a (time discounted) net-present-value. This deterministic model is shown in concept in Fig. 2.

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(1) Of the Interfaculty of Business Administration, Rotterdam.

(2) Consulting Engineers and Systems Analysts, the Netherlands.

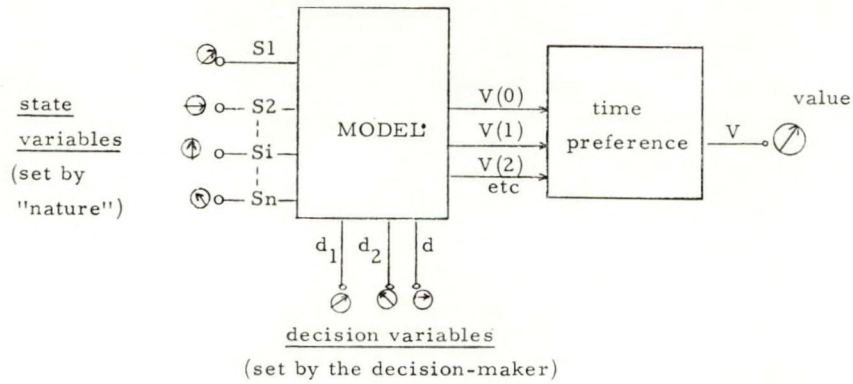

Fig. 2.

Deterministic Model.

The relevant state- and decision-variables in this problem were :

— general cargo flow via Rotterdam;
— the expected growth of goods traffic and the development of Rotterdam as a seaport;
— feeder services and container transportation development;
— development of the rate of containerization of general cargo;
— the completion of Rijnpoort-harbour;
— berth capacities at existing terminals and Rijnpoort;
— capacity development possibilities (index);
— the relevant investments and annual costs;
— the relevant charges (revenues) per container;
— inflation and the cost of capital.

To show the structure of the interrelationships between the various state- and decision - variables, the structural model used is indicated in concept in figure 3.

Instead of only selecting fixed or slightly varying values and then calculating the various NPV's, the sensitivity of the variables on the outcome was tested.

It turned out that the handling-capacity per berth, the number of berths, the handling-charge per container and the cost of capital showed a high sensitivity. The real wage growth, the number of personnel per berth and shifts in the investment per berth showed a medium sensitivity.

The enormous advantage of this analysis was that the influence of the variables on the objective (NPV) function could be quantified.

In the next phase probabilities were assigned to values for the most important state-variables and this resulted in a value lottery for the NPV's with each set of decision variables.

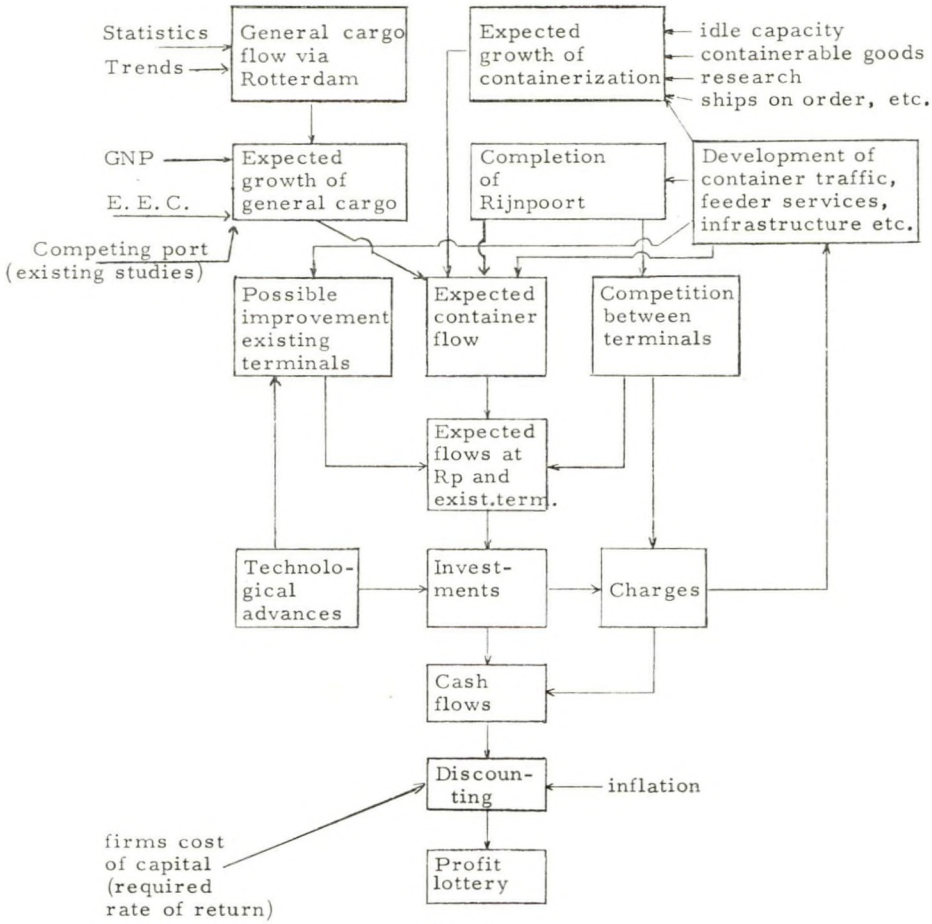

Fig. 3.

Structural model (conceptual).

At this stage it was possible to draw a decision-tree, visualizing all possible courses of action, the certainty of each course of action and the net-present-value of each branch of the tree together with its probability of occurrence.

The study has arrived at this point. Various probability distributions are now tested and discussed with possible decision makers to arrive at an improved information gathering program. The results so far however have made it possible to test the impact of actual results achieved in practice on the net-present-value of planned investments in facilities, efficiency improvements and research projects before they are executed. The decision-maker can feel more comfortable.

C. An example of sensitivity-testing and risk-analysis in port extension planning.

As a serious side effect of the shift of general cargo towards containers, the often already planned development of more conventional berths in a port is disturbed.

Even existing berths may become obsolete as larger and more modern ships with containers cannot efficiently utilise them any more.

Under these circumstances further extension of facilities of an existing or even modified type may be a very risky investment indeed and alternative approaches to accommodate growing cargo flows of a different nature have to be found.

In order to further structure this problem and to get an indication of the advantages of certain approaches over others, Nedeco/TTA commissioned a study which had as one of its objectives to evaluate the impact of certain measures of improvement (or alternative approaches) of port performance on the integral costs per ton.

In this study, parallel to a « best guess » approach and variation of assumptions, the sensitivity of these variations was tested. By adding probability distributions the risk of alternative sequencing of the recommendations was to be indicated.

Although this study is also continuing it may be worthwhile in the context of this paper to mention a few intermediary results.

As an example an existing port in Africa was taken, for which, recently traffic forecasts had been made and port improvement measures had been recommended.

These latter measures can roughly be grouped as follows :

1. Investments in improvement of the organizational structure and procedures for port operations.
2. Investments in training of middle management to improve coordination and cooperation.
3. Investments in ancillary facilities such as communication equipment, pallets, stevedoring gear, spare parts to decrease stoppage times and improve productivity.
4. Investments in port facility improvement such as adapting storage, parking and traffic arrangements, cargo handling equipment.
5. Major investments in facility extension.

It was recommended to have these measures executed in parallel leaving the major investment decision till specific later dates after further examining its modular implementation and phasing possibilities as well as port user plans. This implementation plan was suggested because of uncertainty about the start and acceleration of full container operations as well as about general traffic developments.

In line with the development, described in the first example a model was constructed indicating the variables, their interrelationships and functional characteristics.

The decision criterion chosen was the total throughput costs per ton from/to landtransport vehicle (TTC), including ship days in port and in a waiting line.

Variation was assumed, after initial work cycles, in the following (crucial) state-variables :

a) Facility costs.

b) Ship costs.

c) Equipment costs/gang.

d) Labour costs.

e) Expected total tonnage/year.

f) Gross production figures per gang-hour.

g) Overhead costs per ton.

Initial sensitivity testing indicated that the sensitivity to changes in the productivity per gang-hour is very high (a 10% change initiates a 4-5% change in TTC) followed closely by changes in ship costs (10% change gives 3-4% TTC change). Changes in facility costs are also quite sensitive (10% gives about 2%), while changes in overhead costs and labour costs follow (10% gives about 1%).

For the latter a further exercise is planned by developing the model further to be able to vary the overhead costs per ton (which represent about 25% of TTC) in a better manner.

By adding probability distributions to the above variables and ranking them in different calculation sequences a risk-analysis was made, aiming at indicating the priorities of the recommended measures.

A series of computer-programmes was written to execute the various calculations.

This part of the study at present only gives very tentative results, which are not altogether surprising, but which have as an added value that priorities are better quantified.

Probabilities of a « rise » or « fall » in the variables relative to a « best guess » result in a new « most likely » value, emerging after more experts have given their opinion on possible changes in the range of value of the (crucial) state-variables mentioned above.

Table (Fig. 4) indicates the results.

The computer programmes have calculated the probability distribution of the subsequent changes in throughput costs/ton (TTC). The table (Fig. 4) also indicate the « most likely » values of these TTC-changes relative to the « best guess ».

If the total set of probability distributions of TTC could be reproduced, one could see their « skewness » and « variance ». Preliminary exercises in this

field indicate that economizing on facility investments would be advantageous, together with an improved turn-around time of vessels.

Table Fig. 4 « Most likely » values (*)
of the crucial variables and their impact (*) on TTC. (all %)

Case : 12 conventional berths.

Crucial state variable		TTC - change
Facility costs	+ 5	— 1.35
Ship costs	— 4.5	— 1.71
Labour costs	— 6.6	— 0.51
Expected tons exp.	— 8.3	— 0.83
Expected tons imp.	+ 3.4	+ 0.22
Productivity exp.	+ 2.8	— 0.86
Productivity imp.	+ 2.7	— 1.43

Note : (*) all relative to : « best guess ».

Further study is going on, in particular because changes in certain variables are interrelated and by « digging deeper » it is hoped to quantify the major interrelationships.

Nevertheless it can be stated that the original plan of action seems to hold, notwithstanding the following overriding effect :

Avoiding a waitingline of vessels is of prime importance, but in the case of uncertainty about the start and acceleration of different modes of transport (such as containers) a parallel improvement of the productivity and layout of existing facilities and investments in modular expansion is the most advantageous plan of action.

V. REQUIREMENTS AND CONSTRAINTS

The use of probability- and computer-oriented techniques in port extension and port operations planning requires a very formal following of certain procedures and development steps outlined above. And as already stated in the introduction this again implies the availability of sufficient data, know-how and « systematizing power ».

Important obstacles however appear in the development of proper decision criteria, specifically in ports, where :

A. there is often a total split of interests (port authority, terminal operator, the Government as an investor, the public, the port users);

B. it is not always clear where the benefit of improvements is going.

As one tries to optimize a solution to a problem :

1. the problem has to be clearly stated, and
2. the decision-maker is to be identified.

Another obstacle, already mentioned, is the high cost of execution of the exercises, and while a solution for a small system (or firm) is much easier to get, it is actually only in complex and uncertain circumstances, that the added value of these techniques becomes apparent.

The work that has been done however indicates that « the way of thinking » and restricted use of the techniques described above can give a good insight into the environment of the decision and will certainly add to the comfort of the decision-maker.

We hope that others will join in identical reconnaissance-tours to add to the development of the practical application of these techniques.

RÉSUMÉ

Le rapport parle de l'influence provoquée par l'incertitude découlant des rapides changements technologiques et opérationnels. De plus, il traite du phénomène qui fait que les usagers des ports sont de moins en moins en mesure de faire connaître avec certitude leurs besoins à ceux chargés d'établir les projets de ports pour l'avenir.

Il s'ensuit qu'on est amené à élaborer des techniques plus avancées que précédemment.

Parmi les techniques appliquées dans ce domaine, le rapport développe principalement celle de la « Théorie des décisions » avec introduction de facteurs de probabilité, et illustre celle-ci au moyen de deux exemples.

L'application des concepts d'incertitude et de probabilité mène à l'emploi de ce qu'il est convenu d'appeler la « sensitivity testing and risk-analysis ».

Il apparaît ainsi possible d'effectuer une reconnaissance du terrain bien plus sérieuse que par l'approche conventionnelle du « best-guess », par simple variation des paramètres et par estimation prudente des variables.

Les rapporteurs espèrent que les techniques décrites pourront être utilisées avantageusement par d'autres.

S. II - 5

PAPER

by

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MODULAR SIMULATION OF MARITIME SYSTEMS

INTRODUCTION

The paper outlines the techniques of modeling and simulation of dynamic systems which the author calls « Modular Simulation of systems ». The technique was developed as a product of experience in designing and programming mainly seaport and maritime transportation simulation models used for solving a wide range of problems in design, identification, and control of original systems.

Design and programming of computer simulation systems in « classical » way, i.e. separately for each type of model, and their application was too much time-consuming and costly. Even small changes in model logic, model structure or in output cannot in most cases be done without additional redesigning and reprogramming work. This is too often equivalent to developing a completely new computer program, or system. A port simulation model developed by the UNCTAD (see ref. 7) is a good example of the rigid, unflexible, « classical » simulation technique.

A much more effective solution would be a computer simulation system that is able to process any model of dynamic system. It was therefore assumed that even a general model structure cannot be fixed in advance. A flexible tool should always be available to build such a model structure as required by current needs and according to the amount of available information on simulated system. It means that always the same simulation algorithm should accept any composition of model components as well as their qualitative or quantitative characteristics, and any degree of model aggregation. Elements of the original system should be interpreted by one method, irrespective of kinds and number of items included in the model. Further postulate is that the very simulation algorithm (i.e. simulator) should be fully independent from the model type. The possibility to insert arbitrary heuristic procedures into a model is another essential requirement.

The paper discusses theory of the Modular Simulation, gives a simple example of its application to simulation of seaport systems, and exposes most significant utility features of the technique.

THEORY OF MODULAR SIMULATION OF SYSTEMS

Cybernetic similarity of various systems is the basic source of the concept of the Modular Simulation of systems. This regularity implies the possibility to make logically uniform the method of systems description. If one assumes the possibility of a uniform method of systems interpretation, it is all the more evident in relation to their simulation models.

R. L. Ackoff defines system as « A set of interrelated elements » (ref. 1). Consequently, each dynamic system is a set of purposely organized elements gathered to perform definite activities. There are functional relations between these elements, constant or temporary, in space of time. According to C.W. Bell and R.N. Linebarger (ref. 2) « models are quantitive hypotheses of system behavior ». Every type of model is then in fact some abstraction of real processes, their approximation. Modeling is, according to J. McLeod, « the development of a system, computer or otherwise, which is similar in some pertinent respects to a real world system of interest » (ref. 3).

The problem consists in the technique of conversion of the original system, either real or hypothetical, into its simulation model. Direct conversion of the original system into the model has been most popular practice in various simulation applications, and with simulator adapted to process only a definite type of model, or a narrow class of models. It means that a given element E_m or process P_m existing in model M always remains a simulation copy of an element E_s or process P_s of the original system S, and always performs the same function in the model during the simulation period. That mutual interdependence of model, simulator and original system produces rigid models which are destined for a narrow range of applications.

Much more abstract and synthetic approach is necessary if one aims at developing a simulation tool of versatile use, and independent of the model type.

According to the technique of Modular Simulation the model of a system may consist of :

(i) elements that exist in the original system;
(ii) abstract elements which can exist only in the model;
(iii) human logical decisions;
(iv) real world and abstract processes and events;
(v) variously interpreted states of elements;
(vi) optionally imitated abstract of real world phenomena;
(vii) optional indicators of simulated system behavior;
(viii) model parameters.

All the above listed items which compose the structure of a model may be uniformly defined as modules of simulation model. Modules are smallest and undivisable parts of model structure. Differences between modules become evident when attributes will be assigned to every module, and values of the attributes in an optional way will define distinction of a module in comparison with remaining model modules. It was found that exactly three types of attributes are sufficient to describe a module, namely : attributes of

kind, number, and time. The attribute of kind in a symbolic way defines some distinction of a given component of model structure. The attribute of number is used to store some qualitative or quantitative value connected with a given module. The attribute of time is used exclusively to characterize module in respect of time.

Thus the type of the model is defined by types and values of attributes of modules which create a model. As a result of the specific approach of the Modular technique to the original system there is a feasibility to construct by means of identical « language » models of any kind of either real world or hypothetical system,since each model is treated uniformly as a set of modules differing between each other only with values of respective attributes. Flexibility in model construction is the result of flexibility in interpretation of model modules. To exemplify, let us assume that there are individualized in model X modules A, B, C and D. In an alternative model Y of the same system exists module E which is equivalent to the set of modules A, B, C and D in model X. The example illustrates the degree of model aggregation. Modular Simulation of systems enables therefore to contract or expand model structure depending on purpose of investigation and amount of available data (see fig. 1). It gives the possibility to introduce more details into a current type of model (vertical expansion), or to further develope the model by adding new fragments of the original system (horizontal expansion). A module of a model can be a direct, more or less abstract, copy of element of the original system (see Fig. 2, var. 1). A module of a model can also be an equivalent of more than one element of the simulated system (see Fig. 2, var. 2), and vice versa, one element of the original system can be represented in the model by more than one module (see Fig. 2, var. 3).

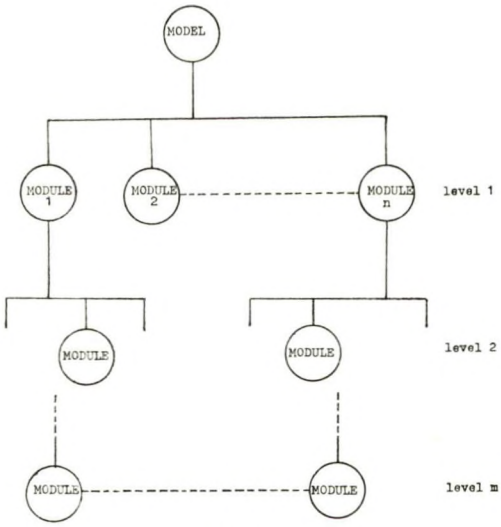

Fig. 1.
Vertical and horizontal breakdown of model.

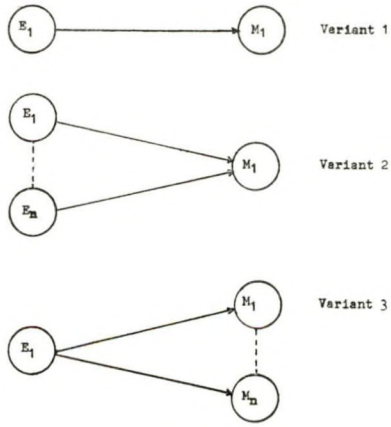

Fig. 2.
Conversion of original system to its simulation model. Basic variants.
E = element of original system.
M = module of simulation model.

The next notion of Modular Simulation of systems are structural patterns of the model, which are the form of organization of the whole imitated system or, in other words, the form of organization of model modules. A structural pattern represents activity of some real or abstract part of an imitated system. The activity is a consequence of definite relations existing in simulated system. Selected modules chained in conditional and modifying expressions are components of a structural pattern which may be regarded as a « genetic code » of system. The attributes of kind, number, and time of modules are subject to conditions and modifications in the pattern. A controlled event occurs in a simulated system if a set of conditions directed at attributes of respective modules is true. The result of an event are quantitative or/and qualitative changes in the imitated system or, in other words, changes of values of respective attributes of the model modules. However, a pattern is false if, at least one pattern conditional expression is false, i.e. there are no circumstances which generate new model structure at a current moment of time. The consequence of satisfying a set of conditions built in a pattern are modifications of values of attributes of kind, number, and/or time of respective model modules. The structural patterns may be considered as the source and mechanism of simulated system dynamics.

General form of a conditional expression of a structural pattern is a follows :

$$M_a \; A_a \; C \; M_b \; A_b$$

where C is a symbol of condition used to compare value of the attribute A_a of module M_a with value of the attribute A_b of module M_b. The symbol C stands for one of the following conditions : equal, not equal, greater than, greater than or equal, smaller than, less than or equal. Conditional expressions of a structural pattern can control occurencies of events of any type, those connected with passage of time, or those generated as a result of existence of definite values of respective attributes of kind and number of model modules. From an other point of view, a conditional expression can control occurencies of events which exist both in the imitated system and its model, or exclusively in the model.

The general form of a modifying expression of a structural pattern is the following one.

$$M_a \; A_a \; O \; M_b \; A_b$$

where O is a symbol of arithmetic operation which performs modification of value of attribute A_a of module M_a by means of value of attribute A_b of module M_b. The symbol O denotes one of the following arithmetic operations : multiplication of current value of attribute A_a by value of attribute A_b, division of current value of attribute A_a by value of attribute A_b, increase or decrease of current value of attribute A_a by value of attribute A_b, or replacing current value of attribute A_a by current value of attribute A_b.

The general form of a structural pattern may therefore look as follows :

$$\begin{array}{lllll} M_{1a} & A_{1a} & C_1 & M_{1b} & A_{1b} \\ M_{2a} & A_{2a} & C_2 & M_{2b} & A_{2b} \\ \multicolumn{5}{l}{\ldots\ldots\ldots\ldots \quad \text{m conditional expressions}} \end{array}$$

$$
\begin{array}{lllll}
M_{ma} & A_{ma} & C_m & M_{mb} & A_{mb} \\
M_{1a} & A_{1a} & O_1 & M_{1b} & A_{1b} \\
M_{2a} & A_{2a} & O_2 & M_{2b} & A_{2b} \\
\cdots & \cdots & \cdots & \cdots & \cdots \quad \text{n modifying expressions} \\
M_{na} & A_{na} & O_n & M_{nb} & A_{nb}
\end{array}
$$

The above general form of a structural pattern may be alternatively represented as a conventional flowchart (see Fig. 3).

As each element of the original system, and consequently, each module of its model serves a predefined purpose, we may assume that there is no one pattern which is completely unrelated to other patterns in the model. In other words, we assume that no structural pattern exists for itself. The effect of the action of one pattern (i.e. its response) remains under permanent control of one or more other patterns, and changes of values of respective modules attributes which occur if a pattern is true, provide an impuls initiating the operation of other unrelated patterns.

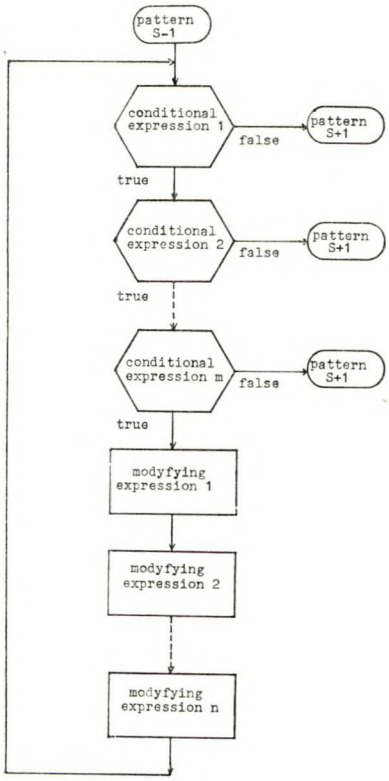

Fig. 3.
Graphical representation of a structural pattern S.

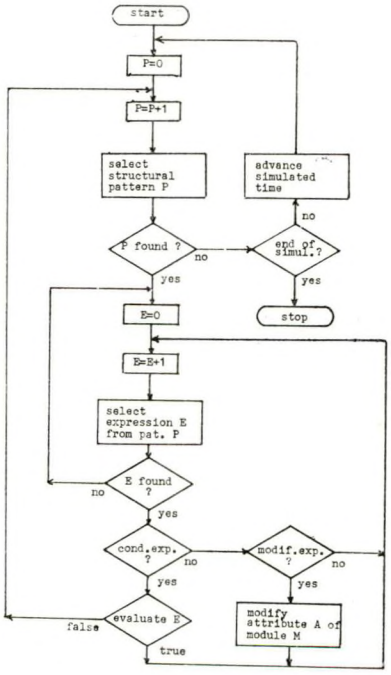

Fig. 4.
Concept of the Modular Simulator.

MODULAR SIMULATOR

Figure 4 illustrates the concept of the simulation algorithm which operates on the base of the above described technique of Modular Simulation of same

systems. We shall call the algorithm the Modular Simulator of the systems.

For each moment of simulated time the Simulator scans all the structural patterns of the model according to a preset priority. Each structural pattern is trying as if it were becoming true. After some pattern P is selected the algorithm control evaluates all included conditional expressions. If all the conditional expressions are true then the whole pattern is true or, in other words, there exist circumstances which permit modifications to be executed. If however any conditional expression is false then the pattern is false and the control is transferred in turn to the next structural pattern, P + 1. The true result of the evaluation generates modifications of values of attributes of kind, number, and/or time of model modules by means of one or more modifying expressions. Each structural pattern is executed as many times as it is true. One of the patterns may be built and included in the model for control of simulation run length. The end of the simulation will occur if conditions of this pattern formulated for a specific model become true. Otherwise the control is passed to the next structural pattern or system time advance procedure which imitates the passage of time in original systems by means of modifications of values of time attributes of all modules existing in the model. After time advance of the imitated system is performed, transfer of the control is executed to the structural pattern of highest priority and the simulation cycle is repeated for a new moment of simulated time.

The algorithm assumes that the passage of time in the simulated system is discrete, and periods of time between consecutive advances of time are usually irregular. It results from the assumption that only specific, essential events occurring with different frequency define consecutive advances in time of the simulated system. The action of time advance procedure in the Modular Simulator starts with the moment when no more changes in the system are observed at some point of time or, in other words, when all structural patterns are false at the moment. The time advance procedure scans all time attributes of the model modules and selects the time attribute with the smallest positive value which means the period of time before the occurrence of earliest controlled event in simulated system. The selected shortest time interval is then subtracted from all other attributes. This operation gives advance of the whole imitated system in time by the found time increment. The imitation of the passage of real time by means of regular time increments may also be done by construction of a special structural pattern, as if a pseudo-clock, which incorporate expressions controlling and modifying time attributes of a chosen module by a predefined equal time interval. This time advance procedure used by the Simulator is one of the well known techniques used to imitate passage of real time (see e.g. ref. 6).

AN EXAMPLE MODEL

Restrictions on the length of papers make it impossible to illustrate the theory of the Modular Simulation with full and practical models. We can there-

fore present only an abstract and simplified fragment of a port model that was constructed following the concept of the Modular Simulation.

Let us assume that we are modeling a bulk cargo terminal equipped with berths type B and loading facilities LF. Ships type S arrive empty and start loading bulk cargo BC as soon as the facilities are available, otherwise they are waiting in queue. For the sake of simplicity we ignore the number of berths and loading facilities available, size of vessels, frequency of their arrivals, etc..

We will select the following modules to construct the model :

Module No.	**Interpretation**
01	Ship S waiting in queue.
02	Ship S loading cargo BC.
03	Free loading facility LF.
04	Busy loading facility LF.
05	Free berth B.
06	Occupied berth B.
07	Cargo BC stored at terminal.
08	Loading time of ship S.
09	Frequency of arrivals of ships S.
10	Comparative module; its number attribute set to zero.
11	Comparative and modifying module; its number attribute set to one.
12	Amount of export cargo BC on ship S.

The above listed modules may be organized in the form of three structural patterns.

Let the first pattern be destined to control arrivals of ships S to terminal. The first and the only conditional expression of the pattern may then be constructed as follows :

M09T EQ M10N

where M will symbolize the module, T signifies the time attribute of the module, N means number attribute, and EQ may be chosen as a symbol for condition « equal ». The expression checks if time attribute of module 09 (frequency of ships arrivals) is equal to number attribute of module 10 (comparative module with number attribute equal zero). If the time attribute of module 09 reaches the value of zero, it signals the moment of arrival of ship S to take cargo BC. Positive value of the attribute would mean the amount of time remaining to next arrival. If the condition is true then respective changes in the model take place, i.e. the values of definite attributes of the modules, are modified. The first consequence of the true result of the condition is an increase in the number of vessels S waiting in queue for free berth B which is executed by the following modifying expression :

M01N + M11N

where + will be a symbol of an operation incrementing value of the number attribute of module 01 (ship S waiting in queue for free berth B) by the value of the number attribute of module 11 (modifying and comparative value equal to 1). The second modifying expression of the pattern is :

M09T = M10N

where symbol = defines substitution of the current value of the time attribute of module 9 (frequency of ships S arrivals) with the value of the number attribute of the same module.

The next in hierarchy will be the pattern No. 2 which initiates the process of loading ship S. It is assumed that three conditions must be fulfilled in order to start loading : (i) at least one ship S is waiting in queue, (ii) there is a free loading facility LF, and (iii) there is an unoccupied berth B. The three criteria of starting the loading process are represented by the following conditional expressions :

M01N GT M10N
M05N GT M10N
M03N GT M10N

where GT is a symbol of condition « greater than ». The pattern will be true if the number attributes of all the three modules (01, 05, 03) will be greater than zero. The following changes in the model will take place if the above conditions are true : there will be a decrease by one of (i) number of ships S in queue, (ii) number of free loading facilities LF, and (iii) the number of unoccupied berths B. This is executed by the following modifying expressions :

M01N — M11N
M05N — M11N
M03N — M11N

where — will be a symbol of arithmetic operation which decreases the current value of the number attributes of modules 01, 05, 03 by the value of one. On the other hand there will also be an increase by one of (i) the number of ships S loading cargo BC, (ii) the number of busy loading facilities LF, and (iii) the number of occupied berths B. These modifications are performed by the following expressions :

M02N + M11N
M04N + M11N
M06N + M11N

which decrease the values of the number attributes of modules 02, 04, 06 by the value of one (i.e. the number attribute of module 11). Te last modification in the pattern no. 2 will be generated by the following expression :

M02T = M08N

This expression will assign loading time value of ship S by substituting the current value of the time attribute of the module 02 (ship S loading) with the value of the number attribute of module 08 (loading time of ship S).

The third and the last pattern in the example will be the structural pattern which controls the termination of the loading of ship S. We will insert only one conditional expression in the pattern :

M02T EQ M10N

The expression checks if the value of the time attribute of module 02 (ships S loading) is equal to the value of the number attribute of module 10 (zero). Loading will be completed when the condition is true. This event will bring about an increase by the value of one : (i) the number of ships S loading cargo BC, (ii) the number of busy loading facilities LF, and (iii) the number of occupied berths B. On the other hand there will be an increase in number of free loading facilities LF, and unoccupied berths B. All the above changes in the model are executed by the following modifying expressions :

M02N — M11N
M06N — M11N
M04N — M11N
M05N + M11N
M03N + M11N

We may add another modification to the pattern namely, the decrease of the total amount of bulk cargo BC currently on stock at the terminal :

M07N — M12N

The above very simplified model may be further developed by adding other modules and new structural patterns which might represent e.g. such phenomena as the influence of weather conditions and tides on port operations, or we may include port services, various types of vessels and cargoes, delivery of cargoes from hinterland, labor, various costs and profits accompanying port activities, heuristic decisions, etc.

The essential feature of the technique is that irrespective of the kind of process, element or phenomena we intend applying to the model, we always use the same « language » of the system conversion into its model.

BASIC UTILITY FEATURES OF MODULAR SIMULATION

(1) The technique of Modular Simulation makes the simulation of systems of an arbitrary structure possible. It means that the degree of model aggregation, types and number of items included in a model as well as the whole logic of a model performance are just input data formulated always according to the same concept and always for the same simulator which remains fully independent from the model. Particularly the simple construction of the simulator may be easily programmed in any computer language. The technique of interpretation of the original system gives a simple and effective tool for an evolutionary (« bootstrapping », see ref. 5) building of very complex and hierarchical models (ref. 4) along with gaining sufficient data about the system being modelled, along with advances in its identification. The Modular technique enables to independently

model and simulate selected fragments of a system and integrate them afterwards in one larger model (« compartmentation », see ref. 5). Elasticity in contracting and expanding model structure up to current needs results from the very concept of modeling. An interesting feature of the Simulator is the possibility of heuristic optimization of the model. Logical decisions which aim at improving model structure and behavior can be incorporated into the model structure by means of structural patterns following the same agreement as all other data.

(2) The technique of Modular Simulation is a simple and easy to handle tool of modeling systems. The model of a complex system may be first represented in the form of a set of conventional flowcharts, each of them illustrating clearly a selected structural pattern (see Fig. 3). After careful checking and analysis, the flowcharts may be coded in the form of conditional and modifying expressions, each of them corresponding to a flowchart element. Even most complex models may be alternatively constructed directly in the form of structural patterns without graphical presentation since the « language » of the conversion of the original system into its simulation model is particularly simple.

(3) Current values of attributes of time and number of the model modules reflect the behavior of the limitated system during the simulation run. Time series produced during the simulation run always consist of identical types of data namely : (i) current value of simulated time, (ii) module symbol, i.e. attribute of kind, (iii) value of number attribute of the module, and (iv) value of time attribute of the module. Uniform in form and contents, and independent of the model type method of recording simulation output enable extreme flexibility in obtaining the required model response. One may formulate demands to output model behavior data of particular interest by means of an arbitrary set of selection and format keys.

(4) The purpose of the simulation is usually to find some optimum or at least an improved model structure of either existing or hypothetical systems. The selection of the best solution by trial-and-error technique with human assistance is cumbersome, uncertain, and uneffective in case of more complex models. An automatic optimizing algorithm operating outside of the model, which analyses current model response and modifies the values of the respective controlled factors taking into account criterion function and restrictions, is usually the best solution in that situation. The uniform form of recording observations about the model behavior processed by the Modular Simulator is particularly convenient just in case of application of an automatic procedure which optimizes stochastic simulation models, since it ensures independence of optimizing algorithm and type of model as well. Besides, components of the model criterion response and controlled factors may be selected at user's option, and N.B. without any changes in simulation or optimization algorithms.

FINAL COMMENTS

The theory of Modular Simulation presented in the paper has been verified in practice with satisfactory results. The author developed the computer simula-

tion system MODUS (abbreviation of MODUlar Simulator) which was used to simulate a number of various seaport and maritime transportation systems. System MODUS was programmed partly in CSL (Control and Simulation Language), and partly in FORTRAN for ICL computer System 4/50.

Further research is being carried on in the following fields :

(i) increase of the computing power of MODUS;

(ii) application of the MODUS system to the simulation of other types of port and shipping models of different structure and purpose;

(iii) application of the MODUS system to modeling and to the simulation of other non-maritime systems;

(iv) investigation of the effectiveness of the MODUS for heuristic optimization of various models as well as in cooperation with mathematical optimizing routines.

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RÉSUMÉ

Le rapport présente une nouvelle conception de la technique de modelage et de simulation sur modèles réduits des systèmes dynamiques, dénommée par l'auteur : **La simulation modulaire des systèmes maritimes.** Cette conception s'est développée comme résultat de l'expérience acquise pendant l'élaboration des projets et de programmes de modèles simulatifs de divers systèmes de la gestion des ports et de la navigation maritime, destinés à résoudre de larges problèmes concernant les projets, le contrôle, le programming et les pronostics du développement de ces systèmes.

Les projets et le programming classique des systèmes simulatifs d'ordinateur, élaborés séparément pour chaque genre de modèle, et pour chaque objectif d'investigation se sont révélés

par trop laborieux et coûteux. Une solution beaucoup plus effective au point de vue de l'applicabilité en pratique et des frais de réalisation représente un seul système simulatif d'ordinateur apte à transformer un modèle d'un système dynamique quelconque. On a adopté le principe que la composition du modèle du système ne peut être fixée d'une manière invariable. Par contre il doit exister une possibilité de composer un tel système modulaire, qui donne satisfaction au but et aux exigences courantes de recherche en permettant l'obtention des renseignements désirés. Cela signifie que toujours le même algorithme simulatif doit accepter une conception quelconque de la nature des composants du modèle, de leurs caractéristiques quantitative et qualitative et du degré de l'agrégation du modèle. La méthode d'interprétation des composants originaux des systèmes doit être toujours identique, sans tenir compte de la nature et du nombre des composants inclus dans ce modèle. L'algorithme simulatif, c'est-à-dire le simulateur, doit être absolument indépendant de la caractéristique de la variante donnée du modèle. Un autre principe essentiel adopté dans la conception de l'algorithme universel simulatif est son aptitude d'imitation de différentes décisions humaines, qui peuvent ou doivent intervenir dans les systèmes originaux en dépendance de la situation simulée dans le modèle et cela dans le but d'améliorer ou de régler certains processus.

Dans le présent rapport le côté théorique de la simulation modulaire est discuté et un bref exemple de l'application de la simulation d'un système portuaire avec les avantages de son application sont présentés.

S. II - 5

RAPPORT

par

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INFORMATIQUE DE GESTION PORTUAIRE

I. INTRODUCTION

1. L'accélération continue des progrès de la technologie navale et l'application de nouvelles modalités de transport, résultant d'une spécialisation croissante, ont mis en service, sur les voies de navigation, une série de navires qui associent, à leurs périodes réduites d'amortissement, plutôt pour des impératifs techniques qu'économiques, une structure de coûts d'exploitation réclamant impérieusement un haut niveau de productivité, permettant d'atteindre une rentabilité convenable.

En même temps, en alternative avec l'évolution navale mentionnée, que ce soit à titre de précurseur ou à la remorque de celle-ci, se produisent des changements continus de structure et de rapport dans les processus de manutention de marchandises, avec une tendance fortement marquée vers la rationalisation de produits et de méthodes.

Les ports, support structurel des processus dont le développement a été schématisé précédemment, réclament dans leur gestion, l'utilisation de moyens et de techniques adéquats qui permettent, tant au niveau global qu'aux différents échelons fonctionnels et opérationnels, de prévoir, de développer et de contrôler le complexe portuaire et son trafic.

Il s'agit donc, sur le plan opérationnel, de passer d'un système de simple obtention de données à des fins historiques et d'élaboration intuitive de tendances et de décisions, au traitement systématique de l'information vivante que pourraient fournir ces données, à une révélation de tendances qui permette une prise constante et actualisée de décisions à court terme, et sur le plan fonctionnel à

l'établissement de structures de planification à long terme permettant de formuler des politiques de développement portuaire et de prendre des décisions visant la rentabilité de la chaîne du transport dans la zone portuaire.

Ce traitement systématique, programmé et permanent à tous les niveaux, issu d'un ensemble de théories et de techniques basées sur le calcul électronique, constitue l'informatique et son application, en l'occurrence pour résoudre les problèmes de gestion et d'administration des ports, donne lieu à ce que nous avons dénommé « *Informatique de gestion portuaire* ».

2. La gestion et l'administration des ports comprend les problèmes posés par quatre secteurs fondamentaux :

— Planification portuaire.
— Elaboration et construction d'ouvrages.
— Exploitation portuaire.
— Rapport avec les économies externes.

à propos desquels on développera ensuite les applications éventuelles de l'informatique de gestion.

A. **Planification portuaire.**

1. La planification, arme primordiale de la stratégie de gestion dont le rôle fondamental est le développement de politiques devant permettre d'atteindre des objectifs à long terme, se nourrit à la base :

a) d'une information synthétisée dont on peut extraire des tendances amenant une prise de décisions à niveau global, et

b) de structures permettant d'embrasser un champ visuel le plus ample possible, de telle sorte que ces décisions aient des effets sur un plan équilibré où se trouvent intégrés tous les intérêts et économies relatifs au port.

C'est ainsi par exemple, que les objectifs permanents et à long terme constitueront l'optimisation des voies de transport qui passent par le port et des processus de manutention des marchandises qui les utilisent, la programmation échelonnée présentant des possibilités d'actualisation permanente, des plans de développement et d'investissement des ressources dans les ports et la correction de déséquilibres grâce au montage d'instruments adéquats, capables de les prévoir et de les détecter.

2. Dans ce but, l'information à recueillir en vue de son traitement ultérieur comprendra des données précises pour déterminer les tendances sociales, économiques et industrielles de l'environnement portuaire, les tendances se manifestant dans le développement du trafic mondial et interzonal, dans la technologie navale et dans les processus de manutention des marchandises; il s'agira donc d'une information vivante, orientée vers l'avenir, synthétisée, comportant de nombreux processus d'exception couvrant de longs termes, l'accent étant mis sur la précision en matière d'estimations plutôt que sur les réalisations.

L'incidence de ces tendances, examinée théoriquement comme « inputs » d'un système, se traduira en modèles de simulation de processus portuaires tant fonctionnels qu'opérationnels qui, programmés avec flexibilité adéquate, permettraient de formuler des plans de développement à court et à long terme, de planifier des investissements et de programmer des changements structurels.

3. On a parlé d'une « *flexibilité adéquate* » du modèle, ce qui constitue réellement l' « *échelle* » de celui-ci, d'accord concordant avec l'importance et l'étendue du problème. Traiter de celui-ci d'une façon générale, c'est-à-dire produire un modèle très flexible, est une tâche très difficile, non seulement en raison de la complexité propre du port considéré globalement mais aussi de par ses multiples rapports avec des économies externes et son incidence économico-politique comme infrastructure d'un service public national, ce qui conduirait même à l'étudier dans son rapport avec d'autres ports et d'autres réseaux de transport.

C'est la raison pour laquelle une première estimation, malaisée à faire, consisterait en l'établissement d'un modèle de port, considéré comme un système fermé et intégré, en tout cas, dans une série de sous-systèmes qui constituent des unités naturelles de développement et d'investissement et dont le processus opérationnel soit le plus indépendant possible de celui d'autres sous-systèmes.

4. Dans l'ensemble, on analyse les décisions à prendre par périodes, et les possibilités d'application de plans de développement et des critères d'investissement annexes, ainsi que les problèmes posés par les changements structurels et leur solution :

a) dans le schéma existant d'installations portuaires;

b) en modifiant celui-ci.

Comme inputs du système figurent, entre autres, les volumes de trafic et les fréquences d'arrivées, les données physiques et économiques du port et de sa zone d'influence et celles des moyens de transports maritimes et terrestres qui utilisent le port, ainsi que la prévision de leurs modifications technologiques.

Les outputs du modèle sont constitués, de façon synthétisée, par l'information obtenue pour évaluer les alternatives du développement de l'investissement, ses coûts (capital et main-d'œuvre) nécessaires dans chaque cas.

5. On effectue, au sein du système, des processus itératifs de simulation qui, en premier lieu, essayent de couvrir toute la gamme de combinaisons possibles de développement à l'échelle totale, en appliquant les plus intéressantes aux différentes parties du système et en construisant, pour elles, des modèles de temps et de coûts entrainés par des navires et des marchandises à leur passage par les différents échelons portuaires, tels que le pilotage, la remorque, l'accostage, le chargement et le déchargement aux différents quais, les diverses classes de stockage portuaire et l'enlèvement par divers moyens de transport par terre.

6. Naturellement, un système de ce genre est beaucoup plus facile à exploiter s'il s'agit d'obtenir des alternatives à court terme pour améliorer les conditions

existantes dans une structure donnée car les prévisions de trafic et de technologie sujettes à fluctuations introduisent dans les études d'alternatives à long terme, des facteurs très aléatoires. D'autres part, l'optimisation économique suppose l'établissement de critères dont la formulation n'est pas facile à classer dans des suppositions préalables et prédéterminées.

B. **Élaboration et construction d'ouvrages.**

1. En ce qui concerne l'élaboration et la construction d'ouvrages portuaires, l'emploi du calcul électronique ne présente pas, en général, d'aspects particuliers qui le différencient des autres branches du génie, en raison de la nature des travaux en cause. Il peut donc être employé dans des calculs de structures, d'évaluation économique de projets, de critères d'investissement et de réseaux de programmation, d'exécution et de contrôle de travaux, entre autres.

2. Cependant, il existe des applications de l'informatique dans des domaines très spécifiques de la technique portuaire, comme par exemple dans le projet des grands ouvrages d'abri, dont nous parlerons plus loin.

C. **Exploitation portuaire.**

1. Le domaine de l'exploitation portuaire convient très bien pour développer amplement les activités propres de la logistique fonctionnelle et des tactiques opérationnelles, qui contribuent à la prise de décisions à court et à très court terme, afin de satisfaire à des objectifs tels que le développement et le contrôle d'opérations, le processus productif, le contrôle des coûts, la rationalisation de processus de manutention et tant d'autres qui constituent l'activité quotidienne du port dans ses aspects techniques et économiques.

Un des « inputs » fondamentaux de l'informatique d'exploitation est constitué par la statistique, non orientée vers l'avenir comme révélatrice de tendances, ce qui est propre au niveau stratégique déjà traité, mais orientée vers le passé; en détaillant les processus antérieurs, leur résumé, et en couvrant de courtes périodes, on pourra ainsi obtenir des données relatives aux marchandises, qui seront classées selon les valeurs, l'origine et la destination, ainsi que des navires avec leurs caractéristiques techniques, frêts, processus opérationnels, productivité, délais et autres. Les données intéressantes concerneront l'occupation de superficie couverte et découverte, la durée des stockages, les moyens de transport par terre et le processus opérationnel.

2. A l'aide de toutes ces données, qui permettent de composer des schémas opérationnels de génération de trafics, on peut établir des modèles mathématiques ou de simulation pour :

a) Déterminer des coûts associés à certains trafics spécifiques qui, dans leur processus, permettent de rattacher les ports à leur zone d'influence, de planifier

les terminaux et leur connexion avec les voies terrestres et maritimes, et d'établir des entrepôts intérieurs.

b) Établir des modèles de simulation qui, par l'emploi de techniques propres de la recherche opérationnelle, étudient la planification intégrale de nouvelles installations portuaires, programment les besoins en main-d'œuvre et en outillage et permettent de fixer rationnellement les options devant améliorer les terminaux ou modifier leur emplacement, les remodeler ou les abandonner, augmenter leur facteur d'utilisation ou en construire de nouveaux comme solution anticongestive et, enfin, d'étudier des problèmes tels que la situation de magasins, les zones d'entrepôts et l'établissement de zones viables.

c) Contrôler les aspects physiques des opérations portuaires tels que l'interconnexion des processus de chargement et de déchargement, les systèmes de mouvement et la progression des chargements sur les superficies d'entrepôts et de magasins, le processus d'enlèvement et la remise des marchandises aux moyens de transport par eau, le contrôle de la congestion des superficies et les mesures préventives en employant des méthodes de rationalisation ou de tarification et autres.

d) Développer et contrôler les processus administratifs de gestion tels que la comptabilité générale et analytique, le contrôle budgétaire, les coûts d'entretien normal et préventif de l'outillage, le contrôle du personnel, l'inventaire permanent de marchandises au port et la liaison avec la statistique générale; faciliter le processus d'enregistrement, tenir les comptes des usagers et obtenir des données pour leur emploi dans les calculs de rentabilité, tout cela conçu dans un processus général d'aide à la direction.

3. Naturellement, l'exposé de ces modèles se complique progressivement, même pour le traitement électronique, à mesure que son rapport avec le processus réel est plus étroit. D'une façon générale on doit apporter des simplifications et, bien que celles-ci diminuent leur exactitude, elles permettent une utilisation dans le domaine économique propre de l'informatique.

Certaines simplifications sont apportées, dans des cas spéciaux, par la nature homogène du trafic ou les conditions particulières qui modèlent leur processus d'une façon rationnelle, comme, par exemple, dans le cas de la conception et de l'exploitation d'un terminal de containers, où l'on peut procéder à des études telles que le contrôle individuel des unités et de leur situation temporaire dans la chaîne de transport, la programmation du plan de chargement le plus favorable au moyen d'éventuelles permutations par rapport aux ports d'escales, l'étude de l'entreposage le plus rationnel dans les parcs en vue d'un enlèvement programmé en rapport avec le processus d'arrivée des moyens terrestres d'enlèvement et de retrait et, en dernier lieu, l'étude de simulation du processus intégral d'où puissent découler l'information sur la vitesse de rotation des bâtiments, le facteur d'utilisation des quais, les temps moyens de manutention et d'emmagasinage, et même la détection des tendances apparues de l'impact de cette modalité de transport sur le trafic, la puissance du travail et le développement régional.

D. **Economies externes.**

1. Enfin, et en ce qui concerne la relation du port avec les économies externes dans un processus global, l'arme de l'informatique permet de programmer des modèles de coût analytique dans un système de transports intégré, dont l'objectif primordial est de sélectionner la chaîne de transport la plus adéquate sous le rapport d'une marchandise donnée en volume, en nature, en fonction d'une flotte prévue et du coût des frets et des alternatives de ports d'arrivée ainsi que des zones et moyens de réception et d'expédition terrestres.

Cet objectif sera atteint par l'évaluation et la comparaison en un processus itératif, des opérations successives, des flux de trafic et des décisions concernant l'exploitation et le financement.

2. C'est ainsi que pourront être abordés, en ce qui concerne les infrastructures, des problèmes tels que le nombre optimum de ports du système, la ventilation du trafic parmi ceux-ci, les possibilités de leur liaison avec d'autres moyens de transport, le choix de l'équipement portuaire le plus convenable et le développement opérationnel et à long terme. Du point de vue de l'usager, on considère le type et la classe de marchandises à transporter économiquement, la composition optima de la flotte, l'itinéraire et la structure la plus appropriée des frets.

Tout cela se fera en posant le problème dans ses grandes lignes car s'il s'agissait uniquement du développement d'un modèle moins flexible, on pourrait étudier des problèmes plus spécifiques comme les mouvements quotidiens et les itinéraires de la flotte, les processus d'un terminal en combinaison avec les schémas d'avis préalable des moyens de transport et les déviations des prévisions et leur correction.

3. Et même si ces études pouvaient uniquement s'effectuer avec des temps différés d'ordinateur on pourrait aboutir, dans un cas particulier, au traitement en temps réel du problème, avec des systèmes de téléprocessus des données permettant l'utilisation immédiate de l'information dans l'adoption de décisions sur la correction de déviations, les changements d'itinéraires, voire d'options pour la signature de contrats d'affrètement.

E. **Niveau d'utilisation.**

1. Tous ces instruments, que l'informatique de gestion appliquée aux ports permet de développer, est en principe indépendante de la production de machines applicable dans chaque cas, qu'elles soient ou non la propriété de l'organe de gestion et quel que soit le processus d'utilisation individuel ou centralisé, car tout cela conduirait au difficile problème de l'établissement d'une proportion convenable entre le genre d'études demandé par la gestion portuaire et les possibilités techniques et économiques d'exploitation, avec des moyens propres ou provenant de l'extérieur et suivant quels degrés d'autonomie.

II. APPLICATIONS

En ce qui concerne ce que nous avons exposé plus haut, nous allons traiter ci-dessous, d'une façon résumée mais suffisamment nette, trois cas pratiques correspondant aux sujets A, B et C du chapitre I, c'est-à-dire de ceux qui se rapportent à la planification du projet et à l'exploitation des ports.

A. — MODÈLE DE SIMULATION D'OPÉRATIONS PORTUAIRES

1. Les systèmes analytiques actuels de prévision du degré de congestion et d'occupation d'installations portuaires, basés sur la théorie des queues qui tout en étant une arme estimable, se heurte à de grandes limitations principalement en raison de la spécialisation accrue et l'augmentation des dimensions des navires, exercent une influence considérable sur la vitesse de rotation en rapport avec les lois d'arrivée et les temps de service, se répercutant ainsi sur la durée des séjours dans le port.

   La prise en considération du genre et les dimensions des navires, l'influence des rendements de manutention, les systèmes de transport terrestre et leur connexion avec les zones d'entrepôts, rendent impossible, dans la plupart des cas, l'étude analytique du problème, considéré dans son ensemble.

2. C'est la raison pour laquelle des techniques de simulation d'opérations basées sur des modèles mathématiques, prévoyant l'aide opérationnelle des ordinateurs, se développent de plus en plus. Le système optimum qui devrait être instauré, non pour un exposé préalable mais précisément par l'analyse du modèle, dépend fort de la véridicité des données d'entrée et du caractère rationnel des prévisions. D'où l'importance qu'il y a de compter sur des données statistiques de qualité, comprenant des fréquences d'arrivées de navires, de séjours de ceux-ci, des temps opérationnels et d'utilisation d'équipements, tout cela selon la catégorie et les dimensions des navires. Il s'agit simplement de connaître le passé d'une façon la plus exacte possible afin de prédire l'avenir, non par simple extrapolation, mais aussi comme résultat des variations introduites dans le temps par la propre technologie.

Le schéma le plus général d'un modèle de simulation comporte les parties suivantes :

— Sections de réception des navires;
— Sections opérationnelles;
— Zones de manutention et d'entrepôts;
— Systèmes de transport terrestre;
— Zones d'emmagasinage dans l'hinterland.

La complexité du modèle dépendra essentiellement du nombre de sections dont l'étude sera abordée simultanément, et du soin avec lequel seront examinées

les opérations relatives à chacune d'elles. ce qui influera sur l'analyse. la programmation et le temps d'opération dans l'ordinateur, L'attaque du problème par le traitement d'une partie fondamentale du processus (comprenant les deux premières sections) et l'obtention de processus acceptables d'exploitation permettront l'entrée rationnelle dans ce jeu passionnant, sans complications initiales excessives en fournissant ainsi un outil de travail qui permettra d'entreprendre plus tard le développement d'un modèle plus audacieux. Le premier pas consisterait à observer le déroulement des accostages prévus dans une première phase, en passant ensuite à la seconde (encore à l'étude) de sa liaison avec les processus séquentiels des zones de manutention et d'entrepôt.

En partant de cette idée initiale, on a réalisé le modèle qui est décrit ci-dessous et dont le comportement a été satisfaisant. Il a été programmé en FORTRAN IV et son temps moyen d'exploitation sur machine est à peu près de 1 minute par hypothèse étudiée.

Description du modèle.

Pour le calcul des valeurs statistiques opératives des installations de deux terminaux portuaires, on a employé un modèle mathématique, les hypothèses étant les suivantes :

— Les deux terminaux peuvent avoir une longueur (et par conséquent un nombre de postes d'accostage) non limitée.

— On a créé une zone de mouillage, contiguë aux terminaux et commune pour les deux, d'une capacité déterminée et sans aucune limitation.

— Lorsqu'un navire entre dans un port et n'a pas de possibilité d'accostage (soit parce que le port est totalement ou partiellement occupé), il attend dans la zone de mouillage; si celle-ci est également occupée, il le fait dans la baie (zone dénommée rade).

— Les intervalles d'arrivée de navires dans chaque période saisonnière, sont soumis à des fluctuations imprévisibles, conformément à une distribution d'Erlang (généralement K = 1, mais adaptable à un K quelconque).

— Les variations saisonnières à l'entrée et à la sortie des marchandises, la distribution des volumes de chargement par bateau ainsi que la distribution de la grandeur des navires (facteurs déterminant leur tonnage et leurs dimensions) peuvent suivre une loi quelconque, bien qu'elles s'adaptent préalablement à des variations linéaires.

— Les temps de service s'adaptent à une distribution d'Erlang (K = 1 à 00), dont le temps moyen est déduit conformément au volume de chargement à transborder et aux moyens de chargement disponibles. Cette distribution comprend, en outre les variations du service dues à des causes non imputables aux installations, telles l'insuffisance de capacité d'emmagasinage, les vices de l'équipement, de l'entretien, et autres.

— Les temps d'attente dans la baie et le mouillage sont définis comme représentant le laps de temps compris entre l'arrivée du navire dans la baie ou zone de

mouillage et le moment où il est accepté dans la zone du quai. On ne tient pas compte de l'absence de remorqueurs, de pilotes, de douaniers.

— Chaque navire est réparti dans l'accostage spécifique en fonction de la norme de priorité d'arrivée et selon la spécialisation de chaque poste d'accostage.

— La période de délibération du modèle est de 3 heures (8 périodes jour) en arrondissant par excès au suivant.

La convergence du modèle exige des périodes de simulation variables, et l'on estime que celle-ci est obtenue lorsque les données de base d'entrée s'écartent de ± 10 % des résultats de base du départ.

Fonctionnement du modèle.

Les données relatives à l'*entrée* sont les suivantes :

— Tonnages à manutentionner dans la période considérée, à chaque terminal ;

— Loi de variations de ces tonnages au cours du temps;

— Lois de distribution de la grandeur et des dimensions de chacun des types de navires, et leurs tonnages moyens;

— Lois de distribution des volumes de chargement à transborder selon le type de navire;

— Rendement des installations de chargement et de déchargement;

— Distribution des temps de service. (Le modèle travaille avec des fonctions Erlang pour toute valeur de K; on doit donc déterminer la valeur K correspondant à la distribution observée);

— Période comprise dans la simulation;

— Il n'est pas tenu compte des jours fériés ou chômés et l'on incorpore en outre les arrêts de travail nocturnes dans les rendements quotidiens des installations.

Les données de *sortie* que fournit le modèle sont les suivantes :

La séquence optionnelle de tous les navires et de chacun d'entre eux, lesquels interviennent dans le système, classés selon leur période de départ, en indiquant pour chacun :

— le moment d'entrée et de sortie dans le système;

— le type du navire;

— le temps d'attente, dans la baie et dans la zone de mouillage;

— le temps de service;

— le volume du chargement transbordé;

— le tonnage du navire (TPM);

— le nombre de navires de chaque type entrés dans le système;

— les temps totaux d'attente et de service par type de navires;

— les tonnages de marchandises déplacées au cours de la période de simulation, pour chaque type de navire;

— le nombre de navires qui attendent un certain nombre de périodes et le nombre de périodes dans lesquelles il y a un certain nombre de navires en attente.

Nous présentons maintenant l'analyse d'une des multiples simulations réalisées :

On a étudié le comportement de deux terminaux, une pour céréales, l'autre pour containers, les données de base étant les suivantes :

— Tonnage annuel de grain à déplacer : 2.000.000 Tm.

— Tonnage annuel de containers : 1.700.000 Tm.

Variation dans le temps des tonnages de chargement et déchargement.

	Céréales	*Containers*
Janvier	15.000	uniforme sur toute l'année
Février	30.000	
Mars	40.000	
Avril	50.000	
Mai	120.000	
Juin	260.000	
Juillet	400.000	
Août	370.000	
Septembre	290.000	
Octobre	215.000	
Novembre.	140.000	
Décembre	70.000	

Nombre de postes d'accostage par terminal.

Terminal pour céréales : 1 poste.
Terminal pour containers : 2 postes.

Ventilation de la grandeur des navires.

Navires pour marchandises en vrac		*Navires pour containers*	
TPM (moyen)	Fréquence (%)	TPM (moyen)	Fréquence (%)
3.700	26	600	21
13.000	26	3.200	14
22.500	21	4.700	28
30.000	10	6.600	15
38.200	11	9.300	16
51.400	5	12.600	6
62.000	1		

Lois de distribution de chargement à transborder.

Volume à transborder = FC × TPM.

Navires pour marchandises en vrac		*Navires pour containers*	
FC	Fréquence (%)	FC	Fréquence (%)
1,00	100 %	0,4 0,8 1,2 1,6	25 % 25 % 25 % 25 %

Rendement des installations :

Terminal pour chargement de céréales : 38.400 tonnes/jour.

Terminal pour containers (3 grues) : 1.344 containers de 12 tonnes/jour.

Distribution des temps de service :

Distribution d'Erlang pour K = 2 (aux deux terminaux).

Période de simulation : 1 année ∿ 2.400 périodes
(équivalant à 300 jours ouvrables par an).

Chronologie d'entrée et de sortie du système.

Navires	Période	Période	Type	Périodes de séjour en			Tonnage de	Tonnage du
Nombre	Arrivée	Sortie		Rade	Mouillage	Quai	CA-DE	navire
451	2360	2366	2	0	0	6	7440	9300
452	2361	2364	2	0	0	23	14880	9300
453	2376	2386	2	0	0	10	5640	4700
454	2386	2392	2	0	0	6	7520	4700
455	2390	2393	1	0	0	3	13000	13000
456	2396		2	0	0	4	11160	9300
105			1	0	84	495	1909300	
	Temps moyens			0.0	0.80	4.71		
351			2	1	449	2139	1700452	
	Temps moyens			0.00	1.28	6.09		

Tableau de navires par nombre de périodes d'attente.

Périodes	*Type* [1]	*Type* [2]
0	82	267
1	6	21
2	6	9
3	4	9
4	2	4
5	2	9
6	1	7
7	0	3
8	0	4
9	0	3
10	1	1
11	0	2
13	0	5
15	0	1
16	0	1
17	0	3
20	1	0
22	0	1

Tableau de périodes par nombre de navires en attente.

Navires en attente	*Périodes*
0	2061
1	226
2	66
3	20
4	20
5	6
6	1

Les résultats de la simulation figurent aux tableaux ci-contre que nous allons analyser :

	Terminal pour	
	Céréales	*Containers*
Temps moyen service (heures)	14,1	18,3
Temps moyen d'attente (heures)	2,4	3,8
Temps d'attente/temps service	0,17	0,21
Pourcentage de navires qui n'attendent pas	78,1	76,1
Marchandises (tonnes)	1.909.300	1.700.452
Congestion.		
Heures sur l'année pendant lesquelles il y a 1 ou plusieurs navires en attente		1.017
Facteur de congestion : 14,1 %		

Les graphiques des figures 1, 2 et 3 représentent la loi d'attente des navires, ainsi que le pourcentage de journées annuellement pendant lesquelles un certain nombre de navires restent en attente.

Afin de vérifier l'exactitude de la simulation on compare ensuite certaines données de sortie du modèle aux données d'entrée de base.

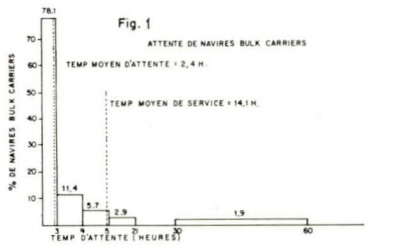
Fréquence d'arrivées de navires.

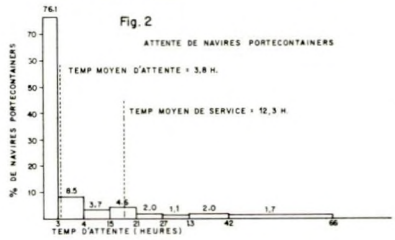
A partir des données de mouvements de marchandises et une fois connue la valeur moyenne de la grandeur du navire, on a déduit théoriquement les lois d'arrivée de navires, mensuellement.

Aux graphiques des figures 4 et 5 on a représenté ces valeurs tant partiellement qu'accumulées, pour les données théoriques et les données simulées.

Ventilation des temps de service.

Au graphique de la figure 6 on a représenté la courbe théorique Erlang K = 2 ainsi que les résultats de la simulation des temps





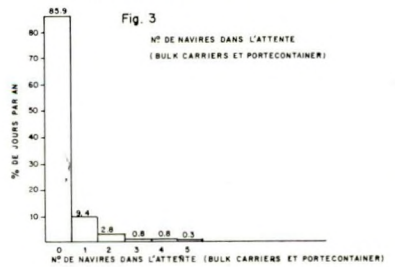


Fig. 4

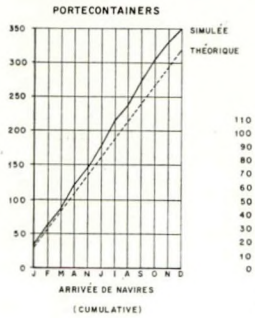


Fig. 5

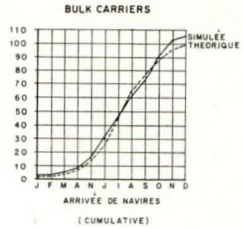
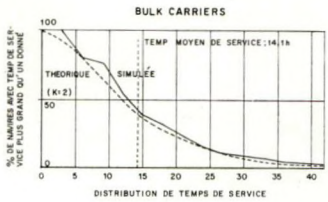


Fig. 6



de services du terminal pour céréales.

Comme on peut le constater, le réglage de celles-ci indique un degré d'exactitude acceptable.

B. — APPLICATION AU PROJET D'OUVRAGES PORTUAIRES

1. Au point de vue du génie portuaire et des côtes, il est absolument intéressant de disposer de l'instrument statistique adéquat, permettant de connaître le pourcentage de temps que la vague signifiante (H 1/3) dépasse pour l'année moyenne (régime de houle) et la fréquence à laquelle surviennent les tempêtes, quelle que soit leur durée, la hauteur de vague signifiante maximale étant égale ou supérieure à une certaine valeur (régime de tempêtes).

En même temps qu'une connaissance précise de la vague de calcul, à appliquer en fonction des caractéristiques de l'ouvrage (rigide, flexible), il est très important de disposer de l'information nécessaire et de son traitement adéquat pour connaître et analyser le spectre de la houle, déterminer son énergie (de plus en plus importante pour la technique d'essais sur modèle réduit) et établir des rapports valables entre la vague caractéristique, la vague maxima et l'énergie totale.

2. En l'occurrence, on a procédé, en Espagne, tout au long de l'année 1972, à l'établissement d'un réseau extérieur devant servir à mesurer et enregistrer la houle, qui comprend en principe 10 points à des profondeurs supérieures à 50 mètres, en plaçant sur chacun et à une profondeur de 15 mètres, un appareil qui, par des différences de pression, enregistre la hauteur de la vague et la transmet au moyen d'un câble (d'une longueur non supérieure à 2 milles) vers la terre. C'est ici que se caractérise ce dispositif. Le signal est codifié et transmis par radio (fréquence modulée) au poste télégraphique le plus proche et, de celui-ci, par des lignes à 200 baudies, à une station centrale réceptrice qui se trouve au Laboratoire des Ports « Ramon Iribarren » à Madrid. Dans cette station centrale, les signaux peuvent être enregistrés sur bande magnétique à 14 circuits ou être introduits dans un ordinateur

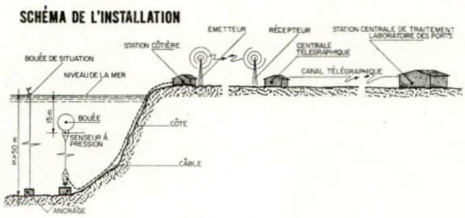


Fig. 7.

analogique ou analyseur de Fourier. Le fonctionnement des appareils à pression peut être commandé de la station centrale, l'ordinateur travaillant alors en temps réel, ou bien enregistrant toute particularité qui se manifesterait subitement en mer, pour son envoi ultérieur et son analyse par ordinateur. (Figure 7.)

3. L'analyseur de Fourier effectue des analyses de données digitales de fréquence et de temps dans l'intervalle 0-25 KHz, avec des signaux continus ou provisoires. Le calculateur, qui utilise le système pour le calcul et l'accumulation de données et de programmes, a une mémoire comportant 8.000 mots et a la possibilité de doubler ce chiffre et d'échantillonner des blocs de 4.096 mots. Le système dispose de 70 instructions de base et même de 8 instructions pouvant être microprogrammées en un seul mot. La mémoire est magnétique et chacun des mots a 16 débits, le temps du cycle étant de 1,6 microsecondes.

Le système d'entrée et de sortie est doté de 18 circuits, tous bidirectionnels et, parmi les fonctions déjà programmées et pouvant être obtenues par une simple pulsation, on trouve : transformation de Fourier directe ou inverse, autocorrélation et corrélation croisée, multiplication complexe, différentiation et intégration et opérations de base.

Le spectre de puissance nécessite seulement deux appuis. Cette faculté qu'a le système de mémoriser les passages du programme est très utile dans des opérations répétitives comme l'établissement de la moyenne, dans lequel une certaine sous-routine doit être suivie dans un certain nombre de passages. Au total, 200 pulsations peuvent être accumulées dans la mémoire de l'analyseur, pour être effectuées autant de fois que nécessaire.

Le clavier est doté de 6 positions de correction, lesquelles donnent accès à un correcteur emmagasiné dans la mémoire, de sorte qu'une séquence de passages composant un processus automatique de mesure peut être modifiée « on line » sans nécessité de correction « of line ». En outre, une série de passages de programmes nécessaires pour effectuer une opération déterminée peut être enregistrée sur ruban en papier perforé, afin de faciliter une nouvelle entrée dans l'analyseur.

Les données d'entrée et de sortie sont également contrôlées au clavier. L'information peut être introduite d'une façon analogique ou digitale, soit directement de la propre source d'information, soit au moyen d'un ruban magnétique ou perforé, soit d'une façon manuelle au départ du clavier. L'information peut être introduite d'une façon analogique par le converseur analogique digital, qui accepte une ou deux entrées simultanées (la double chaîne est nécessaire pour le calcul du spectre croisé de puissance, de la fonction de corrélation croisée et de toute fonction nécessitant deux signaux temporaires). Quand on opère sur une double entrée, les deux signaux sont échantillonnés simultanément.

Les résultats de toutes les opérations apparaissent sur l'écran de l'oscilloscope, qui reste constant et automatiquement calibré. Comme il importe parfois de garder copie de la figure exposée sur l'écran de l'oscilloscope, l'analyseur de Fourier dispose d'une sortie analogique permettant de dessiner sur un enregis-

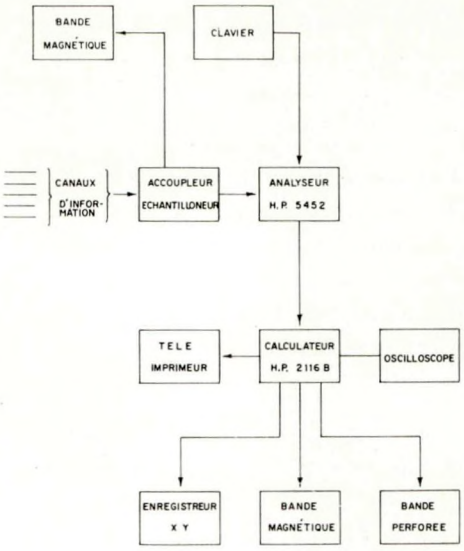


Fig. 8.

Station Centrale — Laboratoire des Ports « Ramon Iribarren » — Diagramme bloc.

treur x-y tous les points de l'écran cathodique à une vitesse de 50 points/seconde. D'autre part les résultats peuvent être enregistrés sur un télétype ou sur ruban magnétique ou perforé.

Un diagramme bloc de la station centrale est représenté à la figure 8.

C. — APPLICATION A L'EXPLOITATION PORTUAIRE

L'intérêt qu'elle présente est de vérifier les problèmes qui se posent aux premières phases du traitement, l'objectif étant de disposer de moyens propres.

Afin de résoudre les problèmes posés par le traitement d'un grand volume d'informations telles que les différents enregistrements, les statistiques et les états de salaires de son personnel, la « Junta del Puerto de Barcelona » utilise depuis quatre ans les services d'un Centre de Calcul, ne faisant pas partie de son organisation.

Le système développé n'est pas satisfaisant, de sorte que la critique et sa future programmation peuvent être intéressantes des points de vue suivants :

1° Situation actuelle, fondamentale, du processus de données.

2° Quel est le procédé de processus de données le plus recommandable.

1. **Situation actuelle.**

Actuellement deux applications mécanisées sont en vigueur :

1. Facturation et sous-produits — Statistiques.
2. Etat de salaires

tous deux posant des problèmes très différents. D'une part, la facturation est caractérisée par sa grande complexité — grand nombre de tarifs à appliquer avec différente base, grand nombre de statistiques comme sous-produit et comptabilité de la recette à contrôler —, et d'autre part l'état des salaires, qui, bien qu'étant d'un volume appréciable — 211 pour le personnel technique et administratif et 650 pour les ouvriers — comporte un processus relativement simple.

Nous analysons ensuite, séparément, chacune des applications.

1.1. **Facturation.**

La plupart des données sont perforées dans le port sur une bande en papier et traitées de manière adéquate par l'ordinateur du Centre de Calcul, elles donnent ensuite lieu aux liquidations, quittances et statistiques.

Théoriquement le processus et l'analyse de cette application sont corrects bien que, logiquement, divers points puissent être améliorés; cependant, on ne peut pas dire que les résultats obtenus sont satisfaisants; 15 % à peu près d'erreurs sont découvertes « a posteriori », ce qui représente un pourcentage inadmissible pour un procédé correct de processus de données, surtout s'il s'agit d'une facturation de la répercussion économique en question.

Les quittances passées à l'encaissement, bien que peu nombreuses (environ 350 par mois) constituent le résumé d'une grande quantité de liquidations de traitements très différents et rendent très complexe l'ensemble total. Nous considérons donc comme très important :

a) Que les données initiales fournies à la machine, qui interviendront ensuite dans divers processus et statistiques, soient garanties et exactes.

b) Que les programmes effectuant les opérations au moyen de ces données respectent les spécifications fixées par l'analyste de l'application.

Ces deux points sont la cause principale des erreurs qui se produisent, car le processus suivi à l'entrée des données et à la programmation est le suivant :

Entrée de données — Le plus grand volume s'effectue au moyen d'une bande perforée, et aucun moyen n'est capable de vérifier l'information que l'on perfore.

La vérification des données n'est pas prévue dans le système de bande en papier. En tout cas on utilise des systèmes d'enclavement de domaines plus critiques, mais à la condition que la quantité des différentes familles soit réduite.

Dans ces conditions, et en opérant sans vérification, on s'expose aux erreurs commises par l'opérateur même — admissibles normalement — et à celles qui sont commises par les machines, l'information qui est reflétée sur la feuille de fond n'est pas la même que celle qui est perforée sur la bande en papier du fait d'erreur mécanique de la machine.

Ces erreurs, bien qu'étant décelées à l'ordinateur — nous dirions plutôt refoulées — constituent une source de retards, car il faut perforer de nouveau et établir un procédé de réintégration dans le processus une fois repérée l'erreur.

Programmation. — Une série d'erreurs imputables aux programmes se produisent plus fréquemment que souhaité, d'où : perte d'une importante partie de l'information, over-flow de certains domaines comme c'est le cas des ports d'origine, liquidations erronées sur les quittances, etc.

Un autre inconvénient grave que l'on observe actuellement est qu'une grande quantité de données nécessaires pour les liquidations est détruite une fois élaborées les quittances. — Les statistiques obtenues en partant de ces données ne peuvent être différentes de celles qui ont été posées initialement, excluant ainsi toute combinaison que désirerait connaître le service ou qui serait souhaitable dans la pratique.

Par exemple, pour établir les liquidations d'accostage de navires on doit opérer sur 11 données particulières. Or de celles-ci, 4 seulement sont utilisées pour la statistique, les autres étant détruites une fois élaborée la quittance.

Il eût fallu établir des enregistrements de processus intermédiaires de telle sorte qu'ils comprennent tous les domaines nécessaires afin d'en tirer toute combinaison de données et, simultanément, il eût fallu accumuler les valeurs nécessaires — sur une mémoire ou sur une certaine partie du disque, en établissant ainsi un fichier intermédiaire dont l'exploitation pourrait fournir non seulement la gamme de statistiques d'intérêt actuel mais aussi celles qui présenteraient un intérêt à l'avenir.

1.2. **État de salaires.**

Les données qui interviennent dans ce processus sont perforées et vérifiées au Centre de Calcul, les erreurs étant pratiquement exclues, celles qui se produisent étant facilement décelables.

Le procédé employé est correct, mais on peut y apporter des améliorations telles qu'un nouveau dessin pour les modifications et données variables et pour les liquidations qui sont remises au Centre de Calcul, ce qui faciliterait le travail du personnel de l'Administration.

2. **Possibilités d'amélioration.**

Comme on l'a indiqué ci-dessus, les erreurs qui se produisent sont dues dans la plupart des cas, à l'entrée de données et postérieurement à leur traitement-programmes.

Nous exposons ci-dessous les mesures suivantes qui, une fois imposées, amélioreront sans aucun doute les processus actuels.

2.1. **Entrée des données.**

Il faut user de méthodes valables, afin de vérifier les données d'entrée.

Dans le cas d'une bande perforée, on devra utiliser le procédé des nombres simples de contrôle ou effectuer des enclavements des domaines les plus critiques en employant un certain nombre de machines additionneuses. Cependant, étant donné la quantité de données qui interviennent à chaque processus, l'adaptation d'une quelconque des méthodes antérieures ne ferait que compliquer et rendrait beaucoup plus difficile le travail à effectuer.

Il semble donc opportun de modifier la base de l'information en passant de la bande perforée à la fiche perforée.

En employant cette nouvelle base, on pourra vérifier totalement ou partiellement, selon les nécessités, les données introduites dans l'ordinateur en réduisant ainsi les erreurs à des minima admissibles, inférieurs à un pour mille.

Un autre avantage des machines perforatrices — qui, dans le cas des travaux de la Junta permettrait de gagner beaucoup de temps lors de la perforation — est constitué par les dispositifs de bond et de doublement, qui sont de type standard.

Grâce au premier dispositif la machine saute automatiquement sur les domaines qui, à un moment donné, ne contiennent pas d'information, ce qui la différencie de la bande de papier, sur laquelle il faut perforer des zéros.

Grâce au second dispositif, l'information commune peut être doublée d'une fiche à l'autre. La fiche qui a été perforée par la deuxième station transmet à la fiche suivante se trouvant à la première station — celle de perforation — les données qui doivent être doublées. Le doublement peut être contrôlé domaine par domaine ou colonne par colonne, soit du programme, soit manuellement du clavier.

On estime que le nombre total de machines perforatrices et vérificatrices ne sera pas supérieur au nombre actuel de perforatrices de bande à papier.

2.2. **Processus.**

Dans certains cas, le programme occasionne une perte d'information ou fausse cette dernière. Il faut donc corriger les programmes sur ces points.

Une autre modification à recommander est celle qui consiste à améliorer les programmes d'entrée de données, en ajoutant certaines routines de vérification de données et d'inconsistance — codes qui ne sont pas possibles — et en incorporant dans les programmes certaines données fixes, comme les tarifs, ce qui réaliserait une économie de temps lors de la perforation.

3. **Applications actuelles.**

Afin de faciliter leur étude, les différents travaux et programmes actuels peuvent être groupés comme suit :

3.1. **Facturation.**

1. Liquidations mécanisées.
2. Liquidations manuelles.
3. Unités de chargement.
4. Résumé des liquidations.
5. Quittances.
6. Statistiques.
7. Programmes modifications fichier permanent.
8. Programmes auxiliaires.

3.2. **État de salaires.**

9. État concernant les ouvriers.
10. État concernant le personnel technique et administratif.

Nous détaillons ensuite quelques-uns des programmes contenus dans les paragraphes précédents en tenant compte :

Des pulsations de perforation par jour. — Pulsations qui sont nécessaires pour perforer l'information quotidienne et avec laquelle on peut mesurer le volume de ce travail et les répercussions éventuelles sur : le nombre de machines perfora-

trices et vérificatrices, la vitesse minima de la lectrice de fiches de l'ordinateur et autres.

Lignes d'impression par jour. — Intimement liées à la vitesse minima de l'imprimeuse de l'ordinateur.

Code difficulté de programmation. — On donnera à chaque programme un code en fonction de la difficulté de sa programmation :

MD = Très difficile.
D = Difficile.
R = Médiocre.
F = Facile.
MF = Très facile.

Avec ces trois critères, nous donnons ensuite le détail de travaux actuels, ainsi qu'un résumé final de volumes.

Liquidations mécanisées (n° 1 du « résumé de volumes » ci-après).

Tarifs	*Description*	*Pulsations perf. par jour*	*Lignes imprimées de liquid./jour*	*Code difficulté programmation*
G-1	Entrée et séjour	1.600	480	D
G-2	Accostage	1.600	480	D
G-3	Embarquement et débarquement	48.400	1.200	D
G-spéc.	Croisières touristiques	40	12	R
E.1.1	Grues quai	4.000	2.400	D
E.1.2	Grues Automobiles	400	240	D
E.1.3	Bennes	200	120	D
E.1.4	Tracteurs	200	120	D
E.1.5	Grue flottante	400	240	R
E.1.6	Barcasse	400	240	R
E.2	Occupation superficie	38.200	13.200	D
E.3.1	Eau	165	120	R
E.3.2	Energie	165	120	R
E.5.2	Remorqueurs	200	120	R
E.5.4	Scaphandriers	200	120	R
E.5.5	Téléphones	60	120	R
	TOTAL	96.000	19.452	8 D 8 R

Unités de chargement — Employées seulement pour les statistiques (n° 3 du « résumé de volumes » ci-après)

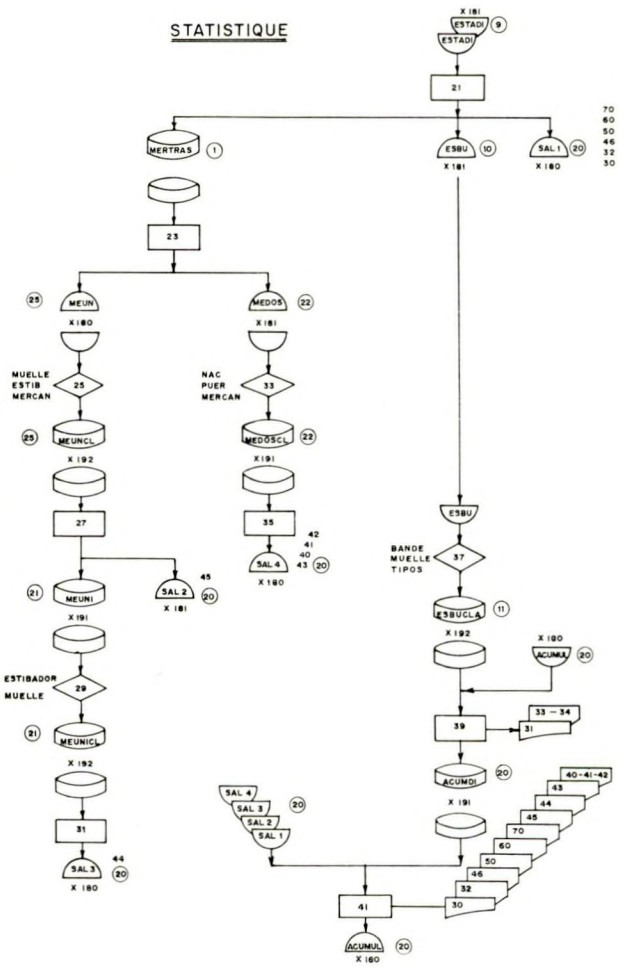
Description	*Pulsation perf. par jour*	*Lignes imprimées de liquid./jour*	*Code difficulté programmation*
Unités de chargement	2.000	à la statist. 70	F
Provenance et destination terrestres	7.000	à la statist. 20	F

Quittances (n° 5 du « résumé de volumes » ci-après).

Description	*Pulsations perforées jour*	*Lignes imprimées de liquid./jour*	*Code difficulté programmation*
a) Quittances	aucune		
	sous-produit liquidations	175	D
b) Inform. recettes	»	34	R
c) Quittances encaissées	360	aucune	R
d) Liste quittances encaissées	aucune	15	R
e) Comptes courants	sous-produit quittances encaissées	300	R
	TOTAL	240	

Statistiques (n° 6 du « résumé de volumes »).

Description	*Pulsations perforées/jour*	*Code difficulté programmation*
1. Navires entrés, par type et T.R.B. .	sous-produits	F
2. Navires entrés, par pavillons . . .	sous-produits	F
3. Navires entrés, par type	sous-produits	F
4. Navires accostés par quai	sous-produits	F
5. Navires, durée mouillage	sous-produits	F
6. Marchandises débarquées, par classes	liquidations	F
7. Marchandises embarquées, par classe	liquidations	F
8. Marchandises, par port	liquidations	F
9. Marchandises, par provenances et destinations terrestres	liquidations	F
10. Marchandises, par arrimeur et quai	liquidations	F
11. Marchandises, par quai, arrimeur et manœuvre . . .	liquidations	F
12. Marchandises, par groupement tarif G-3	liquidations	F
13. Statistique passagers	liquidations	F
14. Unités de chargement	liquidations	F
15. Digue et cale d'échouage . . .	liquidations	F
		15 F



État de salaires (ouvriers) (n° 9 du « résumé de volumes »).

	Pulsations perforation hebdomadaire	*Lignes imprimées hebdomadaires*	*Code difficulté*
Variations hebdomadaires . .	13.000	650	R
Quittance bordereau	—	5.850	D
Liste paiements	—	700	R
C-2	—	200	R
Inscriptions, cessations et modifications	13.000	7.400	F

État de salaires du personnel technique et administratif

(n° 10 du « résumé de volumes »).

	Pulsations perforation hebdomadaire	*Lignes imprimées hebdomadaires*	*Code difficulté*
Variations hebdomadaires . .	4.220	211	R
Quittance bordereau	—	1.899	D
Liste paiements	—	211	R
C-2	—	50	R
Inscriptions, cessations et modifications = Total	4.220	2.371	

4. **Plan de conduite.**

D'après les données antérieures, on observe d'une façon très nette qu'une série de modifications à court et à long terme doivent être introduites. Ces modifications sont les suivantes :

Entrée de données. Ce processus doit être remplacé par un autre qui permette la vérification, probablement sur la base d'une carte ou fiche perforée. On ne doit pas oublier que, de par l'expérience acquise, c'est à la perforation que se trouve la difficulté de tout le processus. Les rectifications ou réajustements

RÉSUMÉ DE VOLUMES

	Frappes/ jour	*Lignes imprimées jour*	*Code difficulté*				
			MD	*D*	*R*	*F*	*MF*
1. Liquidations mécanisées	96.490	19.452		8	9		
2. Liquidations manuelles	680	—			5	2	
3. Unité de chargement	2.000	—				2	
4. Résumé liquidations	—	5.000			1		
5. Quittances	360	240		1	4		
6. Statistiques . . .		9.000				17	
7. Programmes modifications Fichier Permanent . . .					11	5	
8. Programmes auxiliaires							50
9. Etat salaires ouvriers	2.000	1.200					
10. Etat salaires personnel	1.000	400		2	6	2	
Totaux . . .	102.530	32.292	0	11	36	28	50
NOMBRE DE PROGRAMMES 125							

à l'ordinateur augmentent le travail de perforation et produisent des pointes très remarquables, surtout par d'éventuelles suppressions du personnel.

Parmi les deux types de carte celle à 96 colonnes semble être la plus adéquate car, tout en étant la plus onéreuse de l'ensemble, elle admet l'introduction d'enregistreuses, de vérificatrices et possède une ample capacité.

Unité centrale de processus et mémoire externe. En tenant compte des difficultés qui, à un moment donné, pourraient apparaître entre les services du port et ceux du Centre de Calcul il est recommandable de disposer d'un système propre pour obtenir les données.

Si l'on atteignait ce degré dans le système de processus de données, cela permettrait à l'avenir d'y introduire certains travaux et contrôle d'expédition qui actuellement s'effectuent manuellement, non seulement parce que leur programmation n'est pas étudiée mais parce qu'une information quotidienne et instantanée est nécessaire : contrôles de magasin, comptabilité analytique, distribution d'accostages, contrôle de marchandises et entretien préventif.

Étant donné le volume de travail déjà exposé, on en déduit qu'il suffit que l'unité centrale de processus dispose d'une mémoire principale de l'ordre de 12.000 bits, car il n'est pas à prévoir que les programmes actuels subiront de grandes modifications.

Quant à la mémoire externe on pourrait adopter la solution consistant à utiliser les mêmes fiches perforées, groupées convenablement en différents fichiers principaux et secondaires. Cependant, leur utilisation pratique serait très compliquée, mais il semble que la mémoire externe doit être à disque magnétique d'une capacité d'environ cinq millions de bits.

Equipe de sortie. En ce qui concerne cette équipe une imprimeuse à 132 positions serait suffisante (ce sont d'ailleurs celles qui sont utilisées actuellement) et d'une vitesse de 200-300 lignes à la minute, données à étudier d'une façon plus exacte.

SUMMARY

The computer science applied to port management is established as the automatic processing of the information to solve the problems referring to the management and administration of the ports.

Its scope embraces sectors such as port planning, design and construction of structures, port operation and the connections with the outside economies within the general transportation problems.

The paper analyzes theoretically, for every sector, the multiple factors in which the computer science is able to process datas and formulate decisions, both at short and long term.

The second part of the paper is devoted to three practical cases of the use of the computer science in ports.

Case A. — A simulation model of operations on specialized terminals and its application to one for cereals and another one for containers. Examples of the congestion of the systems are shown and also representative diagrams of the correlation between the theoretical hypothesis and the simulation, with respect to the frequency of the arrivals and their servicing times.

Case B. — The paper refers to the application of the computer science to the measurement and recording of the waves by means of a national and offshore network, followed by a centralized processing (in real or deferred time) of the information through another computer whose block diagram is shown.

Case C. — Finally, the paper explains the results obtained in the processing of the information in several operational activities of the Port of Barcelona, such as statistics (with its block diagram), rates and salaries, analyzing the specific difficulties and proposing several procedures for the future.

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PAPER

by

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1. INTRODUCTION

1.1. Wherever there is an activity which requires the collection, storage, processing and distribution of large volumes of information, there are potential computer applications. This is true of ports as it is of other organisations. It is also true that in ports as in many other organisations, there was a period of « computer euphoria » in which managements were persuaded to invest heavily in computers only to find that the anticipated cost savings and/or the increases in efficiency were not forthcoming. This widespread and salutary experience was due to many reasons; one of them was the lack of understanding by management of the basic fact that, although computers can greatly improve the handling of data and enable much more data to be handled, these benefits can be successfully exploited only if the computer applications are based on objective systems investigations which show that the benefits of the computer are likely to exceed its costs. Inadequate preparation for the introduction of computers has been another source of disillusionment. First, for computer applications to be succesful training at all levels is needed; a technical education relating to the potential of computers and, perhaps even more important, training and discussion groups to overcome the natural resistance to change. Sometimes the necessary systems investigations indicate that quite fundamental changes in working practices or in the organisation itself are desirable and it will need all the skills of management to create the right environment for exploiting computers fully. Second, the effort required to transform manual systems into automatic data pocessing systems has often been under-estimated. This is particularly so with regard to management information systems which tend to require far more analysis, specification and programming work than their enthusiastic promoters appreciated.

1.2. However, despite the disillusionment which inevitably followed the period of euphoria, it is undoubtedly the case that the computer can bring great

benefits in many areas of port activities; indeed, in modern conditions, its use is rapidly becoming essential.

2. AREAS OF APPLICATION

2.1. It is convenient to consider areas of potential ADP applications under four heads, viz :—

(a) planning
(b) operations
(c) management
(d) external interfaces.

Before dealing specifically with each area, it is worth making a comment which is relevant to computer applications generally. Within an organisation (indeed, within groups of organisations engaged in the same sphere of activities), it is frequently necessary to collect the same items of data and process them in different ways for different purposes. For example, planning of future developments must have regard to present performance, the measurement of which is needed for both operational and management control. This characteristic of data systems points to a potential for rationalisation which can realise important benefits in manual systems, but is more important in ADP systems where, on the one hand, data collection can be very expensive and, on the other, the system is very much more powerful in terms of capacity to store, collate, process and disseminate information.

2.2. It follows that, although it is convenient to consider applications under different categories, it is also desirable to remember the inter-relationship between these categories in regard to data capture and potential feed-back.

3. PLANNING

3.1. Corporate planning comprises, essentially, forecasting the future demand or potential demand for services and facilities, the allocation of resources and the appraisal — financial and otherwise — of possible strategies aimed at stated objectives. Clearly, these are processes which require the collection and processing of data, often in large amounts and corporate planning is therefore a potential area for computer applications and they are widely used; the applications frequently taking the form of computerised models.

3.2. As an example, the National Ports Council (NPC) have exploited the large input-output model of the U.K. economy developed at Cambridge University to frame detailed long-term projections of import volumes. This system, which relates import demand to activity in some eighty sections

of the economy, is used in conjunction with an equally complex economic model — constructed by the NPC — relating U.K. exports to patterns of growth and price formation in overseas markets. Altogether, trade flows to and from fourteen of the U.K.'s trading partners are analysed, with each flow disaggregated into fifty commodity groups. An undertaking on this scale and at this level of sophistication is feasible only if the statistical calculations involved can be performed on a large computer. But such work is necessary if consistent views are to be formed of the future traffic in various commodities; and investment planning at the port level — and the appraisal of port planning at the national level — must derive from such views.

3.3. To give a further example, the Port of London Authority (P.L.A.) were, some years ago, examining the need for an additional entrance lock to Tilbury Docks. To assist them in this, they used a computerised simulation of the existing lock in order to assess its capacity in relation to anticipated volumes and patterns of shipping.

3.4. These are examples of applications where computers are used, together with operational research techniques, to deal with specific sectors of the overall planning activity. However, it is technically feasible to create a model of a port as a system which is sufficiently comprehensive to encompass all the major factors related to planning. As far as the authors are aware, there is, at present, no case where such a model has been created and successfully used. The N.P.C. and the P.L.A. have carried out some preliminary work in examining ports as systems but have not as yet considered it worthwhile to take it to the stage of implementation. Within UNCTAD (Division for Invisibles) some useful work has been done in this field and very considerable progress has been made in Norway in the creation of a port development model for the Port of Bergen.

3.5. In the authors' opinion, the comparative lack of progress in this field does not stem from computer limitations but from the complexity of ports systems which requires the investment of much time and effort in highly skilled analysis to represent them, by means of computer simulations, with acceptable accuracy and realism. Quite naturally, limited simulations with limited realism have met with reservations by port managers still faced with resolving important areas of decision-making by judgement. As a result managers are somewhat sceptical as to whether substantial resources should be committed to the creation of bigger and better models. This is the kind of situation in which few are prepared to undertake the role of the pioneer. Hence, the results of the work referred to above will be watched with interest.

3.6. In physical planning and engineering, computer applications are many and varied. As far as ports are concerned, they do not, in general, differ from those relating to other fields of engineering except perhaps as regards

dredging, position fixing, hydrographic surveying and chart making, where there are many useful specialised applications.

4. OPERATIONS

4.1. Port operations provide a fruitful field for potential computer applications. They range from the regulation and control of ships in port approaches to real-time, on-line applications to cargo operations. In practice, however, the number of actual applications is surprisingly few. Here again, the reasons are no doubt complex, but it is difficult to escape the impression that they must, in some degree, arise from the innate conservatism of the industry. Thus, in nearly all fields of computer applications, surface transport has been overtaken by air transport, an industry which, from its comparatively recent conception, has been conditioned to use advanced technology.

4.2. Some preliminary work has been done by the N.P.C. on the systems approach to the regulation of ship movements in port approaches. The concept is not dissimilar to computer assisted air traffic control, although the differences in navigational practices, external influences, traffic mixes and the use of the third, height, dimension make close comparisons of doubtful value. With a good deal of development work to be done, computers may be useful in assisting traffic controllers at port navigational service centres to schedule ships in high density traffic. For example, in the British conditions of substantial tidal ranges, bringing in large ships on high water with smaller ships slotted around them in an optimum way is a complex operation requiring the calculation of potential collision situations and ensuring that ships do not run out of depth. Their facility for storing and displaying large quantities of data makes computers suitable for keeping track of vessels in port limits. The positions of ships could be obtained by a navigational aid system, transmitted to the computer and then shown on a CRT display to give the port traffic controller an accurate picture of all ships moving in his area. Simulations have carried out by Liverpool Polytechnic, sponsored by the Science Research Council, which suggest that, in due course, computers might well take over much of the human logging, (and slogging), leaving the controller free to deal with situations where human intervention is essential. However, the only application in practice known to the authors is in the St. Lawrence Seaway.

4.3. Nor are there any applications known to the authors in conventional general cargo terminal operations, ship loading and discharge or berth allocation, although, on the face of it, these are potential areas. An examination of these areas by the P.L.A. has not indicated justification for the very large development effort that would be needed. The N.P.C. in conjunction with the P.L.A. and the Mersey Docks & Harbour Company, has developed

a computerised lorry booking system, but this has not been implemented by the port authorities, which both operate manual systems.

4.4. However, in container operations, computer control systems are being utilised. For example, in Liverpool, details of containers and cargoes are entered into the computer before the containers are received. A controller at the entrance to the container berth checks by means of an on-line video display unit if the container has been booked in and subsequently the machine keeps track of the container movements, and allocates locations throughout its stay in the port. In addition, the terminal printers operating with the videos produce the Interchange Notes which are necessary in the container transportation movement chain. It seems fairly certain that in future, computers will take on duties of a more operational kind, and this might well be associated with automatic container identification and data transfer systems between a central control and straddle carriers. It is understood that in Hamburg computers are being used in the control of container terminal operations. Possible systems are under review by the P.L.A.

5. MANAGEMENT

5.1. All activities within ports are the concern of management in its broadest sense, but here the term management is used in the sense of administration and overall control. These are activities for which large amounts of information are needed as well as a great deal of data processing, much of it of a routine nature; this being so, it is not surprising that computer applications abound. In the main, they are concerned with such operations as payroll, inventory, billing, a wide range of accounting procedures and other work of a similar nature, and very few ports have progressed beyond these areas.

5.2. In paragraph 2.1, it was argued that within an organisation such as a port administration, the same data are needed to be processed in different ways for different purposes. This has led to the concept of an « Integrated Management Information Service » which deals with the rationalisation of all routine management information needs and their provision by means of a computer data base and linked programmes. If all routine management information needs can be specified, all the necessary data can be collected once and processed by means of a series of linked computer programmes designed to produce the information in the form suited to each purpose. In addition to obviating the need to collect the basic data several times for different purposes and the reduction or elimination of manual processing, the system will be completely flexible and capable of expansion and have the advantage that the data can be interrogated by managers (if necessary, remotely) at any time to obtain up-dated information.

5.3. Some progress has been made in the P.L.A. towards the development of such a system (which is referred to by the acronym « IMIS »). Progress is slow because development costs are high and each stage must be justified in cost-benefit terms. Moreover, in a fast changing, dynamic situation such as port managers now find themselves, there is always the possibility of a need to review the objectives radically at any time. The essence of IMIS is a computer data base. Data will be fed into it through a network of remote terminals situated in strategic locations throughout the P.L.A. The data will be held by the data-base in a comprehensive system of files in such a way that each item will be recorded once only and will be uniquely identified. A series of modules will be developed to process the stored data. The terminal network will be used for access to the data base for information. (See Appendices I and II.)

5.4. There will be three main types of data processing modules :—

(a) Functional (e.g. billing, payroll)

(b) Operating - control and allocation of ressources (e.g. plant maintenance and hire).

These modules will generate information for management as a by-product.

(c) Management Information - specifically designed to meet the information needs of middle and top management.

5.5. The P.L.A. computer, like most other port computers, is at present used mainly to perform routine accounting, billing and statistical tasks. Source documents are assembled in batches and transported to the computer department. From these documents, punched cards are prepared to feed data into the computer, and the processed results transported back to user departments. Two major drawbacks of the « batch » processing systems are that results are not available until some time after the events to which they relate, and access to information held by the computer is usually slow and expensive. The integrated management information service now being developed takes advantage of advances in computer equipment, systems design and programming to move away from the situation in which the computer is merely a routine accounting machine to one in which it is used additionally to provide more meaningful, timely and selective information for control at lower management level and for decision-making at middle and upper levels.

5.6. To achieve this more advanced use, the computer must satisfy a number of key requirements :—

(a) It must have the capacity to process a number of user tasks simultaneously. This is in order to receive and process data concurrently from many departments.

(b) Massive backing storage is necessary so that information in the data base is immediately accessible. This is to permit immediate interrogations of data and to provide timely, accurate and meaningful reports to management.

(c) The computer must be capable of « on-line » processing with links to computer terminals located in or near user departments. This will ensure that the data base is kept up to date.

(d) The processing equipment must have a high degree of reliability in order to avoid delays in receiving and processing information.

(e) The methods of holding data files in the computer must be standardised so that « generalised » programmes can be applied to receiving new data and gaining rapid access to the data base. Thus changes in management requirements for information will be more easily accommodated.

5.7. An essential feature of the planned system is the provision of remote video and print-out terminals in the dock groups and elsewhere which will be used to input data and interrogate the files where this type of « on-line » facility is justified.

6. EXTERNAL INTERFACES

6.1. Ports do not exist in isolation; they are part of the transportation system which serves international trade. International trade operates through a tangle of interlocking systems of great complexity which embrace production, sales, banking, insurance, customs, taxation and governmental fiscal and statistical requirements and controls, as well as the wide-ranging needs of transport and port operations. The voluminous and intensive flow of data needed to sustain these systems is, in the main, based on the production, distribution and processing of paper documents which themselves accord to systems devised over the centuries in an ad hoc fashion. These paper based systems exist in a multitude of forms; they are, in general, incompatible one with the other and are often outmoded, cumbersome and expensive to maintain. Their main advantages are their flexibility and low cost of development. They suffer from the increasingly serious disadvantage that they are time consuming to operate.

6.2. In a situation where international transport has been vastly speeded up by the impact of air freight and unitload surface services, the movement of goods is already experiencing delays due to the inherent sluggishness of the paper based data systems which exist to facilitate it but, in practice, often impede it. As international trade increases in speed and volume, the situation must deteriorate unless action is taken on a comprehensive scale and internationally to « take the paper off the back of the goods ». Useful progress is being made in refining and streamlining some of the documentary systems and this is greatly to be welcomed, but it cannot provide the long-

term needs of international trade facilitation. They can only be met by massive computer application based on systems which are international in their coverage and transcend the interfaces of the several elements involved in international trade.

6.3. Although it is conceptually possible to envisage a system comprehending these elements, the extent of the system is so enormous and the variety of data processing needs so complex, that it does not seem realistic to attempt to make progress by way of a total systems approach. Nevertheless, some action must be taken. Within such activities as air passenger and freight services, and container services, computer based systems are in operation. In general, they are systems devised to meet the needs of an individual company or a small group of companies acting in concert. But such systems are « close-circuited » in that they are not designed to interface with other systems, nor, by the nature of the present situation, can they be expected to do so. Thus, as these systems proliferate, new areas of incompatibility are being built up as between one system and others and as between ADP and paper-based systems. These areas of incompatibility are traversed only at considerable expense in time and effort.

6.4. This aspect of international trade facilitation has over the last two or three years received increasing attention. In the United Kingdom, there has been established the Board for the Simplification of International Trade Procedures, known as SITPRO. Its objectives are adequately defined by its title and its activities include the discernment, sponsoring and support of action to promote ADP solutions to problems of international trade facilitation. The authors are members of the Board and of its ADP Working Group. Organisations with similar objectives exist in the United States of America, Belgium, Holland and Japan and, it is inderstood, are being formed or considered in other countries. Some international bodies are engaging themselves in activities related to the general problem area, amongst them being E.C.E. and the International Chambers of Commerce. IATA has been active for some years in the limited field of air transport services. The Customs Co-operation Council is doing useful work in respect of commodity coding.

6.5. In the United Kingdom, SITPRO, after extensive study of the situation, has adopted a clearly defined but flexible approach. It starts from the position that the development of a comprehensive, all-embracing system is not within the realms of practical development or implementation. Hence, it would be wrong to take action which would impede the establishment of domestic or in-house systems by individual companies or organisations even though this will lead to an extension of the problem of incompatibility between systems. It is concentrating on two main lines of progress. One is the possibility of the setting up of multi-organisation systems limited in the area activities they comprehend and the extent of their coverage.

Much work has been done by the N.P.C. to promote such co-operative systems, based on the concept that common inputs of data would benefit the participating organisations in terms of higher accuracy and speed of information transfer and the P.L.A. are considering the feasibility of such a system. The other line of progress is an examination of the nature of the data to see if rules of guidance can be promulgated defining the contents and form of the information requiring to be collected, processed and distributed so as to minimise the generation of incompatibilities at the interface between systems.

6.6. Clearly, the establishment of systems of codes covering all, or a very large part of, the information to be dealt with is a sine qua non of substantial progress. Such codes must be international in character and of a comprehensiveness and technical quality that satisfies the needs of governments and commerce. This is in itself a gigantic task on which a small but very important start has been made by the Customs Co-operation Council and E.C.E.

6.7. Within this complex and important area of data processing relating to international trade, the work now being carried out in SITPRO and other organisations represents only the merest beginnings. It is, however, serving to draw the attention of other organisations to a subject of vital importance. The interest and co-operation of international organisations will be needed if successful development and implementation are to be achieved on a international scale. PIANC is concerned primarily with ports and water transport. Ports form a nodal point in the systems relating to the physical transport of goods. Although they do not occupy a similar situation in the systems relating to data flow in international commerce, they do present a useful starting point in building up the multi-organisational systems to which reference has been made. It is relevant that the most extensive and successful example of such a system that has yet been established, is the London Airport Cargo EDP System, known as LACES, in operation at Heathrow. It is clearly important that those concerned with port development and management should be aware of this aspect of the commercial environment in which they operate.

7. CONCLUSIONS

7.1. The potential for computer applications to port activities is so great that we are clearly only in the early stages. There is a need for the scrupulous examination of proposed developments with a careful eye to cost effectiveness, but too cautious an approach could lead to stagnation. There are some areas where it is now important that those responsible for ports and for other organisations within international trade become aware of the need for action.

RÉSUMÉ

En dépit du désenchantement qui suivit inévitablement l'époque d'« euphorie vis-à-vis du calculateur », celui-ci devient rapidement un outil indispensable à l'organisation progressive des ports. Et encore, la gamme et l'étendue des applications du calculateur ne constituent qu'une fraction du vrai potentiel. Les calculateurs sont déjà largement utilisés dans la conception, mais, bien qu'il soit praticable de le faire, il n'y a aujourd'hui, autant qu'en sachent les auteurs, aucun exemple de l'usage réussi d'un modèle de calculateur englobant tous les facteurs majeurs concernant la conception de ports. Le manque de résultats positifs dans ce domaine est probablement dû aux doutes que l'on a à tirer d'un tel modèle d'importantes décisions d'affaires, dans des situations complexes et dynamiques. A part le système de Liverpool pour contrôle de containers et le contrôle de navigation du fleuve St. Laurent, les auteurs ne sont pas conscients d'aucune vaste application du calculateur dans le domaine du fonctionnement de ports. Ceci est dû en partie aux prix élevés de développement, mais reflète aussi probablement le conservatisme inné de l'industrie des ports et du transport de surface en général. A l'opposé de ce conservatisme, des applications du calculateur à une grande gamme de procédés de comptabilité et autres fonctions administratives courantes ont été introduites aux ports, d'un bout à l'autre du monde. Mais même ici, l'usage de calculateurs manque de potentiel. Bien que le Service de Ports de Londres ait commencé à développer l'idée d'un service d'information administrative intégré, autant qu'on sache, il n'y a que quelques autres ports à coordonner leurs besoins administratifs à des programmes unis.

Les ports font partie d'une industrie internationale de transport entretenue par un réseau compliqué de systèmes d'échange de données, basés surtout sur papier. La vitesse croissante du transport international réclame ce que les systèmes basés sur papier sont, même maintenant, incapables de fournir. Le traitement automatique des données serait la solution à ce problème, pourvu que des modèles internationaux acceptables puissent être inventés et appliqués à l'interface ou aux points d'échange de données. Des organismes nationaux ont été établis durant les dernières années, pour aborder le problème d'ajouter aux facilités de commerce international. Les efforts d'un de ces organismes dans le Royaume-Uni — le Conseil pour la Simplification des Procédés de Commerce International —, dans le domaine du traitement automatique des données, se concentrent sur deux angles principaux, à savoir (a) avancement dans l'application des systèmes de calculateur englobant un certain nombre d'organisations prises dans de jointes activités, et (b) investigations sur les possibilités de recueillir et de présenter les données de façon à réduire au minimum les incompatibilités aux points d'interface. Un facteur essentiel au progrès consiste dans le développement de conditions élevées, de codes acceptés internationalement; du travail important sur un code commercial international est réalisé par le Conseil de Coopération de Douanes et par E.C.E.

Les ports sont des points nodaux dans la chaîne de transport et, pour tels, ils ont un rôle utile à jouer dans les systèmes de calculateurs multi-organisateurs.

Il existe un grand potentiel pour les applications des calculateurs aux activités des ports. L'efficacité du prix doit être établie où il est possible de le faire. Il y a certains domaines où il est maintenant important pour ceux qui sont responsables de ports et d'autres organisations dans le commerce international, de devenir conscients de la nécessité d'une action immédiate.

S. II - 5

PAPER

by

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ABSTRACT

The application of computer science in port planning and operation includes the development of data bases, standard statistical summaries and forecasts, dynamic simulation techniques, and optimization techniques in operations research. In addition, computers can be used in conjunction with RADAR systems to monitor harbor traffic.

It is the purpose of this paper to review some of these techniques and discuss their applications in port planning and operation. Contact was made with major ports around the world concerning their usage of computers, and the results of this poll are presented. Some economic questions concerning the applications of computers are discussed. In addition, we have presented an estimation of the future trend in this field.

Finally, a simulation model of the San Francisco Bay Area as a single port complex is discussed, and the plans for a RADAR-computer complex to monitor bay traffic is presented.

INTRODUCTION

Although the typical port is one of the most vigorously active economic units in the society of man, ports have grown as a result of independent exchange between individuals comprising the port complex, and not as a result of centralized economic planning. It is legitimate, therefore, to raise the question as to whether centralized control and significant use of computer science is becoming necessary for modern port planning and operation. Evidently, there will be widely differing answers to such a question. However, in many cases port management seems to be dealing with problems of increasing complexity whose solutions cannot be developed satisfactorily by traditional techniques. In such cases, the answer tends to be affirmative.

It is worthwhile to amplify on this point. Micro-economic theory is the study of economic behavior based on certain postulates, or « laws », concerning

the behavior of single entities, or individuals, dealing between themselves in the market place. In general, such a theory can adequately explain the large scale characteristics of our present economic systems. This is the result of the fact that the world has not yet become so crowded that the actions of individuals have a far reaching and immediate effect on the rest of the society. In other words, the change in the rest of the system produced by an individual action can be ignored in studying the individual response to his economic environment. The over-all economic system development can then be obtained by summing the contributions from the individual effects. It is in such a system that talented management has been able to accurately foresee and plan for the future.

However, by analogy with physical systems, an economic system can become so « dense » and interactive that it is characterized by a high degree of « collective » interactions. Just as a dense solid cannot be usefully studied, or understood, by the perfect-gas laws, so a dense, highly interactive, economic system begins to lose the ability of being understood on the basis of individual interactions. Feedback and response of the environment to the effects of individual decisions must frequently be considered in studying the results of such decisions. In such a situation — and much of the modern industrial society is approaching such a « collective », interactive situation — the use of new and more powerful computational tools is required.

This latter, « collective », situation is being approached in some port systems, and port management is starting to turn to the use of computer science for assistance in making decisions. One of the most crucial points in considering the use of computers should be mentioned here. It is important to carefully analyze the benefit to be expected from the use of computers, and to balance that against the cost. For example, in some cases careful analysis by computer techniques has been able to realize cost savings of the order of 5% to 10% of the total project cost. On the other hand, computer projects such as the construction of a detailed simulation model have run to costs in the $100,000 range, or more. Thus, if these figures are typical, projects involving costs in the $10,000,000 range are promising candidates for analysis and savings from advanced computer techniques.

For the preceding reasons, we are of the opinion that the computer will be increasingly utilized in port planning and operation, and the remainder of this paper will discuss certain aspects of this relatively new tool. The growth of the computer as such a tool seems to have followed a mixed pattern. The computer was probably most successfully used in business applications as an advanced calculator, and early became a very handy bookkeeper for the purpose of distributing payroll checks and keeping track of the various deductions, etc. Then, a second application would be to record and keep track of customer orders and payments. A corollary use of the computer would be to keep track of the company inventory and to issue management reports on the state of the company in a periodic fashion.

As experience with successful computer usage grew, new and more advanced types of calculations were developed. The field of operations research was

developed during the Second World War, and various advanced computer techniques have been developed, mainly by university personnel financed by government grants. Such fields as linear programming (1), dynamic programming (2), and simulation modeling (3) have had a limited application in certain businesses, and this trend is continuing slowly.

It is felt that this general trend will be followed in port planning, and in the remainder of the paper we will present some of the relevant aspects of the path likely to be taken in computer usage in the near future. First, it is useful to develop a feeling for the present state of the art, and the results of a questionnaire sent to major ports around the world as to their computer usage are presented.

It is felt that the next major step for port applications will be in the use of the computer as a statistics gathering and analyzing device, so that our discussion will cover some of the important statistical techniques used in studying and forecasting data.

It seems that a major type of application of computers in port planning and operation will be the use of the technique of « Monte Carlo » simulation modeling. We will thus spend a major portion of the paper discussing this type of computer application.

Finally, we will consider the construction of a computer simulation model of the San Francisco Bay Area as a major single port. In addition, a plan for a RADAR-computer complex to monitor bay traffic is presented.

COMPUTER USAGE

World wide poll.

A poll of computer usage was sent to several hundred ports around the world. Letter replies were received from 48 ports, of which 30 reported no computer usage whatsoever in their port operations. The remaining 18 ports reported significant computer usage to gather and record statistics on port operations. Finally, several ports reported use of the computer to analyze the data gathered, and to do some forecasting.

Additional usage by a number of ports was reported in the area of engineering analysis, such as the use of computer programs developed to analyze structural forces on off-shore constructions, and, in conjunction with RADAR installations, to determine current ship patterns in the port and approaches.

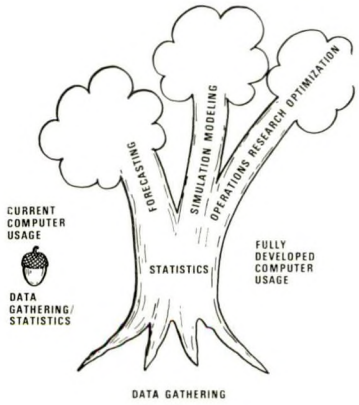


Fig. 1.
Schematic diagram of the present level of advanced computer applications, compared with the « state-of-the-art ».

On a world-wide basis the use of computers in port planning and operations can be summarized by the diagram depicted in Figure 1. This sketch is intended to represent the evolution and growth of the computer usage by ports, and it appears to be the case that the first significant usage has been in the area of data storage and organization. Second, the use of the computer to summarize the store data in the form of statistical parameters is growing. Third, the computer will be used more and more to forecast future requirements. Fourth, the computer will be applied more often to modeling the port via « Monte Carlo » simulation modeling, while the final increase in usage of significance will be in the area of optimization using standard operations research techniques. Current developments seem to be following this evolutionary path.

Growth of model building.

It is felt that the next major area of increased computer usage, following statistical applications such as summaries and projections, is model building.

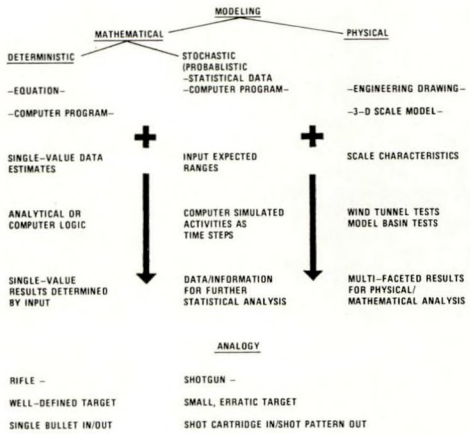


Fig. 2.

Schematic diagram comparing various types of modeling.

In order to set the stage for the following discussion, consider Figure 2. We have divided the concept of modeling into two branches, physical and mathematical. We have further subdivided mathematical modeling into deterministic and stochastic (Monte Carlo). If we had to estimate percentages on the current level of activity in these three types of modeling, we would probably assign over 90% to deterministic modeling, over 9% to physical modeling, and the remaining to Monte Carlo modeling. Nevertheless, the latter is of great importance for application to port modeling. Exploring the nature of these types of modeling, it is helpful to point out that deterministic modeling may be typically in the form of mathematical equations or, of particular interest, in the form of computer programs. Monte Carlo stochastic simulation modeling is in the latter form and physical modeling can be in a number of forms, such as drawings or 3-dimensional scale models.

The use of any of these models proceeds by defining the parameters of the particular application, the single-value data estimates in the case of the deterministic models, the expected ranges and probable shapes of distributions in the case of Monte Carlo simulation models, and the scale dimensions in the case of the physical models.

The process of extracting useful information from the model then involves an analytical solution or computer logic in the case of the deterministic model, a computer run progressing through simulated activities as time steps in the case of the Monte Carlo simulation model, and perhaps, wind-tunnel or model-basin tests in the case of physical models.

The results will be single-valued results determined completely by the input parameters in the case of the deterministic model, data and information in the form of distribution and ranges of results for further statistical analysis in the case of the Monte Carlo simulation model, and multi-faceted results for physical and mathematical analysis in the case of the physical model.

Finally, by analogy, the deterministic model can be likened to a rifle, used on a well-defined target. A single bullet is used in the firing chamber, and a single-bullet result is obtained on the target. On the other hand, the Monte Carlo simulation is to be likened to a shotgun, to be used on an elusive, erratic target. A shot cartridge is used in the firing chamber, and a shot pattern result is obtained at the target. One could say that stochastic, Monte Carlo simulation modeling is the shotgun in the management arsenal of analytical tools for project control.

The development of simulation models of major port activities is not yet strong enough to draw any conclusions. However, let us use analogy with such activity in similar areas, and present briefly some facts concerning this effort in these other areas. G. W. Gershefski (4) discusses the development of corporate model building, and Figure 3 is a plot of corporate modeling « starts » during the decade of the 1960s. Gershefski concludes, not unexpectedly, that such model building was beneficial to the companies involved. He found that on the average it took 3.5 man-years per model. In addition, two-thirds of the companies developed models which begin by considering the total corporation but in very little detail, while the remainder started with a part of the company only. It is interesting that 95% of the models were of the case study, or simulation type, with only 5% mathematical programming or optimization types. However, 88% were deterministic in nature and only 12% were stochastic, or « Monte Carlo » in nature. It is a fair guess that port modeling today is where corporate modeling was a few years ago.

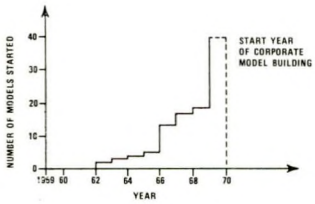


Fig. 3.

Illustrative representation of modeling levels.

Although only 12% of the models mentioned above were described as stochastic, or « Monte Carlo » in nature, this type of model building is likely to constitute an increasingly important activity in the future. Prof. A. M. Feiler (private communication) has kindly supplied the author with a summary of his simulation modeling experience beginning in about 1963. Figure 4 is a series of histograms of the types of projects carried out (by number of projects). Professor Feiler

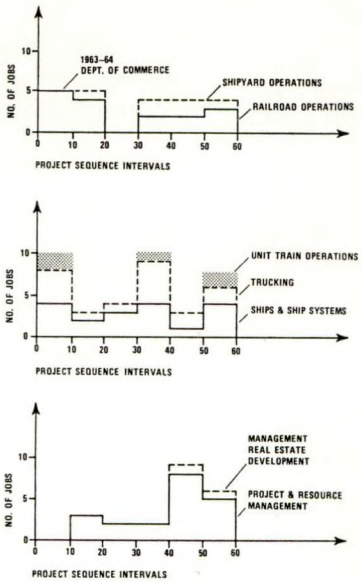


Fig. 4.

Illustrative representation of « Monte Carlo » simulation modeling applications.

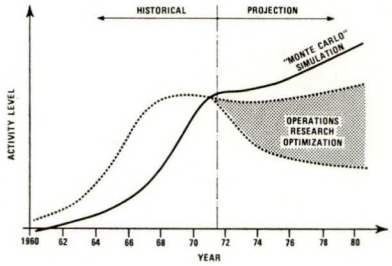


Fig. 5.

Schematic projection of optimization and simulation computer techniques.

has indicated that the growth in this modeling activity has followed much the same pattern as that shown in Figure 3, with the exception that the pattern seems to have followed a growth/retrenchment pattern into the 1970s. Following the retrenchment in the early 1970s, it is anticipated that a solid growth in Monte Carlo modeling will carry on into the later 1970s and 1980s. It is felt as a contrast that the recovery of the optimization techniques of operations research, for example, linear and dynamic programming, from their retrenchment period in the later 1960s will not be as strong as that of the Monte Carlo techniques. These trends are sketched in Figure 5.

There are two factors which tend to boost the use of Monte Carlo modeling with respect to optimization techniques. First, optimization techniques tend to be relatively more expansive in the use of mathematical analysis in order to hold computer run times down. However, as the computer technology has advanced, computer time decreased in cost, and the Monte Carlo techniques have become correspondingly less expensive. The second factor is the nature of the business environment itself. Optimization techniques tend to require rigorously defined conditions and data. The business environment is not particularly conducive to such methodology. In fact, Alchian (5) has argued that « where foresight is uncertain, ' profit maximization ' is *meaningless* as a guide to specifiable actions ». In fact, it is one of the characteristics of Monte Carlo techniques that they have been designed to deal explicitly with situations which have a significant amount of uncertainty in their individual interactions.

FORECASTING AND STATISTICS

Importance of forecasts.

Forecasting is required for intelligent planning, design and operation of a port. It is a decision-making tool. It is particularly important in setting criteria

for planning and design of new or additional facilities and equipment. In the area of port operations, forecasts are needed for efficient manpower and equipment scheduling as well as for the allocation of facilities to particular demands. Many routine decisions can be made on the basis of short run forecasts of a very unsophisticated nature. Where longrun implications are involved, economic impact of the forecast can be extremely significant so that the time and effort required for a sophisticated and reliable forecast is justified.

Forecasting for the expansion or the operation of an existing facility can be based on real knowledge of existing operations and the accumulated statistics related to such operations. In the case of a new port facility, forecasting becomes a more difficult problem requiring a greater degree of application of judgement and experience. Where it is available, the experience of others or the experience with similar installations can be used as a point of departure. In any case, good statistical data for the existing operation or for a similar operation is an important ingredient for making forecasts that lead to good decision making.

Forecasting methods.

Forecasting includes a range of techniques starting with simple opinion polls or surveys and going on to sophisticated model building. Most of the quantitative methods of forecasting can be readily programmed for computer computation. As a matter of fact, many such programs already exist to handle such techniques as :

- o Time series analysis.
- o Exponential smoothing.
- o Linear regression.
- o Least squares polynomial regression.

These statistical techniques are used in model building for forecasting. For example, in building a model of a trans-Atlantic shipping system and its marine terminals, it was necessary to forecast trans-Atlantic crossing times under various wave conditions. Figure 6 is a plot of the trans-Atlantic crossing times as a function of maximum wave height along the great circle route from Gibralter to New York (6). The solid curved line was fitted to the data by a least squares polynomial regression. This is typical of the way in which countless port planning and operation parameters can be estimated by statistical techniques.

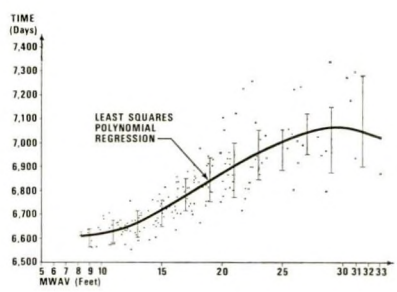


Fig. 6.

North Atlantic crossing times as a function of maximum wave heights.

MONTE CARLO SIMULATION MODELING

One of the most powerful techniques available to study the multitude of problems which beset a complex port situation is to construct a « Monte Carlo » simulation model of the port features of interest. We will pursue some of the steps required for this effort in the remaining portions of this paper. Before we do so, however, it is useful to develop the main features of Monte Carlo simulation modeling.

Risk and uncertainty are naturally present in business and engineering environments. Two main sources of uncertainty are external factors such as changes in the supply of money, political factors, social conditions, and legal modifications, and internal factors such as delays caused by unforeseen subsystem interactions.

Features of the individual Monte Carlo simulation systems currently in use are illustrated in Figure 7. The generalized « view », or « universe », of the system

STOCHASTIC, MONTE CARLO SIMULATION MODELING

	SIMSCRIPT*	GASP**	MODEL***	GPSS****
Worldview	Events, Entities	Events, Entities	Events, Entities	Particles, Transactions
Time steps	Random, Variable	Random, Variable	Random, Variable	Equal Intervals
Language	Simscript (Fortran)	Fortran	Fortran	GPSS (Fortran)

*SIMSCRIPT is a major stochastic simulation modeling system. Its language is somewhat more complex than FORTRAN. Very large and complicated simulation models often can be programmed only in SIMSCRIPT.

**GASP is a stochastic simulation modeling system written entirely in the FORTRAN language.

***MODEL is a stochastic simulation modeling system developed at Bechtel and Pacific International Computing Corporation. It is also based on the FORTRAN language.

****GPSS is a major stochastic simulation modeling system. Its language is easier to learn for an untrained analyst than FORTRAN or SIMSCRIPT.

Fig. 7.
Characteristics of various types of « Monte Carlo » simulation techniques.

being simulated is recorded for the major simulation modeling systems. The type of time advancement is indicated, and finally, the computer language each system uses is set forth. A pictorial representation is supplied in Figure 8. In the SIMSCRIPT-GASP-MODEL system, focus is on the major components in the system, the entities, or the carriers. These could be ships, major equipment, or other major, permanently present, system elements. These entities are visualized as continuoulsy cycling about the system, and their effect on the flow of material, or cargo, through the system is recorded and summarized by the simulation run. This approach thus constitutes emphasis in the permanent system elements of major importance to the project management, and visualizes these elements as cycling permanently about the system.

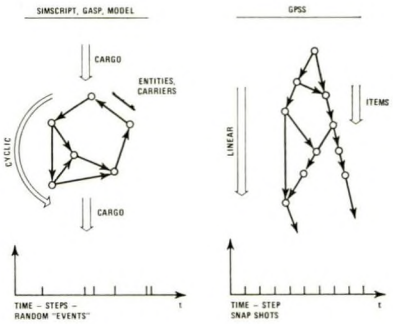


Fig. 8.

Typical behavior of various types of « Monte Carlo » simulation techniques.

By contrast, the GPSS view of the system is to concentrate the primary focus on the times which are being processed through the system. This is a linear flow approach. In GPSS the items are conceived as created initially, and destroyed finally on their exit from the system.

Activities-network diagram.

The first step in constructing a Monte Carlo simulation model of a port facility is to extract from the system being studied a set of entities and activities, as well as flows and storages, to be explicitly modeled. This will involve the construction of an « activities-network diagram », developed by the author. Figure 9 illustrates a very simple example of such an activities-network diagram for a receiving terminal, as well as a particular sequence of a few events occurring during a simulation run. Each numbered node of the diagram represents an event. Event nodes are connected by numbered arcs representing activities. Event routines in the computer program deal with the stochastic aspects of each event and its associated activities. Monte Carlo techniques are used to select values from the statistical distributions for such things as activity times, cargo sizes, ship sizes, etc.

Figure 9a represents the occurrence of an event at time 0.7 days, the arrival of a ship at events node (19), which is the beginning of the ship's leg toward the port. The MODEL computer system uses the event routine (19) to send the ship on its way toward the port, placing it in arc 35, with an activity time of 0.5 days.

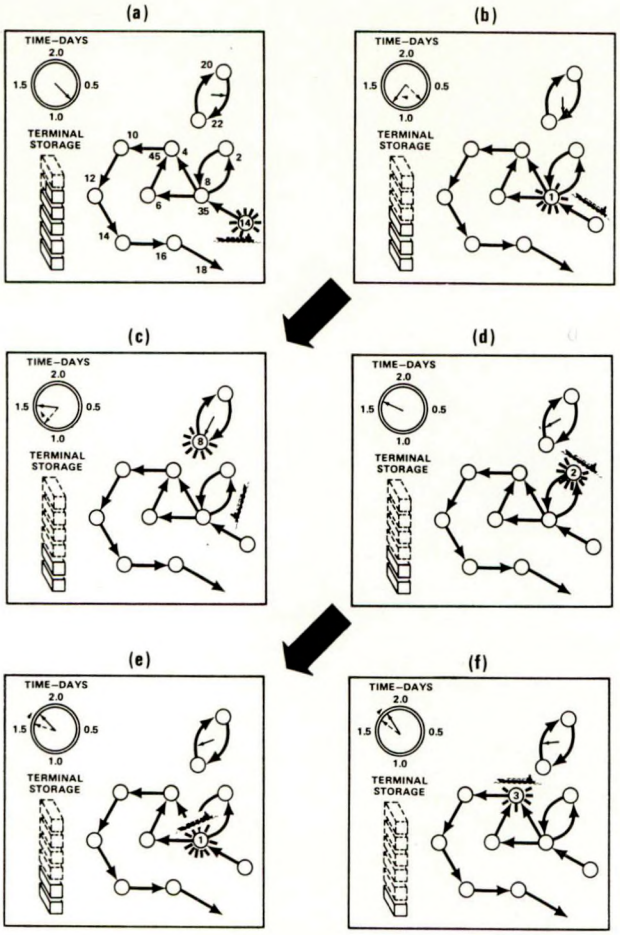


Fig. 9.

Activities-network diagram for a ship entering a harbor.

Figure 9b represents the occurrence of the arrival event at time 1.2 days at the event node (1) at the port entrance. No other event was listed as occurring before this time, so that this event was the next to occur in the system. Time is now advanced to 1.2 days, and the storage inventory level is adjusted to account for the 0.5 day interval of flow out of the terminal. The event routine node (1) has a choice to make concerning the next activity for the ship. It checks the status of the port-closure clock, finds it in the closed phase, and, therefore, sends the ship into arc 2 to wait at anchor until the port opens.

Figure 9c represents the port-open event, the arrival of the port-closure clock timer arm at event node (8). The event routine at node (8) checks to see if any ships are waiting to enter the port, finds one in arc 2, the queue-waiting activity, and sends the first ship (in this case only one) to the event node (2). It also sends the port-closure clock arm entity into the port-open arc with the appropriate time factor according to the program input data.

Figure 9d represents the simultaneous arrival of the ship at the queue-open event node (2) at time 1.6 days. The event routine at node (2) sends the ship into arc 8 with 0 time delay.

Figure 9e represents the arrival of the ship at event node (1) again, where the port status is again checked for port-closure and berth availability. Both are clear, and the ship is sent into the channel-in activity arc 4 with a time interval of 0.3 days.

Figure 9f represents the arrival of the ship at event node (3), and the event routine at node (3) sends the ship into the activities are 10, the tie-in operation, with a time factor of 0.2 days. Notice that time is continuously being up-dated, and that the storage inventory is being continuously adjusted.

As the computer model continues to operate, additional ships arrive and enter the system, ships already in the system are off-loaded and depart, cargo leaves the port by inland transportation, storage levels vary, etc., just as it would in the real-life situation being simulated. The computer is run to simulate the desired time span and the statistics accumulated during the simulation are then analyzed to locate bottlenecks, evaluate traffic patterns, etc. The system can be modified to overcome shortcomings brought to light by the simulation and the changed model run again to determine whether the desired effects of the changes are, in fact, realized. This ability to compare alternative arrangements, layouts or methods of operation is one of the primary strengths of the Monte Carlo simulation modeling.

SAN FRANCISCO BAY AREA PORT MODEL

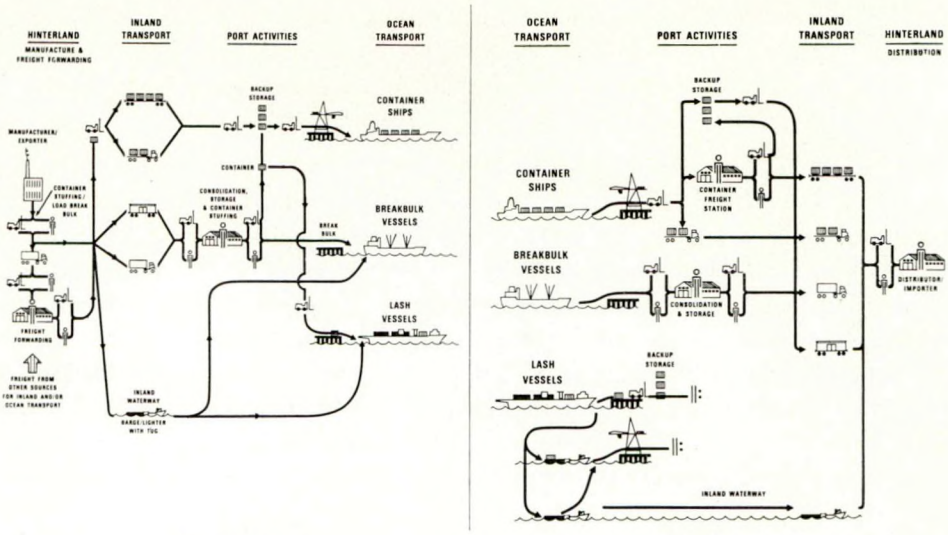
The special value of the construction of a simulation model of a port complex is that interactive effects of actions on the important components of the complex can be studied and more fully understood. The San Francisco bay area is an important regional terminus for shipping activities into and out of the western United States. At present it consists of a number of major independent ports whose activities affect the flow of goods and other activities at all surrounding ports. The construction of a simulation model of the greater San Francisco Bay Area Port would help greatly in assessing such interactive effects.

Activities network.

The activities involved in moving cargo of various types through typical modern ports are illustrated in Figure 10*a* and 10*b*. The first step in developing a simulation model of the San Francisco Bay Area Port would be to construct such an activities-network diagram which was explicit in its connections with the major ports of the bay area. Caution must be exercised at this point, however, in order that too much detail is not drawn into the preliminary model diagram. For example, referring to Figure 10*a* and 10*b*, it may be sufficient to start with the inland transport interface and treat the hinterland flow of cargo as a statistically varying external (to the model) source. In addition, the type of shipping might be restricted to general cargo liner trade initially.

Elements of the model.

The elements which are to be represented in the model must be specified. These would include the berths of interest, and the characteristics of those berths. As an example, these might include the following :



« EXPORT »

Fig. 10*a*.

« IMPORT »

Fig. 10*b*.

Schematic diagram representing flow of goods through a port.

Port of Oakland : Berth 10 (steel, break bulk);
Sealand (containers);
Outer Harbor (break bulk and some containers);
7th Street (containers and ROW-ROW);
Middle Harbor (Sea Train - containers);
Grove Street (Break bulk);
9th Avenue (Steel).

Port of Alameda-Encinal : (Container, break bulk);

Port of Redwood City : (Salt/Cement);

Port of San Francisco : Pier 94 (LASH terminal, containers, lighters);
Pier 90-92 (Automobiles, bulk grain);
Islas (Copra);
Pier 80 (Break bulk, containers, ROW-ROW, passengers);
Pier 70-72 (Containers);
Pier 50 (Containers, Break bulk);
Pier 48 (Break bulk);
Pier 30-32 (Break bulk);
Piers 9, 26, 28, 33, 39 (Empty, operable piers);
Pier 15-17 (Containers, break bulk);
Pier 27-29 (Containers, break bulk);
Pier 35 (Passengers, break bulk).

Port of Richmond : (Break bulk, automobiles, petroleum).

Ports of Stockton, Sacramento : (Break bulk, ore, logs, LASH).

Port of Benicia : (Automobiles, break bulk, petroleum).

Cargo can be broken down into types in order to classify various flows of cargo through these facilities, such as :

1. Containers.
2. Break Bulk.
3. Steel.
4. Ore.
5. Bulk Grain.
6. Unitized.
7. Passengers.
8. LASH.
9. Petroleum.

The computer Monte Carlo simulation model would thus consist of the above listed port facilities, with storages for the defined cargo types. Flow into and out of the facility storages of the various cargoes into ships calling at the facilities would be a function of the arrival pattern of the ships. This must be defined as part of the model.

At the other side of the model, movement of cargo to and from the facility storage sites into the Bay Area would be a function of the ability of the transportation system to handle this flow. Thus, the rail, air, highway transportation system would have to be included in the model in order to determine the efficiency of flow of the various cargoes across the Bay Area to and from the facilities. Finally, the flow of cargo from the Bay Area into the facilities would need to be defined as part of the system input, just as the arrival patterns of ships in the bay were defined.

Statistical forecasting.

A major effort in developing the simulation model is in the area of statistical forecasting of the port needs. In this case, although port activities have been simplified in constructing the model, it is important to consider the entire system, and especially the hinterland activities, the national economy, in forecasting the future flow of goods to and from the port.

Computers in port safety — Traffic control systems.

There is a continuing growth of Vessel Traffic (control) Systems *world wide.* The systemization and management of control of maritime traffic within ports is aimed at the dual purpose of (1) decreasing accidents and the subsequent damage to the port's ecology and economy and (2) increasing the economic capability of

the port by enabling safe operation under weather and congestion situations which might otherwise shut the port down, partially or entirely (cf. Figure 11).

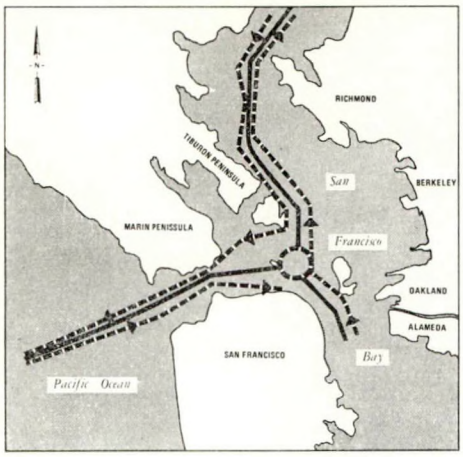


Fig. 11.

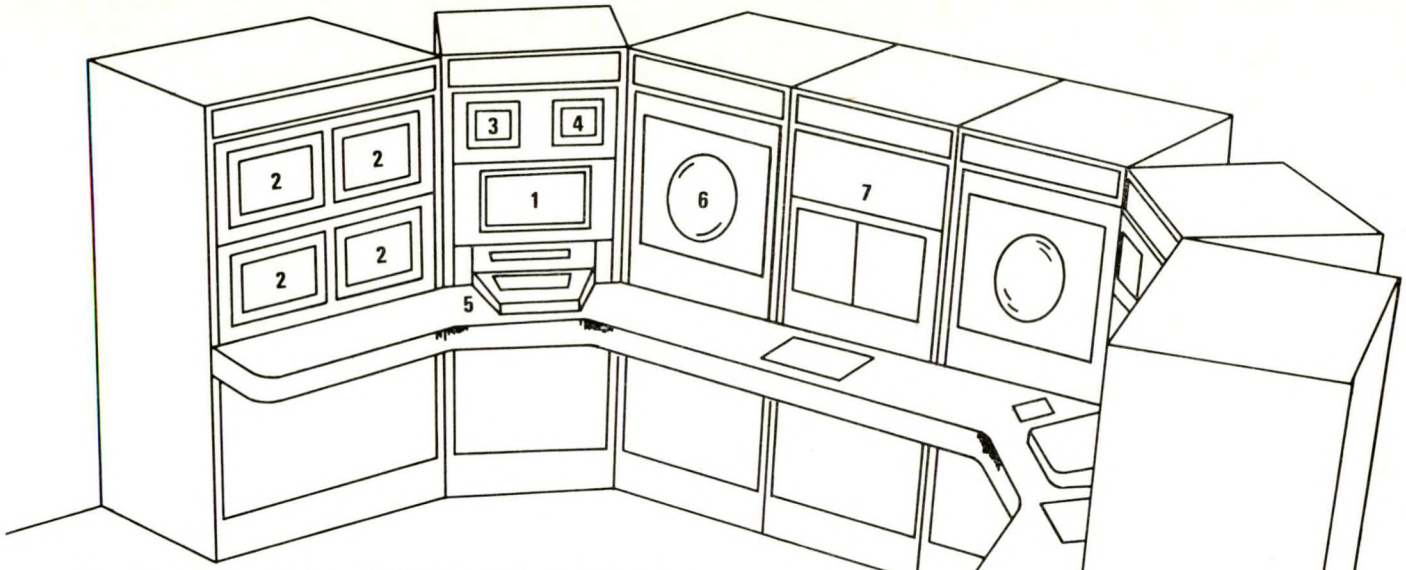
Traffic « freeway » for the San Francisco Bay.

Traffic management generally takes the form of guidance to the pilot from a shore station equipped with radar and communications capabilities and manned by pilots, civil service employees, or, in the case of the United States, Coast Guard personnel.

The Coast Guard has operated a prototype Vessel Traffic System (Harbor Advisory Radar) in San Francisco since January, 1970, and is presently installing a new radar-computer complex there which will be the most advanced, technically, in the world (cf. Figure 12). A total of 18 small to medium capability computers are being utilized to maintain information files on every vessel in the system, to automatically detect and continuously track vessels underway, and to generate synthetic displays which will provide VTS operations center personnel with a single integrated picture of the harbor area using data from two remote radars and various other inputs. (The computer generated displays will eventually « track » not only the vessels within the radar surveillance area but also those in the San Joaquin and Sacramento Rivers based on progress reports from the ships).

Initial analytical operations provided by the computers will include relative position computations, CPA (closest point of approach) analysis, lane segment encounter analysis, lane stray alerts, and congestion/collision alerts. Future programming includes grounding alerts, buoy drift alerts, arrival and departure listings, weather and tidal data listings and computer/radar system operation monitoring and trouble shooting instructions.

The Coast Guard is conducting a study into the interface between the primarily safety oriented operation presently underway and the commercial operations within the port. It is anticipated that the data and techniques used almost exclusively for collision prevention will eventually be expanded to coordinate commercial activities. The day may well come when a single computer complex controls not only the movement of major vessels in the port but also the coordination of pilots, tug boats and lighters, longshoremen and other pierside requirements and the assignment of berths to insure the most efficient use of all the port's capabilities.



1. Computer generated simulated radar picture, working display
2. Computer generated simulated radar pictures, satellite displays
3. Traffic list – computer generated alpha numeric display
4. Ship's data display – complete data on any ship requested by operator
5. Operator access to computers via standard teletype keyboard with special function keys. Operator may insert new data, update old data or request status or analysis.
6. Raw radar display, may be used in conjunction with simulated displays or independently as backup mode.
7. Communications and radar control panel.

The satellite displays (2) continuously depict traffic conditions throughout the entire radar surveillance area and are monitored visually and by computer for lane strays, potential congestion, etc. Having been alerted to a potential problem, or on his own initiative, the operator can place any of seven sectors of the bay in the working display position (1), and there call up computer analyses of any vessel or vessels tracks.

Fig. 12.

Proposed VTS operations Center consoles, San Francisco Vessel Traffic system (planned operational status 1 July, 1973).

SUMMARY AND CONCLUSIONS

It has been the purpose of this paper to discuss various aspects of the applications of computer science in port planning and operation. Such applications include the development of data bases, standard statistical summaries, statistical forecasting, dynamic simulation, and optimization techniques. We have reviewed such applications briefly, and have attempted to discuss in more depth those types of computer applications which we feel will have more immediate urgency and impact.

It is felt that the next major area of computer application by port authorities will be in the field of statistical forecasting, where future port needs and requirements will be developed. The other major area of computer applications deals with port planning and operation. It will consist primarily of the development of stochastic simulation models of the ports.

In conclusion, it is interesting to comment on the results of our poll of worldwide ports regarding their present and projected computer usage. It seems evident that there is significant computer usage in many ports, but that it is at a relatively low level of sophistication. Such usage is progressing slowly, however, and it is our view that it will increase more rapidly in the future. It is hoped that these comments will help individual ports to accurately assess their computer needs.

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RÉSUMÉ

L'application des ressources de l'ordinateur à l'étude et au planning d'opérations portuaires comprend l'élaboration des données de base, la compilation de résumés et prévisions statistiques standard, et l'utilisation de techniques de simulation dynamique et d'optimisation en recherche opérationnelle. De plus, les ordinateurs peuvent être utilisés en liaison avec des systèmes RADAR pour contrôler le trafic portuaire.

L'utilisation des techniques avancées d'ordinateur est en constante progression en raison de la complexité croissante des systèmes industriels et économiques modernes. Il semble que les projets dont le coût atteint 10.000.000 dollars et davantage doivent être directement intéressés par l'utilisation de techniques avancées d'ordinateur, en raison des économies en résultant.

Le but de cette présentation est de passer en revue quelques-unes de ces techniques et de discuter de leur application au planning d'opérations portuaires. Des contacts ont été pris avec les principaux ports du monde entier concernant l'utilisation d'ordinateurs et les résultats de ce sondage sont présentés ici. Des questions d'ordre économique soulevées par l'utilisation des ordinateurs ont également été prises en considération; nous avons présenté de plus une estimation de la tendance future dans ce domaine.

Enfin un modèle simulé de la baie de San Francisco, considérée comme un seul complexe portuaire, est analysé ici; ainsi que les plans d'un ensemble Radar-ordinateur qui contrôlerait le trafic de la baie.

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