運輸省港湾技術研究所 (25th Anniversary Issue)

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REPORT OF THE PORT AND HARBOUR RESEARCH INSTITUTE

MINISTRY OF TRANSPORT

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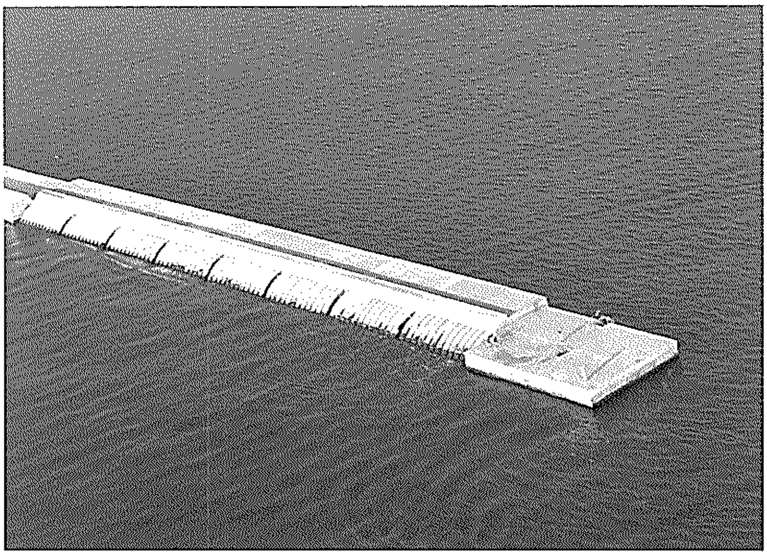
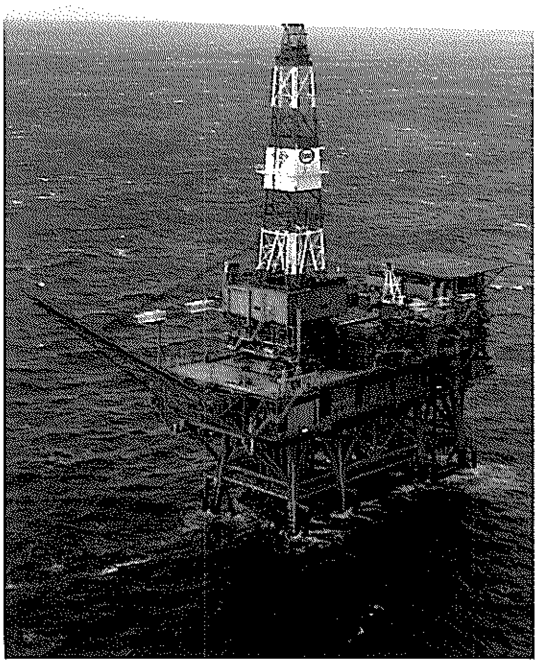
NAGASE, YOKOSUKA, JAPAN



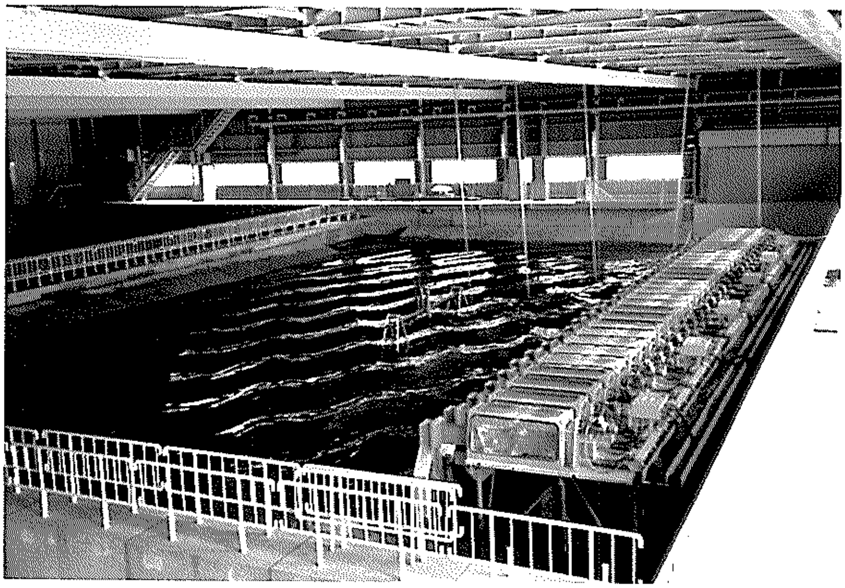
Curved Slit Caisson Breakwater

View of curved slit caisson breakwater completed in the construction at the port of Funakawa. (Courtesy of Akita Port Construction Office, the First District Port Construction Bureau, Ministry of Transport)



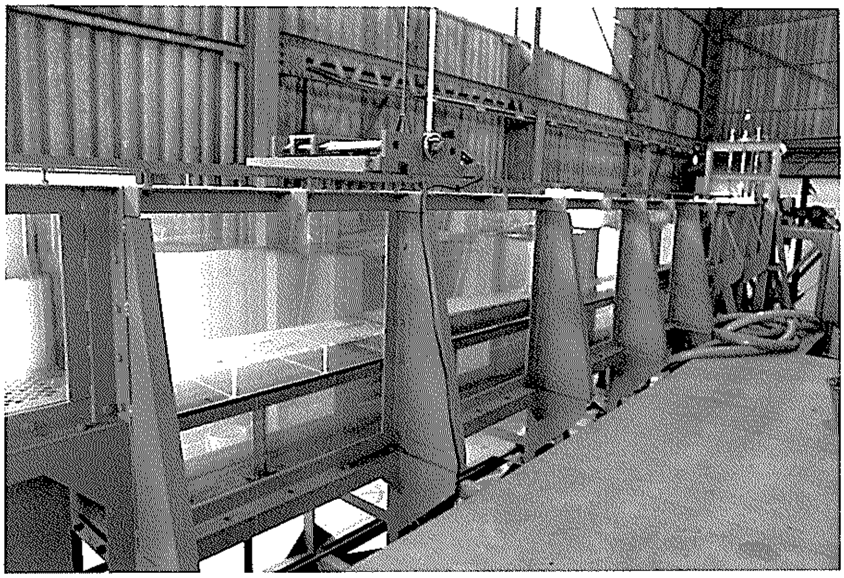
Facilities for Ocean Directional Wave Measurement

Four step type wave gauges and a two-axis directional current meter with a pressure sensor are installed on the legs of an offshore oil rig. They are operated simultaneously for detailed directional wave analysis.



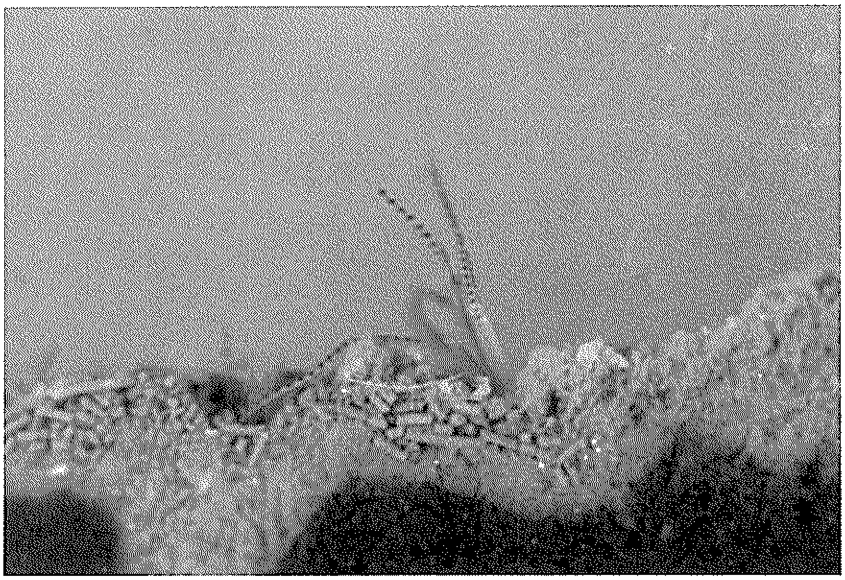
Serpent-type Wave Generator

The photograph shows the serpent-type wave generator in the short-crested wave basin and the superimposition state of two different oblique waves generated by the generator.



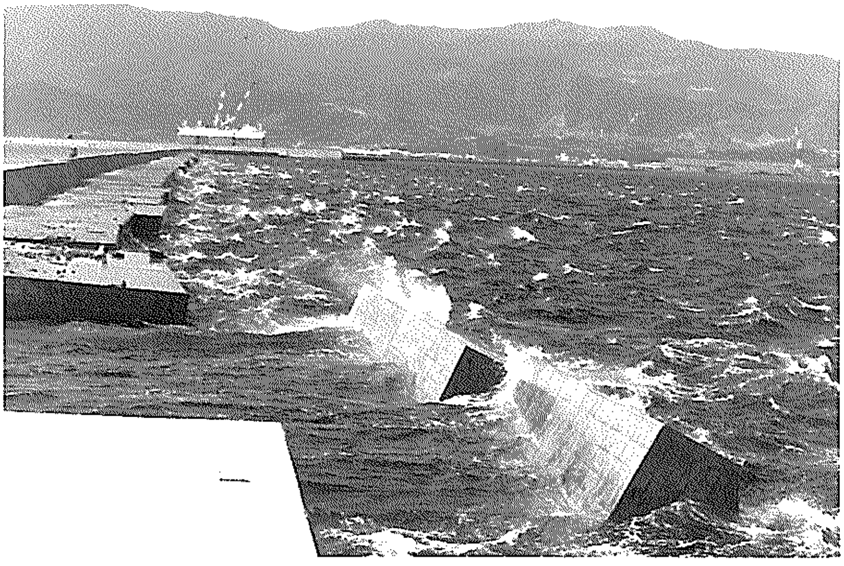
Wave-soil Tank

The experiments concerning the wave-soil interactions are conducted in this tank. The soil tank and the test section are located at the center of the tank. A movable floor is provided at the bottom of the test section and the level of the interface of mud layer and water can easily be adjusted to the level of the flume bottom.



Pararionospio Pinnata

The biomass of benthos is one of the most sensitive indices to know the effect of sea-bed sediment treatments on the marine environmental improvement. The picure shows a kind of benthos, *pararionospio pinnata,* which preferentially exists in the polluted sea-bed.



Breakwater Damaged by Storm

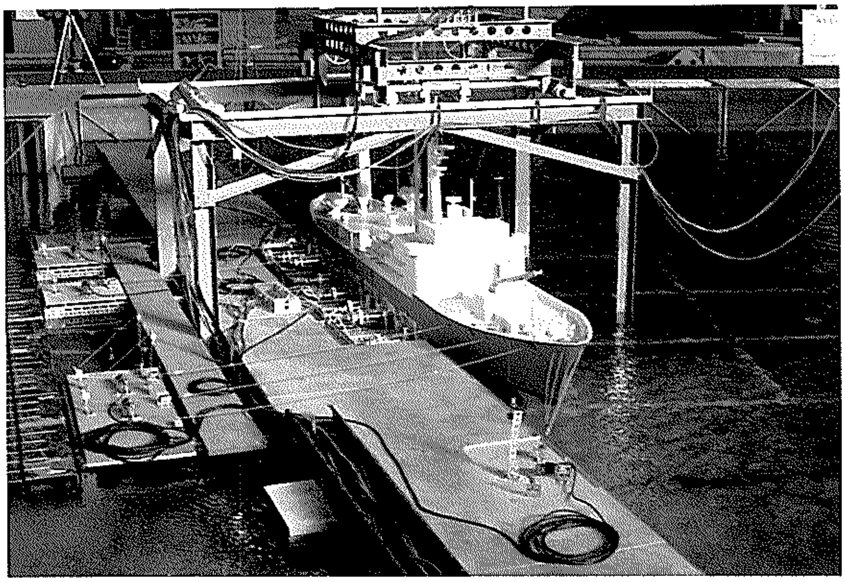
This photograph shows a breakwater damage by a storm.
The breakwater is of the composite type with concrete caisson on a rubble mound. Two caissons were severly damaged due to the instability of a rubble mound.

Nondestructive Evaluation of Pavement

Nondestructive methods for evaluating the load carrying capacity of airport concrete pavements have been developed by using Falling Weight Deflectometer(FWD).

Seismic Damage to Gravity Quaywall

The 1983 Nipponkai-Chubu earthquake(Magnitude : 7.7)caused serious damage to port facilities in northern part of Japan. This photo shows the damage to gravity quaywall. The concrete cellular block walls were collapsed and completely submerged.

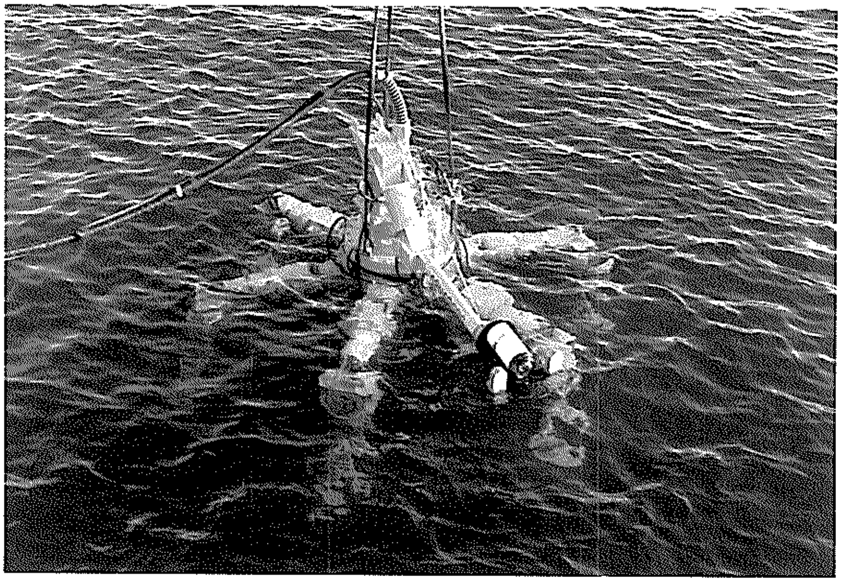


Model Experiment of Mooring Ship

Model ship is moored at a quay wall with fenders and mooring ropes subjected to gusty wind and/or irregular waves.

Vessel Congestion in Japan

As Japan is surrounded by the sea, there are many crowded water areas with various sizes and types of vessels. Arround there, many construction works were planned such as ports and harbours, off-shore airports, huge bridges and so on, so that many marine traffic observations and marine traffic simulations have been carried out.



Underwater Inspection Robot

This is the six-legged articulated underwater inspection robot named "AQUAROBOT". The robot controlled by a computer can walk on uneven sea bed without making water muddy.

Foreword

The Port and Harbour Research Institute is a national laboratory under the Ministry of Transport, Japan. It is responsible for solving various engineering problems related to port and harbour projects so that governmental agencies in charge of port development can execute the projects smoothly and rationally. Its research activities also cover the studies on civil engineering facilities of air ports.

Last April we have celebrated the 25th anniversary of our institute because the present organization was established in 1962, though systematic research works on ports and harbours under the Ministry of Transport began in 1946. As an event for the celebration, we decided to publish a special edition of the Report of the Port and Harbour Research Institute, which contains full English papers only. These papers are so selected to introduce the versatility of our activities and engineering practices in Japan to overseas engineers and scientists. It is also intended to remedy to a certain extent the information gap between overseas colleagues and us.

The reader will find that our research fields cover physical oceanography, coastal and ocean engineering, geotechnical engineering, earthquake engineering, materials engineering, dredging technology and mechanical engineering, planning and systems analysis, and structural analysis. Such an expansion of the scope of research fields has been inevitable, because we are trying to cover every aspect of technical problems of ports and harbours as an integrated body.

The present volume contains eleven papers representing six research divisions of the institute. The materials introduced in these papers are not necessarily original in strict sense, as some parts have been published in Japanese in the Reports or the Technical Notes of the Port and Harbour Research Institute. Nevertheless they are all original papers in English and are given the full format accordingly. We expect that they will be referred to as usual where they deserve so.

It is my sincere wish that this special edition of the Report of the Port and Harbour Research Institute will bring overseas engineers and scientists more acquainted with our research activities and enhance the mutual cooperation for technology development related to ports and harbours.

December 1987
Yoshimi Goda
Director General

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目 次 (CONTENTS)

REPORT OF THE PORT AND
HARBOUR RESEARCH INSTITUTE
Vol. 26, No. 5 (Dec. 1987)

10. Network Simulation

— Macroscopic Simulation Model of Marine Traffic —

Yasuhide OKUYAMA*

Synopsis

In Japan, various kinds of methods for marine traffic simulation have been developed. Of these, network simulation is widely used for port and harbour planning and for marine traffic planning because of its simplisity and effectiveness, especially when simulating marine traffic in large water areas such as in Osaka Bay for the Kansai International Offshore Airport project, and in Tokyo Bay for Tokyo Bay Transbay Bridge project, etc. This report introduces the outline of the network simulation.

The simulation system is composed of the 3 parts, of the input part, the simulation process part and the output part. According to the purpose of simulation, many network simulation alternatives are developed by adding other functions. How to evaluate the project according to the results of the network simulation is also described within.

* Chief of Systems Laboratory, Design Standard Division

港湾技術研究所報告
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10. ネットワーク シミュレーション

—海上交通流のマクロ評価シミュレーション—

奥 山 育 英*

要 旨

わが国において，各種の海上交通シミュレーションが開発されてきた。それらのうちにあって，ネットワークシミュレーシュンは，港湾計画や海上交通計画等に広く利用されている。それは，その分かり易いことと有効性によってであり，とりわけ，関西国際空港建設プロジェクトにおける大阪湾や東京湾横断橋建設プロジェクトにおける東京湾のような広大な海域において有効性を発揮する。ここでは，このネットワークシミュレーションの概要を報告する。

シミュレーションは，入力部，シミュレーション実行部，出力部の3つの部分から成っている。シミュレーションの実行の目的に応じた必要な機能を付加することによって，数多くのバージョンが開発されてきた。ネットワークシミュレーションの結果を基にして，計画を評価する点についても扱う。

*設計基準部 システム研究室長

Contents

1. Introduction

The simulation of marine traffic is carried out (i) when quantitative and qualitative changes are expected in shipping movements involving an increase in traffic volume, or when changes are likely in the ship sizes and types making up the total volume of traffic including the case of introduction of ships of sophisticated design, (ii) when changes are predicted in the area of marine traffic as caused by the broadening or the new establishment of traffic route, and further, (iii) when it is intended to change the procedure of marine traffic either through the introduction of traffic separation schemes or innovative marine traffic control systems, wherever the demand exists. It is performed to give an advance assessment of the degree of likely changes in marine traffic by determining the problems that will arise. If the results of evaluation show no specific problems, or when the degree of problem is found to be insignificant, then the objective of the simulation can be considered to have been achieved. Hence, if problem areas have been spotlit through the simulation, and the degree identified to be beyond the tolerable limit, then efforts are made in such a way that the problems identified amongst the quantitative and qualitative changes serving as the conditions for simulation, and the changes in the area and the procedure of marine traffic, are artificially reduced to perform simulation to determine the tolerable scope of the problems. This is considered to be the objective of simulating marine traffic.

As can be seen from the above, the simulation of marine traffic is frequently carried out where changes in marine traffic are likely to occur, or when it is intended to change the traffic to predict the consequences. However, network simulation will be introduced here as one of the simulation techniques that serves this objective. The term "network simulation," as it will be used here, means "simulation for the macroscopic evaulation of marine traffic flow."[6),14)]

As it is used here, network simulation came into existence after "the simplified simulation of traffic routes is considered indispensable in evaluating the system of traffic routes in the future," was stated in the Report of Investigation on the Marine Traffic Safety System in Tokyo Bay[1)] effected in 1975. Such simulation has shown a striking ability in the investigations and assessments[2),7),8)] of traffic capacities, traffic safety, traffic control and management, checks on the number of berths and capacities of anchorage in the investigation[3)] of systems of traffic routes, and also in surveys[4),5),9),10),11)] for ports and harbours plans.

The reasons behind the usefulness of network simulation may be identified, as its versatile ability to readily incorporate a number of additional functions required for elucidating problems associated with marine traffic because of the extreme simplicity of the simulation model itself, and the clear-cut premises and results which are readily understandable.

2. Network Simulation Model

2.1 A Brief Description of a Network Simulation Model

Simulation for the evaluation of marine traffic simulates the actual marine traffic by computing the traffic of a number of ships in accordance with predetermined ship manoeuvring criteria corresponding to a variety of ships under given natural and social conditions, and incorporating the features of the ships and the dynamic characteristics of the ships. On the basis of the results of such simulation, an objective evaluation of marine traffic is made through data such as frequencies of course and speed changes, the collision-aversion time distribution and the frequency of near miss incidences.

However, rough approximations tend to be included in the computation of ship motions, calculations of external forces such as wind, waves and current, and when the ships have to be simulated incorporating behavioral assessments on ship master's manoeuvring judgement, one has to enter the realm of man's decision-making behavior, which is a relatively weak area in the art of science and technology. It is therefore extremely difficult to establish a method which is convincing to all.

It may not, of course, be impossible to establish certain criteria for a ship master's manoeuvring judgement by improving the accuracy of approximation to a reasonably convincing extent, but such an attempt requires a well prepared preliminary survey and investigation, and voluminous data and calculations for simulation.

In the light of this, when an attempt is made to solve problems relating to marine traffic over a vast expanse of sea area with a heavy traffic density, the forementioned approach not only has its own limitations but also poses the problem of how the overall accuracies can be made compatible with each other by setting the limitations in the intended approach.

The concept of network simulation was created for when dealing with the simulation object in a macroscopic way, after abandoning the old concept of microscopic approach. Network simulation has its distinct features in presenting the traffic routes taken by ships with a network formed by links (either straight lines or curved lines) and nodes (nodal points). Namely, the traffic of ships which is intrinsically two dimensional is expressed, in this system, by lines inasmuch as the ships' path is concerned, and the marine traffic within a given area of water is concerned, and marine traffic within a given area of water is displayed by a network of complex lines interwoven within a plane exactly in a manner compatible with the case for land traffic. In this system, ships are supposed to proceed only on these lines. The intersecting points or end points (starting point or terminating point) represent "nodes" whereas the other components of straight or curved lines represent "links."

For each link and node, the passage time corresponding to the kind and type of ship proceeding along the route is allotted on the basis of a probability distribution in advance, and furthermore, the maximum number of ships which can be accommodated within such a link or a node (in practice, this is not the number of ships but it is the ship equivalence dependent on ship type, and called the "capacity of link or node") is also allotted thereto. For determining the traffic mass and traffic routes, the utilization of the results of actual marine traffic survey reports reflecting the new marine transport technology is recommended, but for areas of water where no such results are available, those results of surveys in known areas of water featuring similar characteristics of marine traffic may be utilized instead.

In this system, a ship, which is generated according to the probability distribution assigned per path, is assumed to proceed from a node to a link or from a link to a node successively on an area of web-like juncture formed by nodes and links, each provided with the passing period and traffic capacity according to the passing period assigned on the basis of the ship speed distribution data dependent on the ship type. If the capacity of the link or node where the ship is about to enter is already occupied by other ship or ships, the ship has to wait upstream of such a node or a link of the traffic flow, or when other ships are proceeding in the direction to cross the heading way of own ship, the ship must wait for the completion of such a crossing manoeuvre irrespective of the link or node capacity.

In this way, when a ship is proceeding along a path on the network from the point of start to the point of termination, the specific traffic flow is evaluated by estimating the degree of traffic density through a variety of statistical quantities, such as probability distributions for the waiting time and number of waiting ships and others.

2.2 Basic Model of Network Simulation

Here, explanations on the network simulation will be given by using the network shown in Fig. 1.

(1) Simulation Data Input Section

In the network shown in Fig. 1, the circled numerals signify the identification numbers of nodes and those numerals not encircled give the identification numbers of links.

For the network input, the node number and its plane coordinates are input for nodes, while no input is required for links where the input programme performs automatic numbering on the basis of the path information as described below.

The ship is assumed to proceed along the network shown in Fig. 1, but here the ship is supposed to take the following six alternative paths:

Path 1 (1) → (3) → (4) → (5)
Path 2 (1) → (3) → (4) → (6) → (7)
Path 3 (1) → (3) → (6) → (7)
Path 4 (2) → (3) → (6) → (7)
Path 5 (2) → (3) → (4) → (5)
Path 6 (2) → (3) → (4) → (6) → (7)

Selection of the paths is made only for the sake of convenience of explanation, and the reverses of the above path or other paths such as (1) → (3) → (2), (5) → (4) → (6) → (7), or even the path (1) → (3) → (4) → (6) → (3) → (4) → (5) are also possible.

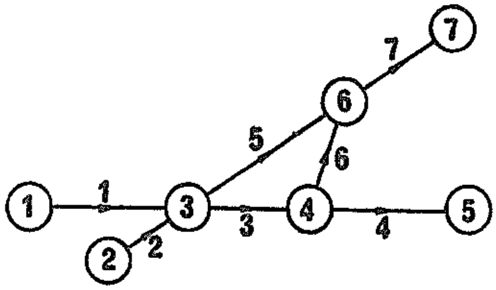

Fig. 1 Example of Network

As for the ship type, the following three ship types are selected also for the sake of convenience of explanation:

Ship type 1 Length overall 200 m speed 10 knots
Ship type 2 Length overall 100 m speed 12 knots
Ship type 3 Length overall 50 m speed 8 knots

It goes without saying that the total length and speed of ships in the same ship type group are not necessarily the same, and these may be given in terms of a probability distribution according to the respective ship types. The speed may be input according to the ship's location.

Subsequently, the link width is given for computing the link and node capacities. These data may vary according to the location of ships.

Furthermore, the volume of generation of ships according to the ship types involved, is input in terms of the probability distribution for each path. However, for types of ships for which the generation is the function of the time of the day, values in the time table may be input without modification.

Finally, the termination time of the simulation is input. Although the input data are as shown above, the programme of the input section not only performs readout of these data in the computer but also edits and rearranges them for easy utilization of input data information in the subsequent simulation, numbering of links by extracting specific links from the path information of ships, the computation of link and node capacities, and computations of passing periods per each ship type per each node and link within each path, and various other computations and tabulations for preparing information on points of crossing, joining and branching by synthesizing the angles between contiguous links.

The numbers of nodes and links, number of paths, and number of ship types are limited by the capacity of the computer used and the maximum numbers so far recorded are approximately 2,000 nodes, 1,000 links, 400 paths and 25 ship types.

An actual example of network for Osaka Bay is shown in Fig. 2.

(2) Simulation Execution Section

The programme of the input section of the simulation execution section carries out simulation by fully utilizing a number of items of information produced by the processing input data, prints out all the process on the output file, and then transfers to the programme of the subsequent execution section.

The detailed functions of the execution section are to have the ships successively generated at each path proceeding at the computed speed, to take records on the times of entrance into nodes and links and times departing therefrom, and after recording the identification number of the ship, ship type and the path number together with all the times of entrance and departure to and from all nodes and links, as an integral lot of data in the output file when the ship reaches the final node, the ship is then removed from the simulation.

As an established rule to be applied when a ship enters the next node or link and if the capacity of the node or link is exceeded by such an entry, a ship must wait before such a node or a link and entry is identified as not possible, and when two paths come to cross at a node and another ship is proceeding through the node, the ship must wait before such a node, until entry is identified as possible. Cancellation of the waiting mode is effected when a sea area enough to accommodate the ship is created in the capacity of the next node or link as the other ship has pro-

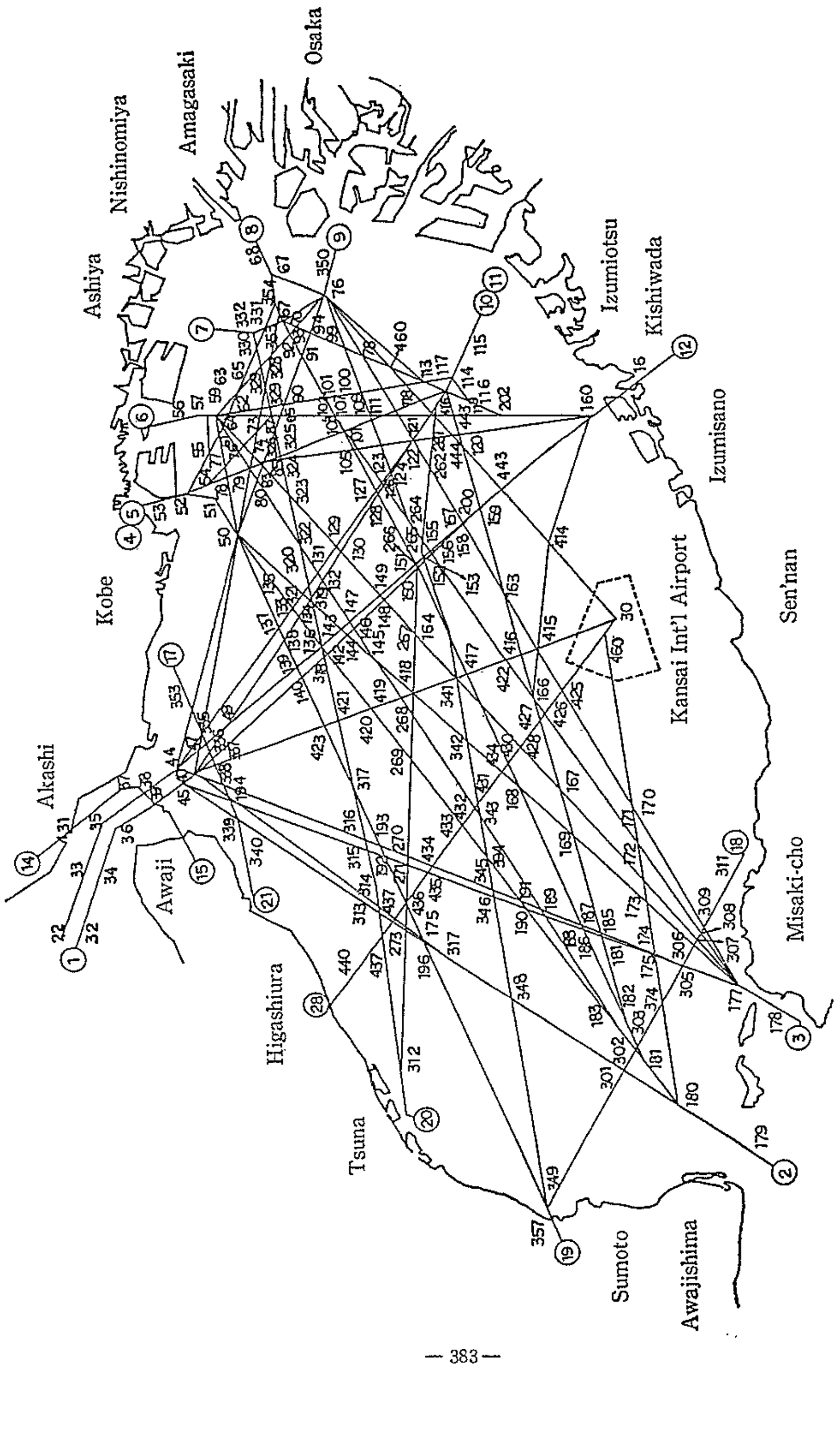

Fig. 2 Network in Osaka Bay

ceeded, while in the case of the crossing node, such a cancellation is made when the other ship has completed her crossing manoeuvres through the node.

Only the simulation process is recorded at the execution section without tables of statistical computations and recording being provided within the computer because the limited capacity of computer memory should not be reduced by inputting a large volume of data on the numbers of nodes and links, ship types and paths as this will create difficulties programme execution when additional functions are provided, as described later in 3.

The time increment system in the execution of simulation employed here, is of the sequential event system in which the time is incremented at every generation and removal of a ship, or at every entry to or departure from node and link, and not of the time slice system in which time is advanced by an elapse of t.

(3) Simulation Output Section

The simulation output section serves to obtain various statistical quantities by making reference to the information prepared by the simulation input section on the basis of the simulation process information created at the simulation execution section, and has the following output. However, since all the simulation process is recorded and kept in storage, the statistical quantities other than those described here are also available without attempting another traffic simulation, simply by making necessary programming.

(i) Distribution of waiting time at node and link
(ii) Distribution of numbers of waiting ships at node and link
(iii) Ratio of the number of waiting ships at a node, to that at a link
(iv) Utilization ratio at node and link
(v) Total trip period per path
(vi) Graphical presentation of the above-mentioned statistical quantities
(vii) 16 mm film describing the simulation process

In the case of the distributions here, the mean values and standard deviations are also obtained. For items (i), (ii) and (iii), these distributions and ratios can be determined for all the ships, specific ship types, all paths, specific paths, specific links and nodes, total time or specific time belt, or their combinations.

The utilization ratio shown in item (iv) represents a quantity derived by modifying utilization ratio ρ in the Queuing Theory. In the general queuing system, an average number of λ customers arrive at service counters at number S per unit period of time, and if the mean service period for one customer is denoted by $1/\mu$, then the utilization ratio of the service counter is defined by $\lambda/S\mu$, and this value completely agrees with the concept of utilization ratio which is generally used.

When this utilization ratio is subjected to modified use in the network simulation, care must be taken for such differences in phenomenon as may such as the case of the arrival of a ship or ships, which corresponds to the arrival of customers at a service counter in the Queuing Theory, involving the possibility where the capacity of node or link is fully occupied by only one large ship and another possibility in which a capacity allowance remains despite the entry of several small ships.

By taking into account such a point, the utilization ratio of links and nodes is defined as follows:

Utilization ratio at link/node

$$\rho=\lambda/C\mu \quad (1)$$

where

λ: equivalent mean ship arrivals per unit time. Accordingly, if n denotes the number of ship types, s_i the ship equivalence in terms of ship type i, λ_i the mean number of arrival ships per unit time, then

$$\lambda=\sum_{i=1}^{n}\lambda_i s_i \tag{2}$$

$1/\mu$: mean period of time required to pass through the link or node for 1 ship equivalence
Hence, if the mean period of time required by a ship of ship type i is denoted by $1/\mu_i$, then the following relationship holds:

$$1/\mu=(\sum_{i=1}^{n}\lambda_i s_i/\mu_i)/(\sum_{i=1}^{n}\lambda_i s_i) \tag{3}$$

capacity of link or node

On the basis of the above, the utilization ratio ρ can be expressed by the formula below by using λ_i, s_i and μ_i shown above:

$$\rho=\frac{1}{C}(\sum_{i=1}^{n}\lambda_i s_i/\mu_i) \tag{4}$$

In determining C and s_i, when the overall length of a ship i is denoted by L_i, C is assumed as the width of the traffic route, and s_i is assumed as bL_i, in the case of node, and C is assumed as the area of traffic route and s_i is assumed as $aL_i \times bL_i$, in the case of link. This idea is based on the concept of ship domain, which incorporates aL_i the component in ship's direction and bL_i the transverse component. The values a and b in usual cases are $a=8$ and $b=3.2$ according to the results of analysis on marine traffic.

As may be seen from the above definition, ρ is irrelevant to execution of the simulation, and thus it represents the value obtained at the time when input data is prepared.

When waiting ships are caused at a link or node during the process of simulation, if a stand is taken in such a way that these waiting ships are derived from the link or node capacity, then the utilization ratio ρ' with an extended coverage of the waiting ships can be expressed by the formula below with different symbols from the above formula:

$$\rho'=\sum_{i=1}^{N}c_i(t_i+w_i)/CT \tag{5}$$

where

i : ship passes at i-th order
c_i : ship equivalence i
w_i : waiting time of ship i
t_i : period of time required for ship i to pass
T : progressive time of simulation
N : total number of ships passed

When the waiting time for all ships is assumed to be zero, it naturally holds that $\rho=\rho'$. Generally, the relationship $\rho\leqq\rho'$ holds. For obtaining ρ', it is necessary to obtain the waiting time w_i but this is not available without carrying out the simulation. On the values pertaining to utilization ratio, ρ, ρ' and ρ'/ρ to be described in 2.3 are obtained for each node and link.

With specific relation to ρ, if $\hat{\rho}$ denotes the utilization ratio without considering the utilization of the waiting ship obtained by simulation, the formula below holds

$$\hat{\rho}=\sum_{i=1}^{N} c_i t_i / CT \qquad (6)$$

(symbols used here are identical with those used in defining ρ')
Further, $\rho=\hat{\rho}$ by assuming that $T \rightarrow \infty$. Since the adequacy in the performance of simulation can be checked through the use of this relationship, the value of $\hat{\rho}$ is also obtained at the output section. For checking to see if the performance of simulation is adequate, a list that compares the input data such as the number of ships per path, the time required for passage at links and nodes with actual simulated values is output as well as the forementioned $\hat{\rho}$.

The motivation for making a film of the simulation process as mentioned in (vii) may be identified in recognition of the shortcomings in the past where simulations were in many cases formed only by premises of simulation, flow charts and simulated results, and the handling of the detailed intermediary simulation process by computer was more or less a blackbox approach and a large part of it had to but be left to the producer of the simulation system. By making a film of the simulation process, every detail of simulation could be visualized for dynamic recognition in addition to those static data including formulae and numeral values which were the only former tools available to understand the simulation. Such an attempt was also motivated by the intention to mitigate the conventional drawbacks of the simulation were too specialized or not readily be understood.

Shown in Figs. 3, 4 and 5 are examples of one frame of film, and Fig. 3 shows a simulation example for the West Region of the Port of Tomakomai, while Figs. 4 and 5 represent examples of the Port of Osaka where Fig. 4 is the result of actual observation through the use of three radars and Fig. 5 shows the simulated results. In Figs. 4 and 5, the ship's dimensions were magnified in such a way that overall length L is expressed in $8L$ in the direction of proceeding, and $3.2L$ in the transverse

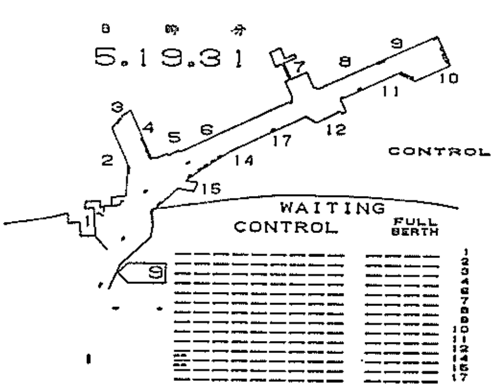

Fig. 3 One Frame of the Film Representation of the Simulation Process

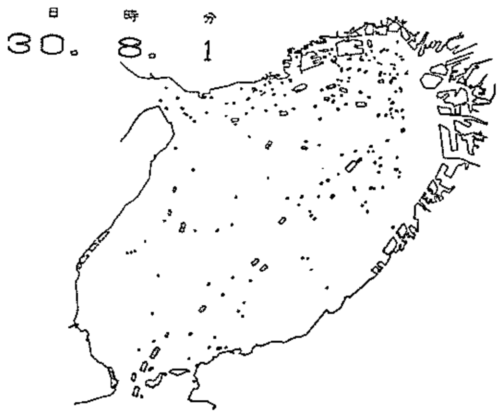

Fig. 4 Film Representation of the Actual Observation

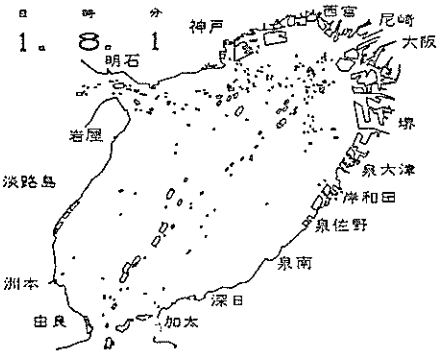

Fig. 5 Film Representation of the Simulation Process

direction since unmagnified representation of the ship's dimensions can not provide any realistic visual image.

2.3 Evaluation

The information obtained in output items can be utilized for the evaluation of marine traffic without any modification.

If the waiting time is referred to as the period required for collision-averting manoeuvres, and the number of waiting ships is regarded as the number of ships in collision-averting manoeuvres, then the simulated results can be readily connected to real marine traffic.

For instance, if the probability of the waiting time at a certain node exceeding one minute is 3%, it signifies that three ships out of one hundred ships proceeding to the node must make collision-averting manoeuvres for one or more minutes. Since such information is obtainable for each ship type, one can make judgement in such a way so that for large tankers, this degree of collision-averting period may be tolerated, or some alternative plan must be worked out in view of the frequent occurrences of collision-averting manoeuvres required, etc.

If absolute values of evaluation are available for the waiting time and the number of waiting ships, it is convenient that the merits of executing simulation increase correspondingly. However, the evaluated values undergo significant changes according to the topographic configuration, the traffic volume and availability of vessel traffic control and management system indiginous to specific area of water, and hence no such absolute values of evaluation have been established so far. Determination of absolute values of evaluation is thus left as a problem to be solved in the future.

The total trip period per each path per ship type is used for evaluating a system of traffic routes in a vast expanses of sea area, and by using the difference between the above and the total trip period involving no waiting time, assessment is made on a new plan for the traffic route.

In addition to the forementioned items of evaluation, the utilization ratio shown in **2.2**(3) may also be used for the purposes of evaluation. Three types of utilization ratio, ρ, ρ' and $\hat{\rho}$ were defined there, but ρ and $\hat{\rho}$ are the values that come to coincide with each other when simulation is properly carried out, and the value ρ can be obtained at the stage when the input data is prepared which seldom exceeds 0.2 even in remarkably congested areas of water according to our empirical data. As may be readily understood from the equation, ρ and $\hat{\rho}$ increase in linear proportion to the increase in traffic volume. Although ρ' also increases in linear proportion, as does ρ when traffic volume is not so large, and when it reaches a certain point the value shows a steep rise due to the increase in waiting time, and hence, if value ρ/ρ' is large, the passage of ships becomes difficult. On the contrary, when the value closes to 1, such difficulties disappear.

On the subject of degree of marine traffic congestion, some explanations may be required for the concept of a waiting time. However, in evaluating the adequacies of the number of berths, the capacity of anchorage and measurements of the effect of various regulatory requirements for marine traffic, network simulation can give fairly reliable results provided that input data are supplied correctly since microscopic ship motions and finely tuned ship manoeuvring judgements give no material effects on the simulated results.

Shown in the above are the evaluation techniques using the numerical results of simulation. However, the film representation of all the simulation processes not only has a large effect on the performance of the simulation procedure in checking the calculations, but also helps determine the entire image of marine traffic through visual representation just as in the case of making the film representation using handy memo motion cameras used in making layouts in factories, offices and stores where effective evaluations were available through such visual means.

In concluding the section on the subject of evaluation, mention must be made of the adequacy of the principle that a ship which has proceeded at a fixed speed stops instantaneously at a link or a node on realizing that no entry thereto is possible, and later resumes passage at the original fixed speed immediately on noting that entry becomes possible. On this point, Hirano[13] has reported the similarity of ship passage in marine traffic to land traffic as exemplified by cars waiting at crossings, and also, the results of study by Oshima[12] on the ratio of ships in collision-averting manoeuvres in the Eastern region of Bisan Seto showed a fairly good agreement with the results of a network simulation of the same area of water with specific relation to the number of waiting ships. In the light of the foregoing, the principle may be said to have been partially proved, and the usefulness of the network simulation in other aspects of evaluation of the degree of traffic congestion may suggest the possibility of absolute evaluation in addition to the conventional relative evaluation.

3. Addition of Functions

In 2, the basic factors of the network simulation have been explained, but these are not sufficient for a complete simulation of actual marine traffic. The functions described in the following sections represent those necessary for simulating an actual plan for the marine traffic.

3.1 Temporal Variations in the Ship Generation Distribution

Although the volume of ship traffic undergoes temporal variations, it has been verified that such a volume is featured by a random distribution having a mean value, and in many cases the mean value also changes as time elapses. This may easily be recognized from the fact that the pattern of marine traffic does not remain the same at night, in the morning, in daytime and in the evening. Therefore, it may be important to carry out simulation for congested marine traffic in the morning and also in the evening. However, such a state of heavy traffic density does not continue throughout a day, and for executing simulation closely correlated to actual temporal transition of marine traffic in its declining process in the morning and in the evening, the provision of additional functions is considered necessary.

3.2 Timewise Variation of Link Capacity

The link capacity was made changeable by time to give an additional function for making it possible to evaluate fishing operation within traffic routes. By making the link capacity zero according to time, such a function makes it possible to evaluate the calmness within harbour area if the link capacity is changed according to the entering/leaving port regulations at night and the weather conditions.

3.3 Priority Traffic Routes

If priority traffic routes are designated for the traffic routes as in the case of those covered under the provisions of the Maritime Safety Law, the passage of a ship at the node of crossing and joining on such a traffic route has priority over the other traffic routes.

3.4 Introduction of a Certain Form of Traffic Control

Introduction of a certain form of traffic control may be considered where priority is given to specific types of ships of those moving on the network. In this case, traffic control is executed in such a way that the scheduled link and node to be passed by such a priority ship are evacuated in advance and the entry of other non-priority ships restricted.

This serves to restrict the entry of non-priority ships to the related link and node whenever the priority ship reaches designated link or node.

3.5 Designation of Discrimination between the Equivalence and Actual Number of Ships

When the capacity of a link or a node is given in terms of the equvalence of conversion, utilization of such a link or node to its capacity is possible provided that the capacity has the required allowance. However, in some cases, a link or node can become unusable even if one ship occupies it. For these links and nodes, there is an additional function to change the equivalence volume used in making decisions as to whether the entrance to a link or node is either in service or unoccupied.

3.6 Concept of Berths

By assuming a node as a multiple numbers of berths of the compatible type, the number of berths is given in place of node capacity, and the period of berthing operation is given in place of passing period. In this case, the ship equivalence represents the number of ship, and hence numeral 1 is given, but in the case of a continuous berth, the node capacity is given by the linear length of berth (m) whereas the ship equivalence is given by the addition of total length L plus the length of allowance.

3.7 Change of Path

For the possible case where the necessity arises to stop a ship due to the reasons as stated in 3.2, 3.3 and 3.4, or when the necessity arises for a ship to wait due to the state of full berth as mentioned in 3.6, a function of predicting such situation and changing the paths is provided. When the berth is found to be full, the ship is led to an anchorage for waiting there till the planned berth becomes available.

3.8 Cyclization of Traffic Routes

Traffic routes may incorporate cyclic loops in their intermediate stages, but the point of commencement and point of termination of each traffic route are not coincident. However, in consideration of those ferries, small waterborne craft in smooth water areas and sediment carriers for reclaiming work, etc., which do not disappear from the scene of simulation, a function of cyclization has been imparted to the network simulation.

4. Conclusive Notes

Network simulation was created in its primary model in 1975. This was the result derived from the need to cope with the growing demand for simulation techniques applicable to marine traffic in large areas of water which were beyond the scope of coverage by the conventional simulations which was good only for simulating ship traffic flow, along with other demands for developing a simulation system of higher performance and workable with computers of small capacity requiring a shorter computation time. In short, the development of network simulation was encouraged by the predominant demand for a system for the macroscopic overall assessment of marine traffic at the cost of finely tuned pin-pointed traffic assessment. At the early stages of the development of simulation, emphasis was laid on the relative evaluation of alternative marine traffic plans. However, with the increasing frequency of utilization and expanding scope of application of network simulation, thanks to the valuable guidance and advice of those experts and learning including the shipping concerns, it is gaining wider acceptance among users because of the extreme ease offered by the system for understanding its basic principles, and the advantage of proven agreement of simulated results with the on-going status of marine traffic. The author of this paper, as a developer of network simulation techniques, is strongly aware of his responsibility regarding the adequacy of the absolute numeral values used in simulation assessment, as these are a controversial subject today in the complete absence of a simple and reliable alternative simulation system.

Although several attempts were made for the partial development of a network simulation system through the incorporation of parameters for ship manoeuvring judgements corresponding to ship type while giving account on the ship manoeuvring characteristics such as the turning ability and speed acceleration/deceleration characteristics, intended for microsimulation, however, is proving that network simulation techniques will still remain an extreme form of simplification of premises which are readily understandable to everyone since microsimulator has the added complexity of the premises and a weakness in convincing many researchers.

One noteworthy thing in the sound growth of network simulation is the very fact that it owes much of its success to the observation of actual marine traffic which has demonstrated extremely significant development within the field of maritime transport technology. Because it may not be too much to say that the determination of path of ships per each ship type represents one type of input data, this system might have been absolutely impossible without the reliance on the results of such observation of actual marine traffic.

In this paper, discussion has been made only on the theoretical aspects of the network simulation at this time in the absence of practical application examples. However, most of those references cited in this paper, although in Japanese, have relevance to the practical application of the network simulation techniques, and hence the author feels that reference to them is necessary as they cover a wide spectrum of considerations on marine transport technology as exemplified by the assessment of the system of traffic routes, preparation of port and harbour plans, assessment of the impact of marine traffic on the construction project of man-made islands, assessments of coastal land roads and bay bridges and many others, and according to recent information, several projects of utilizing the network simulation techniques are under way within fiscal 1987.

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