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MODELLING AND SIMULATION OF PORT OPERATIONS

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Abstract:

A generalized, operational, dynamic computer simulation model of a multipurpose port has been developed. It has been implemented for two Australian ports and used to simulate the effect of investment and technological alternatives.

The model package embodies statistical programs specially developed for accepting raw port data and analysing them to provide necessary inputs to the port simulation model. The model can produce a wide variety of outputs.

INTRODUCTION

Marine transportation plays a significant role in Australia's inter-regional and international trade. It has been estimated that over 60 percent of inter-state and almost all of the overseas cargo is handled through Australian ports (BTE, 1976). It is, therefore, crucial to improve efficiency in ports through reduction of delays and costs to stay competitive in international markets. Moreover, revolutionary changes are taking place in shipping technology in general and cargo handling systems in particular. This necessitates massive investments in port facilities. A rational approach to aid decision-making relating to port investment is, thus, highly desirable.

Motivated by the above considerations, a research project was undertaken to develop a capability to aid the planning and decision-making process for port operations which can

- provide insights into the performance of ports under varying demands and with the use of new types of ships and cargo handling systems
- evaluate a wide variety of operating and investment alternatives
- identify ways and means of improving efficiency in a port.

The primary objective of this research, which is supported by the Bureau of Transport Economics, was to develop a generalized, operational, dynamic computer simulation model of a multipurpose port. Some of the features of this model are the following:

- The model should provide a conceptual framework for integrating the general port structure and operations, information flows and decision-making functions in the port;
- The generalised model was required to be capable of representing the operations of any port by feeding specific information about the port configuration, distributions and regulations;

- The model to be developed had to be capable of accepting port operations data without requiring any data analysis by the user. Associated statistical and data processing programs to provide estimates of relevant model parameters and probability distributions were to be developed;

- The capability of the model had to be demonstrated by simulating technological, operational and investment alternatives for a specific port;

- As an additional requirement, it was considered that the model be as easy to use as possible. Input data requirements were to be restricted to unprocessed data and a variety of outputs were to be made available to meet various requirements of the potential model users. These include an echo of the input data; summary of key operational statistics; statistics on cargo flows, berthing facilities and labour and equipment productivity; and a number of histograms of output variables. In addition, an output representing the complete trace of a simulation run was also to be made available. By specifying an option, the user could obtain the required output in an elegant and clear format.

The scope of the model was, however, limited to the front-of-port operations. Cargo volume forecasting was outside the scope of the model. The cost parameters were not included in the model and, therefore, no financial performance indicators could be determined. The evaluation of investment policies was limited to the determination of operational improvements in response to the provision of newer or better facilities.

MODEL DESCRIPTION

The port model is structured around a number of basic elements and concepts. The physical elements include berths, channel, equipment, manpower, ships and cargo. The operation of the model is dependent upon the priority systems which operate in the port and the operating data relating to ship arrivals, ship service times, times spent in port, etc. This section outlines the way in which the physical features and the operations of the port system are handled.

Port Configurations

Berths: The model is capable of handling port configurations with any number of berths. A berth is considered to be a continuous length of wharf beside which a ship can tie up. Berth characteristics required for the model include the length, the depth, the channel segments required for a ship to move from outside the port to the berth, the minimum allowable depth clearance of a ship and the cargoes which can be serviced at the berth. For each berth, the model maintains a list of the ships and a list of the quantities of each type of equipment currently being used.

Channels: The model is designed to cater for channel configurations ranging from a simple, one-segment channel to a network of channel segments. Channel segment characteristics which must be specified in the model include the depth , the length, the minimum allowable depth clearance for a ship using the channel segment, the minimum allowable time between successive ships using the channel segment, and the time taken for a ship to traverse the segment.

Trade Commodities and Ship Type

Trade commodities: All cargo flowing through the port is divided into distinct groups which are based on berth, labour and equipment requirements. Typical groups are meat, wool, petrol, bulk wheat etc. The characteristics of each group include the required berth - equipment combinations in order of preference, the cargo handling rates, whether an import or an export, the priority rating of the cargo (1 = highest priority), the shifts and the days of the week that the cargo can be worked.

Ship types: The ships which call at a port can be classified into groups according to their physical characteristics. Ship characteristics considered in the model include the length, draught, gross registered tonnage, net registered tonnage, number of holds, container capacity and dead weight tonnage. Most of the physical characteristics are related to the ship's dead weight tonnage through regression relationships. For each ship type, the coefficients for each of the relationships are input to the model. Default regression coefficients (BTE - Regression Analysis of Ships' Characteristics, 1978) for some ship types are built into the model and are used if alternative coefficients are not specified. The ship types having default regression coefficients are Container, RoRo, Bulk Carrier, Ore Carrier, Tanker, General Cargo and Passenger. These default coefficients exist for the length, draught, gross registered tonnage, net registered tonnage and container capacity. Other properties such as cargo types, cargo tonnages, number of holds are generated from histograms derived from the port's working history.

Equipment and Labour

Mechanical equipment and men are both treated as items of equipment in this model because they have similar parameters such as availability, working rate, etc. For each type of equipment, the characteristics which must be input to the model include the total quantity, the proportion of the total quantity available in each shift, the berths on which the equipment can operate, and whether the equipment type is manpower or machinery.

The model allows for the possibility that there may be more than one group of manpower (for example, grain terminal operators, waterside workers, etc). The manpower is considered in units of men rather than gangs which vary in size. The men are formed into gangs when they are required to work a cargo. The size of the gang depends on the type of cargo to be worked and the type of machinery to be used to work the cargo. The model maintains a comprehensive status of all the equipment in use at a particular berth,or idle but available for use.

Priority Systems

The model operates according to rules which are embodied in a number of priority systems, each applying to a different area of operations (e.g. channel use, berth allocation, etc).

General port priority system: One of the characteristics of each cargo type is its priority relative to all other cargoes which use the port. Newly arrived ships are put into a queue according to this priority system to await allocation of a berth and equipment. In the queue, ships with the same priority are listed in order of time of arrival.

Channel priority system: The channel priority system depends on the direction of movement of the ship and the priority of the ship. The priority system divides traffic into outgoing ships, ships changing berths and incoming ships.

The outgoing ships are given the highest priority. Within each of these groupings, the ships are ordered according to the ship's priority which is equivalent to the priority rating of the highest priority cargo of the ship.

Ship's preferences for berths: For each type of cargo, the berth-equipment combinations suitable for handling the cargo are ordered according to the relative preference for each. The ship is allocated a berth and equipment in line with the first of its preferences for which all the requirements of the preference are fulfilled. If none of the preferences can be satisfied, and if immediate pre-emption is not possible, the ship must wait.

Pre-emption: In the model input the user must specify which combinations of ship types and cargoes can be immediately pre-empted as well as whether end-of-shift pre-emption is possible. If end-of-shift pre-emption is operating then a ship (A) can pre-empt a ship (B) at the end of the shift only if ship (A) has a higher general port priority and ship (B) can be physically accommodated at some other berth.

Ship Arrivals

The model contains two alternative methods for generating the arrivals of ships at the port. The first and more commonly used method involves the use of an interarrival time histogram. The second method involves the use of two histograms - one giving the number of ships per day and the other, the time of day of ship arrivals. The user specifies the method to be used, based on th results of analysis of ship arrival times from the statistical package. when a ship arrival occurs, the type of ship and the number, types and tonnages of the ship's cargoes are deterimed from a list giving the probability of occurrence of each combination. This list of probabilities is compiled from the port data, as are the histograms related to the ship arrivals. The physical characteristics of the ship are generated as described earlier.

Service Rates

Total time spent in port by a ship is partially determined by service rate. In the model, these service rates (tonnes/per hour) are found from the histograms of work rates for each berth-cargo-equipment combination at the start of each shift. In situations where such histograms are not available (e.g. fishing vessels), the total time spent by the ship in port is determined directly from appropriate histograms.

Delays

Service delay: Service dealy includes strikes, delay at the beginning and end of the shift due to organisation of men and machinery, delay due to poor weather conditions, equipment breakdowns and workers' meal breaks. The total service delay is obtained from histograms which are developed from port data for each cargo at each berth.

Delay due to port configuration: Ships face delays in movement around the port due to constructions caused by the port layout and operating characteristics. Causes of these types of delays include unavailability of required channel segments, limitations due to possible daytime restrictions on channel use, and restrictions due to the tide. During a simulation run, these delays will occur naturally in response to appropriate conditions.

Delay due to current operating conditions: Some of the delays to which ships may be subjected, can be attributed to the operation of the port. These include temporary unavailability of tug or a pilot or unavailability of a desired berth, machinery or manpower. These are generated normally during the running of the model.

MODEL STRUCTURE

The structure of the model is represented in Fig. 1. A brief description of the major blocks is given below.

Port Data

The port data contains a history of operations data of the port such as ship arrivals and gang workings as well as details of port configuration and operating procedures. The history of operational data is used as input to the STATISTICAL PACKAGE while the configuration and operational details are input to the INPUT phase of the simulation.

Statistical Package

This is a set of programs run before the simulation and designed to produce files of histograms which are read in during INPUT phase and then used for random variable generation (Monte Carlo technique) in the simulation. These programs use as input, data on ship arrivals, cargo tonnages and ship workings and produce histograms of parameters such as inter-arrival times and work rates.

Input

The first part of the simulation involves reading an input file containing operational details of the port as well as files of histograms produced by the STATISTICAL PACKAGE.

Port

The function of the input phase is to create an entity called a PORT which carries all the information necessary for the simulation. The information stored relates to berths, channels, equipment, working hours, cargo characteristics, ship type characteristics, ship type characteristics, ship arrivals and service times.

Ship Generator

The flowchart shown in Fig. 2 illustrates the procedures followed in the generation of a ship's characteristics. The SHIP GENERATOR uses the data, regression coefficients and the histograms stored in 'PORT' for this purpose.

Berth and Equipment Controller

The BERTH AND EQUIPMENT CONTROLLER incorporates procedures for the allocation of berths and equipment during the model operation as well as the pre-emption procedures. The berth allocation procedure is invoked at the arrival or departure of a ship, at the start of a shift and when a ship releases equipment. Equipment allocation is attempted after an allocation of a berth to a ship after the release of

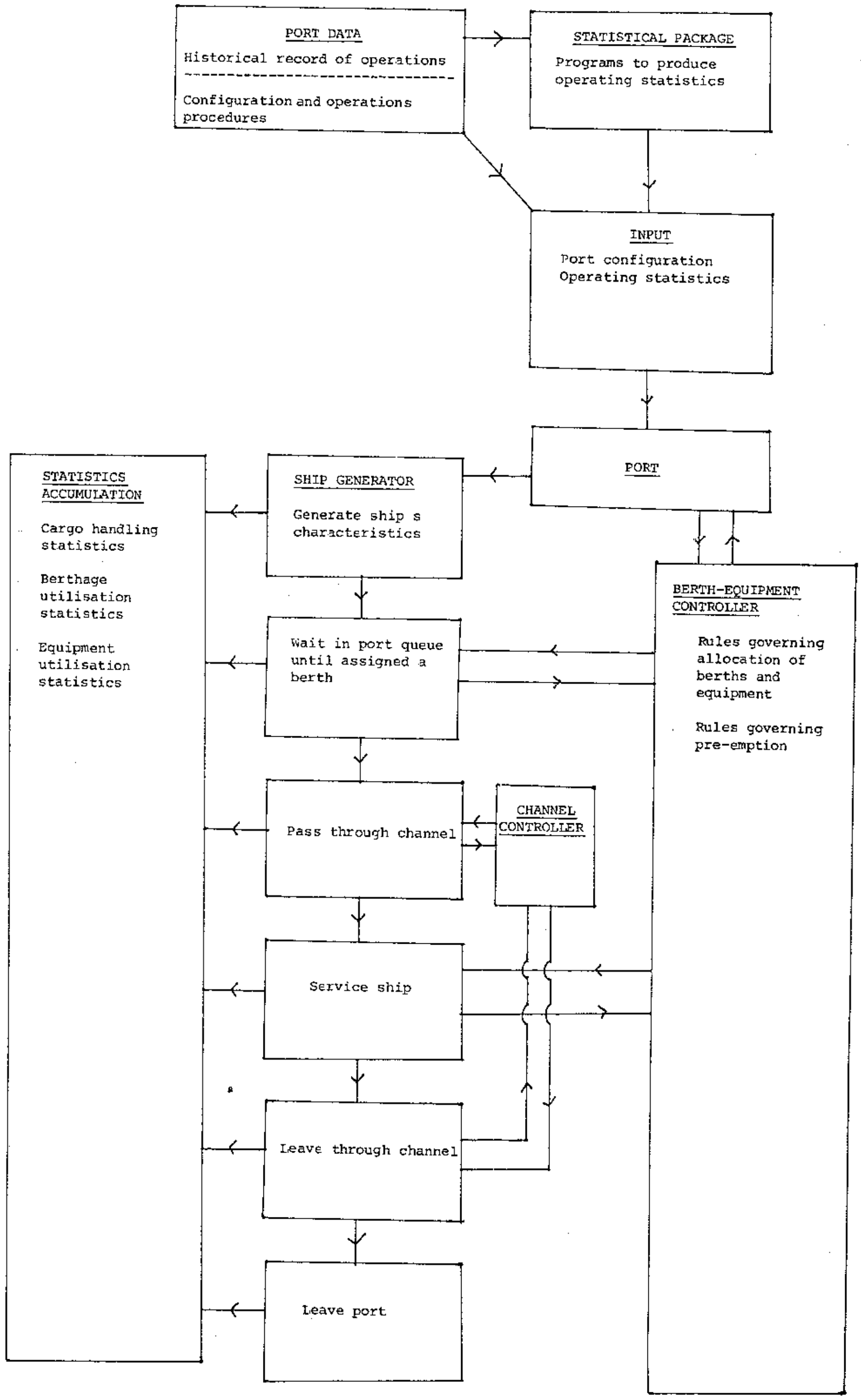

Figure 1: Structure of the Port Simulation Model

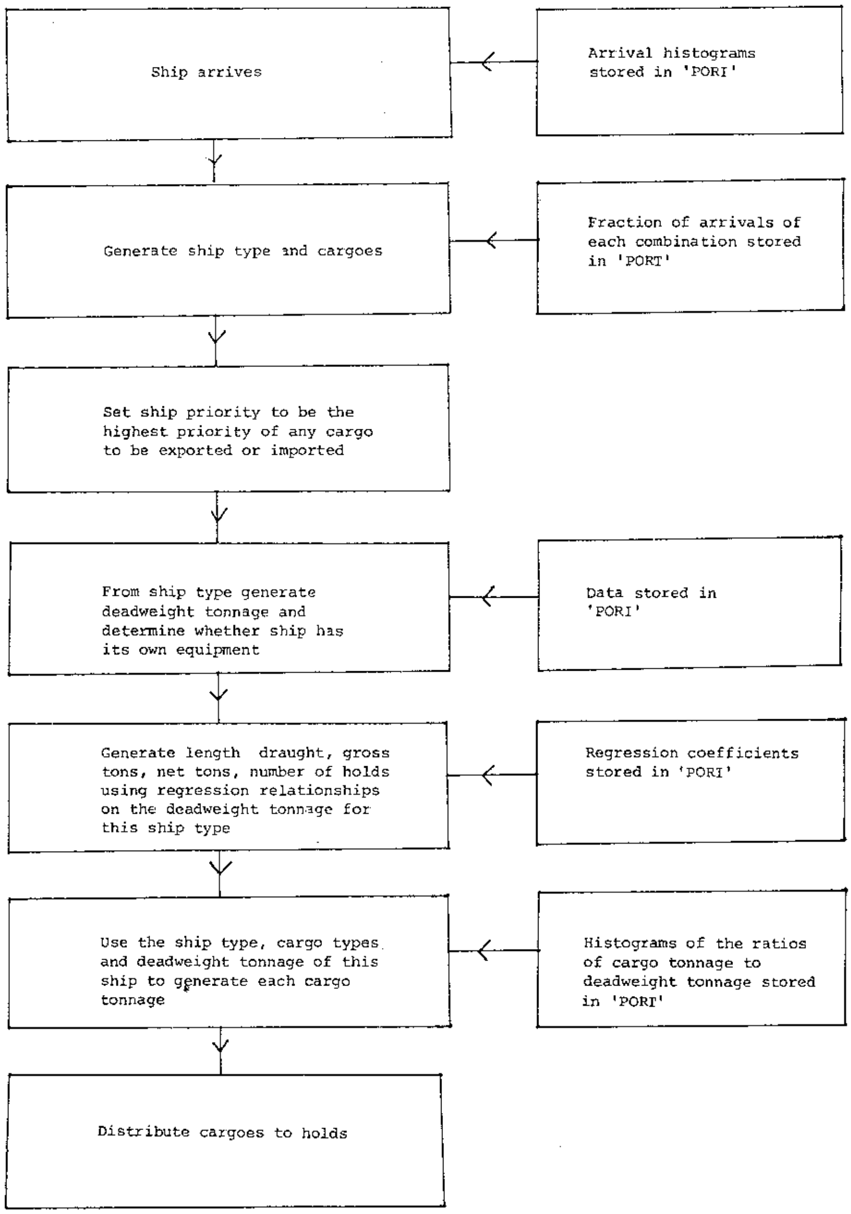

Figure 2: Procedure for Generation of Ship's Characteristics

equipment, and at the beginning of a shift. The pre-emption procedures allow the pre-emption of ships, based on relative priorities, to take place at the end of each shift. In addition, ships which have been designated to have zero priority in the port (eg. small fising vessels) can be immediately pre-empted during the berth allocation procedure

Channel Controller

The CHANNEL CONTROLLER ensures that all shipping traffic is directed in accordance with the channel priority system and safety regulations relating to headway and draught. A ship waiting to use the channel is placed in a queue until traffic and tidal conditions allow access to the required channel segments.

Statistics Accumulation

A large number of statistics on port facilities and operations (also called performance indicators) is accumulated to provide management information for planning and control. However, it is possible to obtain a selected list of statistics based on a port authority's particular requirements and objectives. Some representative outputs are shown in the next section.

SIMULATIONS

Model Simulation

The model was implemented using data from a relatively small Australian port. Simulation of port operations from July 1977 to July 1978 produced the results presented in Tables 1, 2, 3 and 4. The actual performance statistics are included in parentheses in these tables.

Policy Testing

Capital investment: The performance benefits achieved from additional capital investment in a new general-purpose berth were investigated. The new situation was easily modelled by making some small changes to the port configuration data, and to the lists of berth-equipment preferences.

Changes in technology: The model can be applied to the task of evaluating improvements in materials-handling technology. The effects of installing a new conveyor system which doubles the grain loading rate are easily simulated.

CONCLUSIONS

The model simulations have demonstrated the usefulness of the model for evaluating a variety of policies based on economic, technological and institutional alternatives which can help plan port development and operations.

The model is readily adaptable to simulate any multi-purpose port. It requires no statistical analysis of the port data by the user and provides a variety of useful outputs.

REFERENCES

Bureau of Transport Economics (1976). "Estimates of Australian Inter-regional Freight Movements 1971-72", AGPS, Canberra.

JAMES COOK UNIVERSITY PORT SIMULATION MODEL
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STATISTICS ON SHIP TYPES
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DATE: 24/08/1980

PERIOD: 24/08/1980 TO 24/08/1981

STATISTICS	GENERAL	TANKER	ORECAR	BULKCAR	RORO	FISHING	NAVY	LIVESTOCKCAR
1. NUMBER OF SHIPS(SHIPS)	32.00	27.00	15.00	50.00	0.00	7.00	5.00	1.00
2. AVERAGE ARRIVAL RATE(SHIPS/DAY)	0.09	0.07	0.04	0.14	0.00	0.02	0.01	0.00
3. AVERAGE WAITING TIME PER SHIP(HOURS)	19.39	26.58	17.03	2.61	0.00	0.00	0.00	15.01
4. AMMOUNT OF CARGO DISCHARGED(TONNES)	0	78740	157284	0	0	0	0	0
5. AMMOUNT OF CARGO LOADED (TONNES)	82686	15828	1780	780541	0	0	0	8395
6. COMBINED TOTAL OF CARGO TONNAGE(TONNES)	82686	94569	159064	780541	0	0	0	8395
7. SERVICE TIME PER SHIP(HOURS)	54.76	24.18	99.66	172.92	0.00	0.00	0.00	267.04
8. TURN AROUND TIME PER SHIP(HOURS)	82.75	50.76	116.69	177.13	0.00	423.25	21.97	282.06
9. CARGO HANDLED PER BERTH HOUR(TONNES)	49	145	106	90	0	0	0	31
10. CARGO HANDLED PER GROSS GANG-HOUR(TONNES)	76	0	77	257	0	0	0	39
11. CARGO HANDLED PER GROSS MAN-HOUR(TONNES)	6	0	5	29	0	0	0	3

*********************END OF STATISTICS ON SHIPTYPES******************

TABLE 1

JAMES COOK UNIVERSITY PORT SIMULATION MODEL
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SUMMARY OF PORT OPERATIONAL PERFORMANCE INDICATORS
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DATE: 24/08/1980

PERIOD: 24/08/1980 TO 24/08/1981

INDICATOR	VALUE FOR THE PERIOD	UNITS
1. AVERAGE ARRIVAL RATE	0.4	SHIPS/DAY
2. AVERAGE WAITING TIME	12.7	HOURS/SHIP
3. AVERAGE SERVICE TIME	94	HOURS/SHIP
4. AVERAGE TURN-AROUND TIME	131.6	HOURS/SHIP
5. AVERAGE CARGO HANDLED PER BERTH-HOUR	87.7	TONNES/HOUR
6. AVERAGE CARGO HANDLED PER GROSS GANG-HOUR	175.7	TONNES/GANG-HOUR
7. AVERAGE CARGO HANDLED PER GROSS MAN-HOUR	15.3	TONNES/MAN-HOUR
8. FRACTION OF TIME GANGS UNASSIGNED	0.794	
9. FRACTION OF TIME GANGS IDLE	0.254	
10. AVERAGE FRACTION OF TIME BERTHED SHIPS WORKED	0.383	
11. AVERAGE BERTH OCCUPANCY	0.368	
12. AVERAGE NUMBER OF SHIPS IN PORT	2.04	SHIPS
13. MAXIMUM NUMBER OF SHIPS IN PORT	7	SHIPS
14. TOTAL CARGO HANDLED	1119423.9	TONNES
15. TOTAL NUMBER OF SHIPS	137	SHIPS

********************END OF SUMMARY*******************

TABLE 2

JAMES COOK UNIVERSITY PORT SIMULATION MODEL
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LABOUR AND EQUIPMENT PRODUCTIVITY
****

DATE: 24/08/1980

PERIOD: 24/08/1980 TO 24/08/1981

RESOURCE	AVAILABLE	ALLOCATED	IDLE
LABOUR(MAN HOURS)			
PORT-MEN	287880	45521	10276
GRAIN-MEN	71970	28567	8532
EQUIPMENT(HOURS)			
GRAIN-LOADER	4798	3174	1624
MOBILE-CRANE	19192	511	18681
SHEEP-RAMP	9596	828	8768

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AVERAGE TONNES HANDLED PER GROSS GANG-HOUR: 174.8

AVERAGE TONNES HANDLED PER NET GANG-HOUR: 236.8

AVERAGE TONNES HANDLED PER GROSS MAN-HOUR: 15.2

AVERAGE TONNES HANDLED PER NET MAN-HOUR: 20.4

AVERAGE TONNES HANDLED PER GROSS SHIP WORKING HOUR: 229.2

AVERAGE TONNES HANDLED PER SHIP HOUR IN PORT: 77.2

AVERAGE TONNES HANDLED PER SHIP HOUR AT BERTH: 87.7

**********END OF LABOUR EQUIPMENT STATISTICS***********

TABLE 3

PER SHIP HOUR AT BERTH: 87.7

**********END OF LABOUR EQUIPMENT STATISTICS************

TABLE 3

JAMES COOK UNIVERSITY PORT SIMULATION MODEL
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STATISTICS ON BERTHING FACILITIES
****

DATE: 24/08/1980

PERIOD: 24/08/1980 TO 24/08/1981

BERTH *****	CARGO/NET GANG-HOUR (TONNES) ******************	RATE OF BERTH OCCUPANCY **********************	AMMOUNT OF CARGO HANDLED (TONNES) ***********************	SHIPS SERVICED (SHIPS) *************
BERTH-1	83.8	0.624	133868.3	42.0
BERTH-2	364.0	0.658	812159.7	54.0
BERTH-3	87.8	0.290	78827.4	22.0
SOUTH-JETTY	0.0	0.242	94568.6	40.0
NORTH-JETTY	0.0	0.024	0.0	9.0

END OF BERTHING STATISTICS

TABLE 4 .

Table 5: Some Simulation Results

	Basic Model	Improved Grain Loader	Additional General Berth
Average waiting time (hours)	12.7	4.4	12.2
Average service time (hours)	94.0	54.0	95.0
Average turn-around time (hours)	131.6	82.9	132.3
Average berth occupancy	0.368	0.243	0.310
Average number of ships in port	2.04	1.29	2.05