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A SIMULATION MODEL OF TOTAL PORT OPERATIONS

by

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ABSTRACT

FACULTY OF MATHEMATICAL STUDIES

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This thesis describes the work done in developing a simulation model of total port operations for Sir William Halcrow & Partners Ltd, a firm of civil engineering consultants based in Swindon.

The author discusses work previously undertaken to model port operations. This consists of reviewing the use of both simulation modelling, and queuing theory.

The model itself is then described in depth. The model was developed using the Tochsim simulation shell, which was produced by the Operational Research Group at the University of Southampton. It uses the three phase discrete event method of simulation. Both the model and Tochsim were written in Borland Pascal for Windows using Object Oriented Programming.

The verification and validation of the model is considered. The author reviews work done previously in this field, including a discussion of the concepts of model credibility and user confidence. The process of verifying and validating the model is described, including the techniques used. Finally a case study is presented.

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CHAPTER ONE
INTRODUCTION

This project is a continuation of the work started by the author[33] in his M.Sc. thesis of 1993. The project originally arose out of the desire of a firm of civil engineering consultants called Sir William Halcrow & Partners Ltd., wishing to improve their port planning capabilities. In 1989, they had commissioned work by Gooding[16] and Nicell[25] to develop a general port simulation model. However this was undertaken as an M.Sc. project at the University of Southampton, and the three month time limit for the project, had restricted the depth in which the authors were able to go.

This time round a more complex and comprehensive model was required. As has been stated, the first phase of the model, which was to model ship arrivals and departures from a port, was also carried out as an M.Sc. project. The remainder of the model, was developed as a Teaching Company Scheme (TCS) project.

The TCS is a body, partially funded by the Department of Trade and Industry, which tries to combine the skills of academia and industry, and produce something innovative for the company taking part. The projects last for two years, and in this instance, the academic partner was the University of Southampton, and the industrial partner was Sir William Halcrow & Partners Ltd., the objective being to develop the port simulation model.

This thesis presents a literature review of the work undertaken in port modelling., and then a detailed explanation of the port simulation model developed is given. Finally, the use of verification and validation is discussed, in relation to models in general, and then the port simulation model itself. The use of verification and validation to help in obtaining model credibility and user confidence is also discussed.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

In the sixties and seventies the sizes of vessels increased dramatically, due to increasing economic activity. This resulted in ports needing to be enlarged to cope. At the time, past experience, rules of thumb, and physical scale models were the main methods used to design and develop ports. The increasing complexity of the requirements meant that new methodologies were needed. Among the organisations that responded to this call were, the Permanent International Association of Navigation Congresses (PIANC) and the United Nations Congress on Trade And Development (UNCTAD). PIANC drew up general recommendations for port dimensions, and UNCTAD published several books including the Port Development Manual.

These days, ports are often designed and developed based on master plans which usually consider the port's future over a period of at least 20 years. In order to consider and evaluate the possible options, two mathematical based techniques are now available, namely queuing theory and simulation modelling. Easa[10] says ,

> *"Queuing theory is attractive for situations in which the system is simple and is compatible with the assumptions required for the theory. Simulation is the alternative method to be used when the system is complex, or becomes difficult to model mathematically."*

Other authors are more assertive.

Koutitas[20] says,

> *"Queuing theory can be applied only after such simplifications on the properties of*

the modelled system, that the validity of results becomes dubious."

and MacKnight[21] says,

> *"The development of simulation models to reflect accurately the operations of a transportation system can be an expensive and time consuming task. However, the complexity of operations of many bulk transportation systems leaves little choice as analytical methods are clearly inappropriate. The development of appropriate software has now reached a stage where the results from simulation can be used with confidence."*

While simulation can certainly be applied successfully to many more port systems than queuing theory, queuing theory does still have a valuable role to play. Results produced by authors like Mettam[23] and Crook[6], while produced over 20 years ago, are still applicable today, for the types of system that they were produced for. The use of queuing theory is discussed in section 2.2, and as will be seen, work using the theory is still being carried out up to the present day.

To a certain extent queuing theory and simulation modelling go hand in hand. Authors have used simulation models to verify the accuracy of results produced from queuing theory models, and standard queuing theory models can be used to aid the validation of a simulation model. The use of simulation modelling is discussed in section 2.3.

2.2 The role of queuing theory

An early paper on the application of queuing theory to port operations, was by a partner of Bertlin & Partners. In 1967, J. D. Mettam published a paper showing how queuing theory could be applied to the planning and design of ports, to forecast realistically the likelihood of congestion and costly delays, as ships wait for berths. By analysing the results of case studies of shipping data he was able to make some assumptions about the arrival and service times of vessels. He assumed that arrivals followed a Poisson distribution, and that service time followed a Negative Exponential distribution. He found that where service times did not fit a simple Negative Exponential curve, an Erlang distribution was appropriate, with $k = 2$ giving the best fit.

Using the assumption that arrival times fit a Poisson distribution and that service times fit a Negative Exponential distribution, he plots a graph of the ratio of waiting time to service time for a varying number of berths (1 to 20). He then presents a method to use this graph to forecasts delays. He states that even without using the methodology presented, the graph alone gives some useful guidelines for port planners.

Mettam's work was very important and has been much referenced and used. His method for forecasting delays is easy to use, and so particularly useful for people, such as in the third world, who may not have access to computing facilities. It is also a quick way of doing some back of the envelope calculations.

Crook, who is (or was) a member of UNCTAD's Shipping Division, produced a similar style paper in 1980. It gave useful tabular information on the relationship between berth occupancy and ship waiting time, in terms of units of service time, based on Negative Exponential arrivals and Erlang 2 service times. He states that while a more sophisticated approach would be to develop a simulation model,

> *"Research by UNCTAD has considered both approaches, and ...suggests that queuing theory gives sufficiently accurate results..."*

The results from the paper can be used by a port planner to select the number of berths required by the port, and to estimate queuing times. Crook states that for bulk liner operations, an $M/E_2/n$ queuing model is chosen, while for specialised vessels at specialised terminals, he suggests that an $E_2/E_2/n$ queuing model is more appropriate.

In 1971 Miller[(24)] looked at queuing at a single berth shipping terminal. Specifically he was looking at the delays that were likely to occur at a floating terminal planned to handle liquid cargos at an Australian port. Miller references Mettam and states that while this paper is only concerned with 1 berth, as apposed to Mettam's paper which considered a range of berths, this paper would give more detailed results for this 1 berth.

Daganzo[7] (1990) considered the peculiar problem that arises at multipurpose port terminals servicing two traffic types, namely liner traffic (primary), and tramp traffic (secondary), with the liner ships having absolute priority. He was able to find an approximate solution for heavy tramp traffic, and an exact solution for arbitrary traffic levels, although he states that the latter solution only holds for when liner operations are perfectly regular and deterministic.

In 1987 Easa[11] looked at approximate queuing models to help assess the impact of tug services on congested harbour terminals. At the time of writing the paper he says that this area of port operations has received little attention in respect of queuing theory research. This was despite the importance of tug services on port operations, and despite the number of complaints about tug services, particularly in developing countries. He states that the system can be modelled using a G/G/m/n queuing model, which has m servers (tugs) and n customers (berths). He develops two models, one for a large number of tugs, and one for a small number of tugs, and validates both by simulation. He concludes that:

- the models are only applicable to ports where tug shortages are rare
- the models may be used to determine the number of tugs required to achieve a specified level of tug shortage
- the measures of performance produced by the models may be inputted into a cost model in order to calculate the optimum number of tugs to use.

Both Daskin & Walton[9] (1983) and Horne & Irony[19] (1994) apply queuing theory techniques to ship lightering operations. While Daskin & Walton consider the lightering of oil supertankers off the East Coast of the U.S.A, Horne & Irony consider the lightering of maritime prepositioning ships (MPS's) which are used by the U.S. Navy for amphibious landings.

Daskin & Walton explain that oil supertanker lightering is needed due to the shallow nature of the ports on the U.S. East Coast. However it makes commercial sense to use these very large crude containers (VLCC's) with lightering, rather than carrying the oil in smaller ships due to the long distances that these ships have to travel. Daskin & Walton's solution to their problem is to present a model which produces an approximate solution. The model consists of a cyclic queuing model for the lightering operations, and an $M/E_k/S$ model for the VLCC delays. The two models are linked through a VLCC service time model.

Horne & Irony state that lightering is often needed for MPS's due to a lack of suitable port facilities where an amphibious landing is taking place. They (like Easa) compare their queuing model to a simulation model that they wrote in SIMSCRIPT. They found that the results from both models were very similar. They state that their work accurately estimates the expected value of total off-load time in a variety of situations.

2.3 The role of simulation

One of the pioneers in the production of simulation models, and simulation modelling were Soros Associates of New York. They produced 4 basic models called PORTLOG, YARDLOG, TRANSLOG, and MICROLOG. PORTLOG was developed to simulate the operations of port complexes throughout the world. YARDLOG was a series of programs used to simulate the operations of complex material handling systems. TRANSLOG modelled the transportation system to and from the port. The MICROLOG program was developed later, and simulated port, storage, and material handling activities i.e. it combined the activities covered by PORTLOG and YARDLOG.

In his 1984 paper Zador[34], who is (or was) the Chief of Operations Research, and under whom the 4 models were developed, stated that

> *"During the past ten years, as systems have grown more complex and throughputs have substantially increased, the simulation technique has come to be recognised as a necessary tool in engineering analysis."*

Soros Associates have verified their models using data collected from over 100 projects that the firm has carried out since 1972. They were mainly concerned with bulk handling terminals and ports, particularly those handling coal. Zador illustrates the experience of Soros Associates by outlining some of their projects.

In the early days of simulation modelling there would have been no specialist simulation languages. There were also fewer programming languages than at present. Another problem would have been computer time due to computers being substantially inferior to ones that are on the market at the present. Since these early days the choices available to a simulation modeller have vastly increased. The remainder of this section looks at the variety of work done in modelling port operations using simulation.

A good example of the use of simulation was written by El Sheikh et el(12) in 1987. In this paper they describe how a simulation model written in UCSD Pascal was developed and used to aid in the planning of future berth requirements at a third world port (unnamed due to the commercially sensitive nature of the results of the project at the time of publication). The purpose of the study was to estimate the number of berths required in the short and medium term, and to look at the impact of proposed handling improvements.

The port in question was multipurpose. For modelling purposes, the ships were grouped into 6 categories for loading, and 21 categories for unloading. Different arrival and service patterns were developed for each category. It was found that many of the categories of ship only used a subset of the total number of berths available. Also there were berth preferences within the subset of berths for certain categories of ship. The allocation of berths to ships was done at the time by the port management, and was based on some rules and guidelines.

The number of berths required by the port depended on 3 factors:

- the expected traffic
- the handling rate for each commodity

- what is regarded as an acceptable level of service for the ships using the port.

From the expected traffic and handling rates, they estimated the expected number of berth days required to service the ships. An estimate was then made of the waiting time associated with this estimate of the number of berth days. They state that the ratio

W = average ship waiting time/average ship service (working) time

as suggested by UNCTAD, is often used. Generally a tolerable level for 'W' is between 0.1 and 0.2. i.e. a ship waits on average for 10% - 20% of its working time. Sheikh et al decided to plan for a ratio of no more than 0.1.

The required berth days for 1990 were assessed for 3 cases. These were:

A - present set up

B - include affects of present improvement projects

C - improvements in case B, plus other improvement schemes not yet underway.

Berth day figures were calculated for each of the 3 cases, based on the differing handling rates due to the various schemes. Then the total theoretical number of berth days for the port was calculated based on the port having 21 berths. The occupancy levels for the 3 cases were:

A = 95% - 110%

B = 82% - 97%

C = 61% - 70%

Hence only cases B and C were feasible.

Simulation was then used to relate berth occupancy to the average ship waiting time. Simulation also allowed the experimentation with berth allocation rules. They made a total of 12 simulation runs. Most likely waiting day figures were recorded for the 3 cases. From these, values for 'W' were calculated. It could be seen from the results that only Case C gave results under the required target level of 0.1. They also considered the case where the port increased the number of berths by 3. The results showed a very significant decrease in waiting time, but the cost of implementing the scheme was also very high.

Daniell and Vora[8] used the General Purpose Simulation System (GPSS) to create a model to look at the Port of Freeport which his situated at the mouth of the Old Brazos River on the Texas southern coast. The port mainly imports crude oil, and exports petroleum and chemical products. The objective of the study was to estimate the maximum crude oil throughput under the existing conditions, and with various improvements. The model had to take account of, an approach channel of limited width and depth, one way traffic in the channel, the weather, ship parameters, and berth parameters. They state that sensitivity analysis was carried out where their assumptions were dubious. A total of 66 cases were considered. For each case traffic levels were increased until the saturation point was reached.

Baunach, Wibberley, and Wood[4] undertook a study of the Batam Island coal transhipment terminal. A package called AUTOSIM was used to encode the Activity Cycle Diagram (ACD) of the system to be modelled, which produced a working simulation program in SIMULA. They measured the port performance by the amount of queuing time that occurred at the offshore anchorage. They state that normally the ships turnaround time is the appropriate performance parameter. However in their case, this was masked by the wide range of ship sizes that were involved. Determination of the ultimate capacity of the port, which was the main objective, was achieved by looking at what value queuing time began to rise sharply. They state that,

> *"The simulation study successfully achieved its stated objectives and played a useful role in the overall feasibility study."*

and

"As is often the case in simulation studies, the task of designing the computer model was valuable in itself."

Easa simulated the Port of Thunder Bay, which consisted of several grain terminals, in order to assess the future management strategies within the port. This was to be done by analysing the present situation, looking at future performance, and considering specific improvements. He says that due to 2 unique features of Thunder Bay, no existing simulation model adequately represented the port. Hence a new model had to be designed. These 2 unique features were, that a ship could visit more than 1 berth, and that a time period may be required for the accumulation of grain after a ship has been loaded. He decided that due to the involved nature of the activities at the port no specialised simulation language was appropriate, and hence he used FORTRAN. The results showed that performance at the port could be maintained if either,

- grain time was reduced by 30%
- ship movement was reduced by 50%
- the number of terminals was increased from 14 to 17.

Frankel and Oberle[13] looked at the design of oil terminals. They state that

"The planning, design, and operation of offshore terminal systems is full of risk and uncertainty. As a result, deterministic approaches have, in the past, been found to result in erroneous recommendations and outcomes far from those expected."

However,

"Simulation has been found to provide not only an excellent tool for the planning and design of such a facility but also an effective model for the management of the operations of such facilities."

They used SLAM II to evaluate terminal designs, and to carry out sensitivity analysis.

Covering the scope of their work, they say that ship size was found to be the most critical factor. Ship costs accounted for more than 90% of the total costs of the system operations. They say that this figure confirms their belief that the ocean transportation link must be included in any such analysis. They consider SLAM II to be very flexible, efficient, and easy to use. However it has some limitations, and for larger simulation models, it may need the use of a mainframe. The SLAM program written, linked in with FORTRAN subroutines, and provided an interface with Lotus 123.

A summary of some other work carried out in the field of simulation modelling is now given. Koutitas also considered the use of simulation for cost benefit analysis. His model was written in FORTRAN. Goodwin and Ramos(17) discussed the simulation of bulk carrier loading and unloading. They used the high level language BASIC. Wadhwa(32) looked at planning operations of a bulk loading terminal in Australia. The port's capacity was defined by developing relationships between throughput and port performance. The model was written in Think Pascal. Wadhwa states that a significant part of his research relates to modelling the effect of tidal variations on delays incurred by large ships due to insufficient draft except at high tide. Finally, McCall(22) used simulation to analyse the throughput of oil terminals used by the Strategy Petroleum Reserve (SPR) of the U.S. Department of Energy. A model written in FORTRAN v4.0 was used. McCall states that the choice of language was due to constraints imposed by the SPR. Normally he would consider Pascal or Modula 2 to be the appropriate language to use. Particularly as for discrete event simulation, FORTRAN lacks suitable data structures for recording, in a single structure, all the attributes of a particular entity.

2.4 Summary

It has been shown that in simple cases, queuing theory still has a role. However in general it will be necessary to use simulation modelling. A vast amount of work has been carried out in this field. However a lot of the work has consisted of setting up specialised models for particular ports. And even when general port simulation models have been created they often only consider a part of a port, and do not look at total port operations. At the other extreme there are general simulation packages available. However these packages are often so general, that any application that is created to model a port system, is not satisfactory. While there are certainly port simulation models that look at total port operations in existence, there are commercial reasons why Sir William Halcrow & Partners wished to develop their own model.

CHAPTER THREE
THE SIMULATION MODEL

The model has been designed so that it can be used for any port. The three main entities of the model are, ships, cargo, and land transport units. These are described in sections 3.1, 3.2, and 3.3. Flow charts of the system process can be found in Appendix C.

3.1 Ships

Ships arrive offshore and wait to be let into the port. A ship is allowed to proceed into the port when, the weather is satisfactory, the tide is acceptable, the port schedule allows ships to enter the port, the stockpiles are at a suitable level, there is a suitable berth available, there are enough tugs available, and there is nothing already waiting to get through the lock (channel restriction). When the ship has navigated the entrance channel, it will reach the lock, where it has to wait until the lock is available, and there is nothing on the other side of the lock waiting to get out of the port (departing ships are given priority). Once through the lock the ship may proceed to the manoeuvring area, manoeuvre, and then dock at the required berth. Here it will release its tugs and commence servicing.

The servicing of a ship consists of several stages. A ship may need to unload, load, or do both. Any ship which needs to unload has to first of all incur a pre - unloading delay (for cargo inspections etc). Once this has happened, the ship can try and acquire the resources it needs in order to unload. When it has the necessary resources (some waiting may be incurred), unloading may proceed, provided the weather is okay, there is enough room in the relevant stockpile, and the cargo schedule allows work to be carried out. When the unloading is finished, this phase of the servicing is complete. The loading phase for any ship exporting cargo follows the same process as the unloading phase. Once unloading and/or loading of the ship has been completed, the ship has to incur one final delay known as the pre-departure delay. This is to take into account customs checks etc.

When the ship has been serviced it has to wait to leave the port. To leave the port, the weather must be satisfactory, the tide must be acceptable, the port schedule must allow ships to leave the port, and there must be enough tugs available. If all of these conditions are satisfied, then the ship will acquire the necessary amount of tugs, leave its berth, manoeuvre, and head for the lock. When the ship reaches the lock, it has to wait for the lock to become available. Once through the lock the ship then proceeds down the navigation channel. When it reaches the end of the navigation channel, it releases its tugs, and departs.

3.2 Land Transport Units (LTUS)

The LTUS arrive at the port. An LTU will then have to pass through a number of entrance gates, this number being a user input. The minimum number that can be inputted is one. If no entrance gates are required the program has to be set up with only one gate and the service times for the LTUS have to be set to zero.

When an LTU arrives at each gate it may be necessary to queue and wait for a suitable service point at the gate to become available. Each gate will have one or more service points which can only be used by LTUS entering the port. LTUS queue on a FCFS basis. When a suitable service point, that no other LTU nearer the front of the queue can use does become available, then the LTU proceeds to the said service point. Once the LTU has been serviced it will proceed to the next gate if there is one, otherwise it will proceed to the loading bay waiting area.

There, LTUS wait on a FCFS basis for a suitable loading bay to become available. When a suitable loading bay, that no other LTU nearer the front of the queue can use does become available, then the LTU proceeds to the said loading bay. Here the

LTU will be serviced. The servicing procedure followed by LTUS is exactly the same as that followed by ships (see previous section). When the LTU has been serviced it will leave its loading bay, and proceed back to the entrance gates, if there were any, otherwise the LTU can immediately leave the port.

The LTU will pass through the gates in basically the same method as it did on the way into the port. However it will be going through the gates in reverse order as it is leaving the port. Also the service times at each gate may differ from the service times incurred when entering the port. The third and final difference is that the LTU must be serviced at one of the service points which can only be used by departing LTUS.

Once the LTU has passed through all the gates, it can exit the port.

3.3 Cargo

Cargo movement is constrained by the relevant cargo type work schedule, the weather, and the stockpile upper and lower limits. Only when ALL the above conditions are satisfied is cargo movement allowed.

Cargo which is being imported will be unloaded from a ship when the ship has acquired a minimum of, one dock side port unloader, one unit of dock side port transport (from the dock side port transport group which handles the ship's cargo type), and one dock side stockpile equipment unit (either a stacker or a stacker/reclaimer). When a ship has acquired all this, the cargo is removed from the ship and put on the quay by the dock side port unloader(s), taken from the quay to the relevant stockpile by the dock side port transport unit(s), and put onto the stockpile by the dock side stockpile equipment unit(s).

Cargo is removed from the stockpile on a FIFO basis. Cargo can be removed from a stockpile when an LTU which is importing cargo has acquired a minimum of, one land side stockpile equipment unit (either a reclaimer or a stacker/reclaimer), one land side port transport unit (from the land side port transport group which handles the

LTU's cargo type), and one land side loader. When an LTU has acquired all this, the cargo is removed from the stockpile by the land side stockpile equipment unit(s), taken from the stockpile to the relevant loading bay by the land side port transport unit(s), and put onto the LTU by the land side loader(s).

Figure 3.1 shows the flow of imported cargo through the port. Exported cargo would follow the reverse of this process.

3.4 Method Of Simulation

The model was developed using a simulation shell produced by the Operational Research Group at the University of Southampton. This shell is known as Tochsim (named after Professor Tocher[30]), and uses the three phase method of discrete event simulation.

Discrete event simulation is the most appropriate method to use as it represents a system as a series of events. The system consists of entities, resources and activities. An entity is an object in the system being modelled. In this simulation model the entities are the ships, the land transport units, and the cargo batches. Entities can have attributes which distinguish one entity from another (such as size etc). An entity can be in one of three states, namely idle, queuing, or busy. If it is busy the entity is engaged to an activity. Activities can either be scheduled or conditional. A resource is something that is used by an entity, for example ships use tugs and berths.

The three phases of the three phase method of discrete event simulation are, the t-phase, the b-phase, and the c-phase. The t-phase advances the simulation clock to the time of the next scheduled activity. The b-phase executes all the scheduled activities (also known as B activities) due at that time. The c-phase tests each of the conditional activities (also known as C activities) in turn, to see if all the conditions for any of the conditional activities are satisfied. If so, the relevant conditional activity is executed.

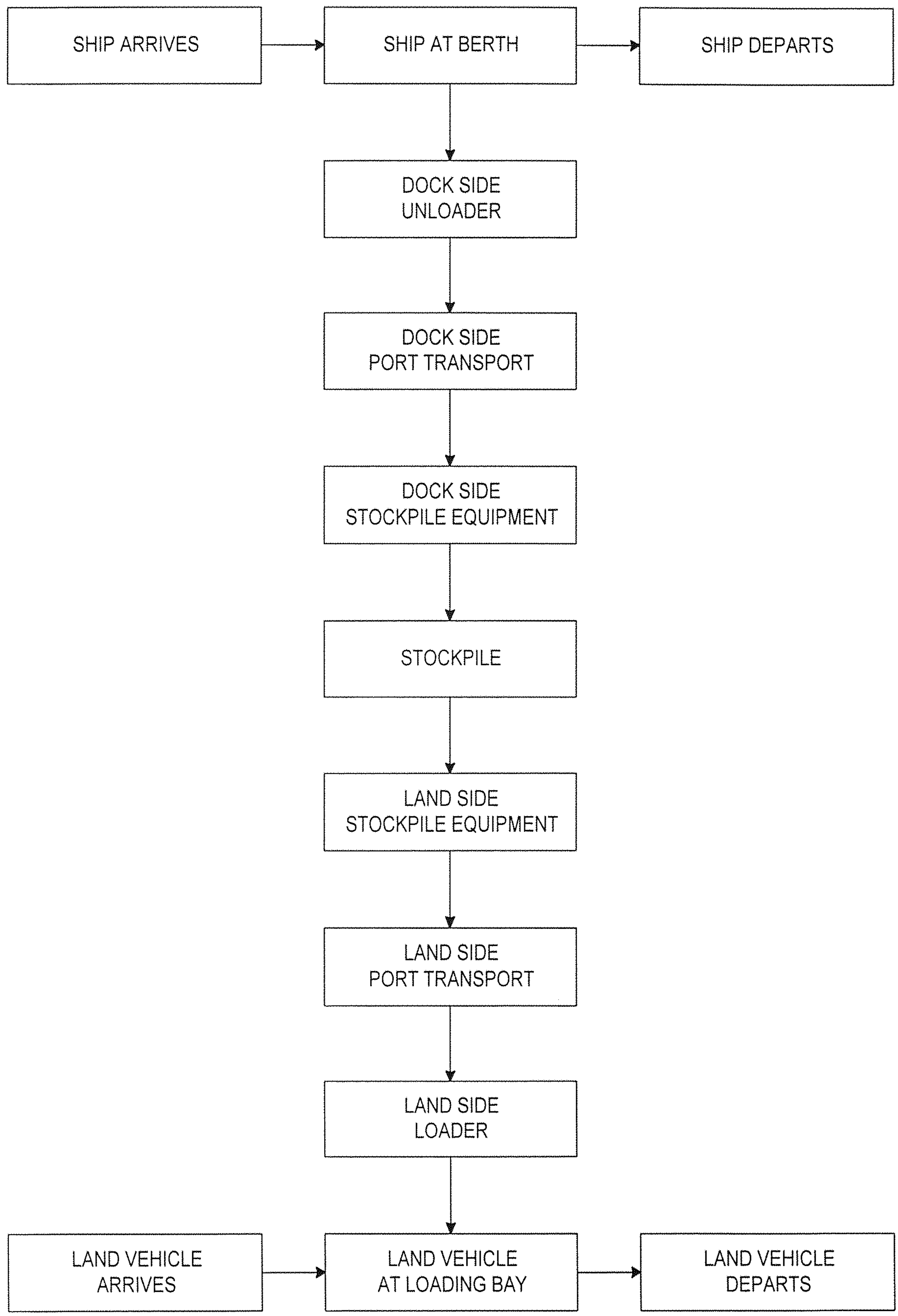


Figure 3.1 Flow of imported cargo through the simulated port.

The model is written in Borland Pascal for Windows (version 7) and uses Object Oriented Programming, as does the version of Tochsim being used by the simulation model, which was specially written by Darryl Gove of the Operational Research Group at the University of Southampton.

3.5 Assumptions

The assumptions that have been made in developing the model are,

(1) Pilots are not modelled.

(2) Each ship carries one and only one cargo type, and so belongs to one and only one ship group.

(3) Each ship visits one and only one berth.

(4) Each berth can only handle one ship at any one time.

(5) Each LTU carries one and only one cargo type, and so belongs to one and only one LTU group.

(6) Each LTU visits one and only one loading bay.

(7) Each loading bay can only handle one LTU at any one time.

3.6 Model Entities

As was stated in section 3.4, the entities in the port simulation model are the ships, the LTUS and the cargo batches. Each of the three types of entity have many attributes, some of which are based on user inputs, while others are just used internally by the program e.g. a ship may have a Boolean attribute triggered when it arrives at its berth. A full description of all the attributes for the three types of entity can be found in Appendix D.

3.7 Model Resources

Resources are used by the entities as they pass through the system. There are many types of resource in the Port Simulation Model, and they are all described in the following sections.

3.7.1 Tugs

Tugs are used to escort ships into and out of the port. The number of tugs that a ship needs depends on its size class (see section 3.10.1). The number of tugs needed by each size class is a user input, as is the total number of tugs available in the port. When tugs are released by a ship, they wait at the end of the port from which they were released i.e. the seaward end if the ship was departing, or the land end if the ship was arriving. Initially all the tugs are sited at the land end of the port system.

If when a ship tries to acquire tugs, there are enough available, but they are not all at the same end of the port as the ship, then a delay will be incurred. The duration of the delay is based on the tug average speed (which is a user input) and the length of the approach channel (also user inputs - the approach channel is made up of the distance from the offshore waiting area to the lock, and the distance from the lock to the manoeuvring area).

3.7.2 Berths

The berths are used by ships during their stay in port, which will consist of unloading and/or loading, and any delays that may be encountered. Only one ship is allowed at each berth at any one time. The total number of berths is a user input, as are the cargo types and trading status' of ships that each berth can handle.

Allocation rules are needed for berths, and are as follows. The queue of ships waiting to enter the port is searched through on a FCFS basis. The first suitable ship to be found in the queue (if any) is allocated to a berth. A ship is considered suitable if, the weather and tide are okay for the ship to enter the port, the port schedule allows ships to enter the port, there is a suitable berth available, and there are enough tugs available. A berth is considered suitable if it handles the ships cargo type and the ships trading status. Of the suitable berths available, the ship is allocated to the berth which is the most restrictive in its use. Restrictiveness is calculated in two stages. The first stage is the trading status of the berth. For example, if a berth has a trading status of import only or export only, it is more restrictive than a berth with an import/export trading status. The second stage is how many cargo types the berth handles. If there is more than one berth that is suitable and available, and has the same restrictiveness level, then one is chosen at random.

3.7.3 Lock (channel restriction)

Ships have to pass through the lock in order to enter and leave the port. Only one ship may use the lock at any one time, and departing ships are given priority. The time taken for a ship to pass through the lock is a user input, and depends on which size class it belongs to. This time covers the whole process, including entry and exit of the lock. Changing water levels are not modelled, so if two ships going in the same direction successively use the lock, there isn't a delay in between. Note that the effect of the lock as a channel restriction can be removed by setting the transition times for all the ship size classes to zero.

3.7.4 Dock Side Unloaders

<u>Attributes</u>

Appendix E gives some necessary details about various attributes for dock side unloaders.

<u>Allocation rules</u>

Allocation rules are needed for the use of dock side unloaders, and are as follows. When a ship is berthed and needs to unload it will try and acquire one or more dock side unloaders. This number depends on two factors. Firstly there is the maximum number the ship is allowed to acquire, which depends on its cargo type and its cargo size. These maximum numbers are user inputs. The second factor is that there may not be enough suitable dock side unloaders in the port for the ship to be able to ever acquire the maximum number previously specified. So the number of dock side unloaders that a ship will attempt to acquire (the 'feasible maximum') is set to the minimum of, the number of suitable dock side unloaders in the port, and the maximum number of dock side unloaders the ship is initially told to try and acquire.

It may be that no dock side unloaders are available when the ship needs them and that therefore the ship has to wait. If more than one ship is waiting for dock side unloaders, if one or more dock side unloaders become available, then the priority rules (see next section) are used to allocate the dock side unloaders to the ships.

Once a priority ordering of the waiting ships has been achieved, the allocation process can begin. The first ship in the priority ordering queue is selected. Then a list of all the suitable dock side unloaders available is created. The number of dock side unloaders the ship will be allowed to acquire this go will be the minimum of, the number the ship still needs to obtain the feasible maximum, and the number of suitable dock side unloaders available.

For a ship selected to acquire one or more dock side unloaders, of the ones which are suitable and available, the ship will be allocated the ones with the highest work rates. If a ship needs one dock side unloader, say, and the suitable available unloaders all have the same work rate then the one appearing first in the list of suitable and available dock side unloaders will be selected i.e. one is *not* chosen at random.

If a ship acquires more than one dock side unloader, the rate at which cargo is to be unloaded from the ship is the sum of the work rates of the dock side unloaders which have been acquired by the ship, multiplied by the relevant multiple dock side unloader factor. The multiple dock side unloader factors are based on the idea that although two unloaders may unload more than one unloader per hour, the individual work rates may go down. The multiple dock side unloader factors and the individual work rates are user inputs.

Priority rules

The priority rules for acquiring dock side unloaders are as follows. Firstly the ships are ordered based on the ship group service priority weighting (which is a user input), the ones with the highest weighting being placed first. For ships with equal ship group service priority weightings, then priority is given to the ships that have acquired the least number of dock side unloaders. Finally, if two or more ships have the same ship group service priority weighting and have acquired the same number of dock side unloaders then give priority to the one which has been berthed the longest.

3.7.5 Land Side Unloaders

As dock side unloaders.

3.7.6 Dock Side Loaders

As dock side unloaders.

3.7.7 Land Side Loaders

As dock side unloaders.

3.7.8 Dock Side Port Transport

The necessary allocation rules are as follows.

Unloading ships

The amount of dock side port transport a ship needs depends on the number of dock side unloaders the ship has already acquired. The total work rate of the unloaders acquired (including adjustment because of the multiple unloader factors) is divided by the work rate of one of the units of port transport. This number is then rounded UP to give the number of port transport units the ship should try and acquire (so that the unloaders can work at full speed). It may be necessary for a ship to wait to acquire the port transport it needs. The priority rules for trying to acquire port transport are the same as those for the dock side unloaders.

Note: if four units of port transport are available, and two ships are waiting for port transport both needing four units each, once a priority order has been worked out, the model will give the first ship all four of the available units, rather than giving two units to each ship. This is not a problem, or an error in the conceptual model, as we will be simulating over a long period of time and looking at general trends.

At this point if a ship has acquired some dock side unloaders and some dock side port transport, it will be given a 'new unloading rate'. This value is the minimum of the sum of the work rates of the dock side port transport units, and the sum of the work rates of the dock side unloaders (with the affect of the relevant multiple unloader factor added in). The 'new unloading rate' is only a theoretical unloading rate, as unloading will only commence once a ship has acquired some unloaders, some port transport AND some dock side stockpile equipment. However the 'new unloading rate' is used in order to work out the number of stockpile equipment that the ship should try and acquire.

Loading ships

As for unloading ships, but the number of port transport needed will depend on the number of loaders acquired.

3.7.9 Land Side Port Transport

As dock side port transport.

3.7.10 Dock Side Stockpile Equipment

The ship will try and acquire enough stockpile equipment units, so that the sum of the work rates of the acquired stockpile equipment units equals or is greater than the 'new unloading rate'. The priority rules are again as for the dock side unloaders.

When a ship has been selected to acquire one or more stockpile equipment units it will acquire the ones with the highest work rates. If the work rates are equal then the first ones in the list will be selected i.e. one is *not* selected at random.

The stockpile equipment units do not have multiple stockpile equipment factors like the ones used for the unloaders, so the total stockpile equipment work rate is just the sum of the individual units work rates.

If a ship is unloading it will be acquiring stockpile equipment units in order to stack its cargo in the storage area, and as a result, the sum of the work rates of the stockpile equipment units is known as the 'stacking rate'. Similarly, if a ship is loading it will be acquiring stockpile equipment in order to reclaim its cargo from the storage area, and as a result, the sum of the work rates of the stockpile equipment units acquired is known as the 'reclaiming rate'.

The 'overall unloading rate'(or the 'overall loading rate') for the ship is the minimum of the 'new unloading rate' and the 'stacking rate' (or the 'reclaiming rate').

3.7.11 Land Side Stockpile Equipment

As dock side stockpile equipment.

3.7.12 Loading bays

The loading bays are used by LTUS while they are serviced. Only one LTU is allowed to occupy each loading bay at any one time. Each land transport group has its own set of loading bays which it exclusively uses. The total number of loading bays available for each land transport group to use can vary between one and ten, and is a user input.

LTUS are allocated to loading bays on a FCFS basis. Unlike ships which acquire a berth before they enter the port, LTUS only acquire a loading bay immediately before they are to occupy it. If there aren't any suitable loading bays available when an LTU needs one, it must wait in the waiting area. All LTUS wait in the same waiting area irrespective of their cargo type. However, as each land transport group has exclusive use of their set of loading bays, the waiting area is effectively made up of five separate queues, one for each cargo type.

3.7.13 Port gates

All the LTUS have to pass through the port gates when they enter and leave the port. There can be upto four port gates which will be in series i.e. each LTU has to pass through each port gate. Each gate has a number of service points dedicated to arriving LTUS, and a number of service points dedicated to departing LTUS. Each service point has an attribute saying which land transport groups it can handle.

LTUS are allocated to service points on a FCFS basis provided the available service points are suitable for the LTUS nearer the front of the queue i.e. if LTU B is behind LTU A, but LTU B is the only one out of the two which can be accepted at the single service point available, then LTU B will be allocated to the service point, even though it arrived after LTU A.

The number of port gates, the number of entry service points for each gate, the number of departure service points for each gate, and the land transport groups each service point can handle are all user inputs.

3.8 Model Activities

As stated in section 3.4, in three phase discrete event simulation, the first phase is the advance of the simulation clock to the time of the next scheduled activity. The second phase is to execute all scheduled, or B (for bound), activities that are due at that time. The third phase is to execute all conditional, or C, activities which have all their conditions met, at the present simulation time.

The following two sections describe the B and C activities used within the model. They have been ordered below, in the order that the entities progress through them, rather than numerical order. The numbers of the activities are not all in order due to additional activities being needed later in the development of the model.

3.8.1 B activities

B22 {Ship arrives}

(1) Add arrival to the back of the queue of ships waiting to enter the port.

(2) The activity is set to be recalled at time 't' in the future where 't' is a random variate of the chosen arrival distribution and the associated distribution parameters (user defined inputs).

(3) The arrival time of the ship is logged as an attribute.

B2 {Tug(s) made fast}

(1) Ship size, cargo size and loaded draught all logged for the respective graphs.

(2) B3 caused to occur when all the tugs have been made fast.

B3 {Navigate channel}

(1) Causes activity B20 to occur, when the ship has navigated the approach channel from the offshore area to the lock (channel restriction).

B20 {Arrive at lock}

(1) The ship is added to the back of the queue of ships waiting to go through the lock.

B4 {Go through lock}

(1) B5 is caused to occur when the ship has passed through the lock.
(2) The average waiting time is recalculated adding in the waiting time of the latest ship.

B5 {Go to the manoeuvring area}

(1) The lock is released.
(2) Updates the total time that the lock has been in use. This will be used later to calculate the lock utilization.
(3) B6 is caused to occur when the ship has navigated the channel from the lock to the manoeuvring area.

B6 {Manoeuvring}

(1) Causes activity B7 to occur when the ship has finished manoeuvring.

B7 {Berthing}

(1) The time the ship arrived at the berth is logged as an attribute.

(2) The status of the berth that the ship has arrived at, is set to occupied. The berth is given a pointer to the ship.

B9 {Release tugs on berthing}

(1) All the ship's tugs are released and the tug utilization graph is updated.

(2) If the ship is importing then activity B40 is caused, otherwise activity B41 is caused.

B40 {Pre unloading delay}

(1) Activity B8 is caused after a delay has occurred. The delay is a random variate sampled from the distribution (with associated parameters) selected by the user for the ship's group.

B8 {Prepare to unload}

(1) An entity attribute is triggered to say that the ship is at the 'unloading stage'.

(2) The ship's berth has an attribute triggered to say it is occupied by a ship which is at the 'unloading stage'.

(3) The ship is added to the back of the queue of ships waiting to unload.

(4) A Boolean variable is triggered to call the C activity which allocates unloaders (C3).

(5) A pointer to the ship is attached to the stockpile that the ship will be delivering its cargo to. The pointer will be used in order to help calculate the inflow to the stockpile while the ship is there.

B37 {Finished unloading}

(1) The ship's berth has the attribute, which says that it is occupied by a ship at the 'unloading stage', cancelled.

(2) The port transport units that the ship acquired are released, and the relevant utilization graph is updated.

(3) The unloaders that the ship acquired are released and the relevant utilization graph is updated. The throughput and utilization of each unloader used by the ship is updated.

(4) The stockpile equipment units that the ship acquired are released and the relevant utilization graph is updated. The throughput and utilization of each stockpile equipment unit used by the ship is updated.

(5) Several ship attributes are reset.

(6) Boolean variables are triggered to call the relevant C activities (C3, C5, C14), as resources have become available.

(7) The pointer to the ship, from the ship's stockpile is removed.

(8) If the ship needs to load B41 is caused, else B42 is caused.

B41 {Pre loading delay}

(1) Activity B36 is caused after a delay has occurred. The delay is a random variate sampled from the distribution (with associated parameters) selected by the user for the ship's group.

B36 {Prepare to load}

(1) An entity attribute is triggered to say that the ship is at the 'loading stage'.

(2) The ship's berth has an attribute triggered to say it is occupied by a ship which is at the 'loading stage'.

(3) The ship is added to the back of the queue of ships waiting to load.

(4) A Boolean variable is triggered to call the C activity which allocates loaders (C4).

(5) A pointer to the ship is attached to the stockpile that the ship will be receiving its cargo from. The pointer will be used in order to help calculate the outflow from the stockpile while the ship is there.

B11 {Finished loading}

(1) The ship's berth has the attribute, which says that it is occupied by a ship at the 'loading stage', cancelled.

(2) The port transport units that the ship acquired are released, and the relevant utilization graph is updated.

(3) The loaders that the ship acquired are released and the relevant utilization graph is updated. The throughput and utilization of each loader used by the ship is updated.

(4) The stockpile equipment units that the ship acquired are released and the relevant utilization graph is updated. The throughput and utilization of each stockpile equipment unit used by the ship is updated.

(5) Several ship attributes are reset.

(6) Boolean variables are triggered to call the relevant C activities (C4, C5, C14), as resources have become available.

(7) The pointer to the ship, from the ship's stockpile is removed.

(8) B42 is caused to occur.

B42 {Pre departure delay}

(1) Activity B12 is caused after a delay has occurred. The delay is a random variate sampled from the distribution (with associated parameters) selected by the user for the ship's group.

B12 {Prepare to leave}

(1) The ship is added to the back of the queue of ships waiting to leave the port.

B13 {Leave berth}

(1) The relevant berth is released. The relevant attributes are set so that the berth is

shown to be unoccupied and unallocated. The berth utilization graph is updated.

(2) The time that the ship left the berth is logged.

(3) The throughput and number of calls for the ship's cargo type and trading status are updated.

(4) The throughput, number of calls, and utilization of the released berth are updated, based on the ship's trading status.

(5) B14 is caused to occur.

B14 {Manoeuvring to leave}

(1) Causes B34 to occur when the ship has manoeuvred.

B34 {Manoeuvring area to the lock}

(1) Causes B21 to occur when the ship has travelled from the manoeuvring area to the lock.

B21 {Departing ship arrives at the lock}

(1) Puts the ship at the back of the queue of ships waiting to go through the lock in order to leave.

B15 {Go through the lock to leave}

(1) The average time that ships have had to wait to go through the lock on departure is updated.

(2) B16 is caused to occur once the ship has passed through the lock.

B16 {Navigate channel to leave}

(1) The lock is released.

(2) The total time that the lock has been in use is updated.

(3) B17 is caused to occur when the ship has navigated the channel and the tug release time has passed. The tug release time is caused to occur before the tugs are actually released because the process of releasing the tugs in the model is instanteous. So if the tugs were released any earlier another ship could acquire them before they are actually available.

B17 {release tugs from departing ship}

(1) The tugs that the ship acquired are released, and the tug utilization graph is updated.

(2) B18 is caused to occur.

B18 {Ship leaves}

(1) The approach, departure, and passage times, and the number of calls, for the ship's size class of the ship's cargo type are updated.

(2) The lock utilization is updated, using the data collected in B6 and B16 (total time lock in use).

(3) The entity (ship) is disposed of.

(4) The ship data collection is carried out if, the present simulation runtime is between the start and end times specified by the user, and the upper limit of 800 records has not been reached.

(5) The total number of departures is logged.

B101 {Land transport unit arrives}

(1) Entity 'arrival time' attribute created.

(2) The cargo size graph is updated.

(3) B101 is caused to occur again at time 't' in the future, where 't' is a random variate from the relevant arrival distribution (with associated parameters)

selected by the user.

(4) Cause B102 to occur straight away.

B102 {Land transport proceeds to gate}

(1) The 'gate number' attribute is incremented by one. Note that by default the LTUS 'gate number' attribute is initialised as zero.

(2) The LTU is added to the back of the queue of LTUS waiting to go through the gate with the LTUS 'gate number'.

B103 {Land transport serviced at gate}

(1) After a service time 't' for the LTU has passed, B104 is caused to occur, where 't' is a random variate sampled from the relevant distribution (with associated parameters) selected by the user to be the service distribution for this cargo type at this gate.

B104 {Land transport finished servicing at gate}

(1) The service point of the gate that the LTU acquired is released.

(2) The average wait at the gate for LTUS of the present LTUS cargo type is updated. *Note: at the present time, the waiting time only consist of the LTUS service time and doesn't include the queuing time incurred.*

(3) If the LTUS 'gate number' indicates this is the last entry gate then B105 is caused to occur, otherwise B102 is caused to occur again.

B105 {Land transport proceeds to waiting area}

(1) There is one queue of LTUS for each cargo type waiting to acquire a suitable loading bay. Add the LTU to the back of the correct queue.

(2) The present number of LTUS waiting for loading bays is updated, and the

relevant graph will be updated in B30.

B106 {Land transport proceeds to loading bay}

(1) A pointer to the LTU is attached to the LTU's loading bay.

(2) The time that the LTU arrived at the loading bay is logged.

(3) If the LTU is waiting to unload then B110 is caused to occur, otherwise B113 is caused to occur.

B110 {Land transport pre unloading delay}

(1) Activity B111 is caused after a delay has occurred. The delay is a random variate sampled from the distribution (with associated parameters) selected by the user for the LTU's group.

(2) The time that the unloading process started is logged as an attribute.

B111 {Land transport prepares to unload}

(1) An entity attribute is triggered to say that the LTU is at the 'unloading stage'.

(2) The LTU's loading bay has an attribute triggered to say it is occupied by an LTU which is at the 'unloading stage'.

(3) The LTU is added to the back of the queue of LTUS waiting to unload.

(4) A Boolean variable is triggered to call the C activity which allocates unloaders (C10).

(5) A pointer to the LTU is attached to the stockpile that the LTU will be delivering its cargo to. The pointer will be used in order to help calculate the inflow to the stockpile while the LTU is there.

B112 {Land transport finished unloading}

(1) The time the LTU finished unloading is logged as an attribute.

(2) The LTU's loading bay has the attribute, which says that it is occupied by an LTU at the 'unloading stage', cancelled.

(3) The port transport units that the LTU acquired are released, and the relevant utilization graph is updated.

(4) The unloaders that the LTU acquired are released and the relevant utilization graph is updated. The throughput and utilization of each unloader used by the LTU is updated.

(5) The stockpile equipment units that the LTU acquired are released and the relevant utilization graph is updated. The throughput and utilization of each stockpile equipment unit used by the LTU is updated.

(6) Several LTU attributes are reset.

(7) Boolean variables are triggered to call the relevant C activities (C10, C12, C15), as resources have become available.

(8) The pointer to the LTU, from the LTU's stockpile is removed.

(9) If the LTU needs to load, B113 is caused, otherwise B116 is caused.

B113 {Land transport pre loading delay}

(1) The time the loading phase started is logged as an attribute.

(2) Activity B114 is caused after a delay has occurred. The delay is a random variate sampled from the distribution (with associated parameters) selected by the user for the LTU's group.

B114 {Land transport prepares to load}

(1) An entity attribute is triggered to say that the LTU is at the 'loading stage'.

(2) The LTU's loading bay has an attribute triggered to say it is occupied by an LTU which is at the 'loading stage'.

(3) The LTU is added to the back of the queue of LTUS waiting to load.

(4) A Boolean variable is triggered to call the C activity which allocates loaders.

(5) A pointer to the LTU is attached to the stockpile that the LTU will be receiving

its cargo from. The pointer will be used in order to help calculate the outflow from the stockpile while the LTU is there.

B115 {Land transport finished loading}

(1) The time that the LTU finished loading is logged as an attribute.

(2) The LTU's loading bay has the attribute, which says that it is occupied by an LTU at the 'loading stage', cancelled.

(3) The port transport units that the LTU acquired are released, and the relevant utilization graph is updated.

(4) The loaders that the LTU acquired are released and the relevant utilization graph is updated. The throughput and utilization of each loader used by the LTU is updated.

(5) The stockpile equipment units that the LTU acquired are released and the relevant utilization graph is updated. The throughput and utilization of each stockpile equipment unit used by the LTU is updated.

(6) Several LTU attributes are reset.

(7) Boolean variables are triggered to call the relevant C activities (C11, C12, C15), as resources have become available.

(8) The pointer to the LTU, from the LTU's stockpile is removed.

(9) B116 is caused to occur.

B116 {Land transport pre departure delay}

(1) Activity B118 is caused after a delay has occurred. The delay is a random variate sampled from the distribution (with associated parameters) selected by the user for the LTU's group.

B118 {Land transport prepares to leave}

(1) The relevant loading bay utilization graph is updated.

(2) The LTU's loading bay is released.

(3) The time that the LTU left the loading bay is logged as an attribute.

(4) The throughput, number of calls, and the utilization of the LTU's loading bay are updated.

(5) The average full service time, the average unloading service time, and the average loading service time are all updated for the LTU's cargo type.

(6) The throughput and number of calls for the LTU's cargo type are updated.

(7) Activity B125 is caused to occur straight away.

B125 {Land transport proceeds to gate for departure}

(1) The LTU is added to the back of the queue of LTUS waiting for the departure gate with the LTU's 'gate number'.

B126 {Land transport serviced at gate for departure}

(1) After a service time 't' for the LTU has passed, B127 is caused to occur, where 't' is a random variate sampled from the relevant distribution (with associated parameters) selected by the user to be the service distribution for this cargo type at this gate.

B127 {Land transport finished servicing at gate for departure}

(1) The service point of the gate that the LTU acquired is released.

(2) The average waiting time at the gate for LTUS of the present LTUS cargo type is updated.

(3) The LTU's 'gate number' attribute is decremented by one.

(4) If the 'gate number' attribute is set to zero it means the LTU has been through all the departure gates and B170 is caused to occur, otherwise B125 is caused to occur.

B170 {Land transport unit leaves}

(1) The number of departures is incremented by one.

(2) The LTU is disposed.

B19 {Weather}

(1) Given the present weather state, a new weather state is randomly selected based on the transition probabilities input by the user.

(2) The length of time to be spent in this state is calculated by selecting a random variate based on the distribution (with associated parameters) inputted by the user.

(3) B19 is set to be recalled at the end of the period of weather.

B200 {Timer}

(1) The relevant text screen is updated so the user knows the present situation of the simulation run. This is particularly useful if the user is running the program in 'interactive off' mode. The rate at which the screen is updated is a user input.

B190 {storage area}

(1) Called at the start of every simulation hour.

(2) For each stockpile

- create a new batch of cargo (which is an entity) and give this batch its initial size. If this initial size is greater than zero then give the batch its creation time attribute and add it to the back of the queue of batches of cargo that make up the relevant stockpile.
- reset attributes for the next hour.
- calculate the amount of cargo to be taken off the stockpile from work done

during the last hour.

- update the stockpile statistics.
- check whether it is okay to continue unloading.
- check whether it is okay to continue loading.
- set B190 to be recalled in an hours time.

B30 {Get graphs}

(1) Calls itself fifty times during the simulation run at regular intervals in order that the time series graphs can be updated. These graphs are the queue graphs (port entry queue, lock queue (on entry), lock queue (on departure), queue of ships waiting to leave berths, queues at the gates on entry and departure), the stockpile 'percentage full' graphs, and the loading bay waiting area present size graph.

B31 {Port schedule}

(1) A Boolean variable is set to TRUE if ship movement is allowed in the present duration, and set to FALSE if ship movement isn't allowed in the present duration. The Boolean variable is used in C1 and C6 to check if ship movement is allowed.

(2) B31 is set to be recalled at the end of the present duration.

B210 {Work schedule}

(1) Called whenever the work schedule for one or more of the cargo types is about to start a duration.

(2) If cargo movement is allowed in the duration then a Boolean variable is set to TRUE, otherwise it is set to FALSE. The Boolean variables (one for each cargo type) are then used in C17 to check if cargo movement is allowed.

(3) B210 is set to be recalled at the end of the present duration for the relevant cargo type.

3.8.2 C Activities

There are 18 C activities. If a series of conditions are satisfied, then one or more actions will be performed. A description of each activity follows.

C1 {Ship waits for weather, berth, tugs and tide}

Conditions:

(1) Are there any ships waiting to enter the port?

(2) Does the weather permit ship movement, does the port schedule permit ship movement, and are there any berths available?

(3) On a FCFS basis select the first ship for which there is a suitable berth (including depth check), the stockpile level check has been satisfied, and the tide allows the ship to proceed down the approach channel.

(4) Are there enough tugs available for the selected ship, and are there no ships waiting to enter the lock on the seaward side?

Actions:

(1) Acquire a suitable berth and update the berth utilization graph.

(2) The acquired berth has its status changed to allocated (but not occupied).

(3) Acquire the required number of tugs and update the tug utilization graph.

(4) Cause B2 to occur once the tugs have arrived (may involve a delay depending on the location on the tugs at the present simulation runtime).

C2 {Ship waits to enter lock}

Conditions:

(1) Are there any ships waiting to enter the lock, in order to reach the port?

(2) Are there no ships waiting to enter the lock from the other side, as departing ships have priority?

(3) Is the lock empty?

Actions:

(1) Select the ship from the front of the queue.

(2) The selected ship acquires the lock.

(3) Activity B4 is caused to occur.

C3 {Ship waits to get unloaders}

Conditions:

(1) Has the Boolean variable indicating a ship is ready to unload been triggered, or has the Boolean indicating a ship has finished unloading (i.e. resources have become available) been triggered?

Actions:

(1) Make a list of all the ships at berths which need unloaders, provided the stockpile that the ship is working at is operating.

(2) Sort the list based on the priority rules.

(3) Go through the whole list and try and allocate any available unloaders.

(4) If a ship acquired some more unloaders ***and*** has already started unloading, then

- update the throughput of the unloaders and stockpile equipment which the ship already had.
- remove the ship from the events calendar.
- calculate the new unloading rate using the extra resources acquired.
- calculate the amount still to be unloaded, and hence the remaining unloading time.
- cause B37 to occur when unloading has finished.
- a Boolean variable is triggered to call C16 as a change in flow rate of one or more of the stockpiles may have occurred.

C4 {Ship waits to get loaders}

Conditions:

(1) Has the Boolean variable indicating a ship is ready to load been triggered, or has the Boolean indicating a ship has finished loading (i.e. resources have become available) been triggered?

Actions:

(1) Make a list of all the ships at berths which need loaders, provided the stockpile that the ship is working at is operating.
(2) Sort the list based on the priority rules.
(3) Go through the whole list and try and allocate any available loaders.
(4) If a ship acquired some more loaders ***and*** has already started loading, then

- update the throughput of the loaders and stockpile equipment which the ship already had.
- remove the ship from the events calendar.
- calculate the new loading rate using the extra resources acquired.
- calculate the amount still to be loaded, and hence the remaining loading

time.

- cause B11 to occur when loading has finished.
- a Boolean variable is triggered to call C16 as a change in flow rate of one or more of the stockpiles may have occurred.

C5 {Ship waiting for port transport}

Conditions:

(1) Have one or more of the Boolean variables indicating that a ship waiting to unload or load is ready for port transport been triggered, or have one or more of the Boolean variables indicating that a ship has finished unloading or loading (i.e. resources have become available) been triggered?

Actions:

(1) Make a list of all the ships at berths that require port transport.
(2) Sort the list based on the priority rules.
(3) Allocate any available port transport units to suitable ships.
(4) If the ship acquires some more port transport units ***and*** has already started ***unloading*** then

- update the throughput of the unloaders and stockpile equipment which the ship already had.
- remove the ship from the events calendar.
- calculate the new unloading rate using the extra resources acquired.
- calculate the amount still to be unloaded, and hence the remaining unloading time.
- cause B37 to occur when unloading has finished.
- a Boolean variable is triggered to call C16 as a change in flow rate of one or more of the stockpiles may have occurred.

(5) If the ship acquires some more port transport ***and*** has already started ***loading*** then

- update the throughput of the loaders and stockpile equipment which the ship already had.
- remove the ship from the events calendar.
- calculate the new loading rate using the extra resources acquired.
- calculate the amount still to be loaded, and hence the remaining loading time.
- cause B11 to occur when loading has finished.
- a Boolean variable is triggered to call C16 as a change in flow rate of one or more of the stockpiles may have occurred.

C6 {Ship waits for weather, tugs and tide}

Conditions:

(1) Are there any ships waiting to leave the port?

(2) Using a FCFS priority rule, select the first ship for which the following is true. Does the present weather state permit ship movement, does the present state of the port schedule permit ship movement, does the tidal level allow the ship to leave the port, and are there enough tugs for the selected ship?

Actions:

(1) Acquire the required number of tugs and update the tug utilization graph.

(2) Cause B13 to occur once the tugs have been fastened (including a tug delay time, if tugs have to come from the other end of the port).

C7 {Departing ship waits to enter the lock}

Conditions:

(1) Are there any ships waiting to enter the lock in order to leave the port?

(2) Is the lock empty?

Actions:

(1) Select the ship from the front of the queue.

(2) The selected ship acquires the lock.

(3) Activity B15 is caused to occur.

C8 {Land transport waits to be serviced at gate on entry}

Conditions:

(1) For each gate, are there any LTUS waiting to be serviced?

Actions:

(1) Go through the queue of LTUS and if there is a suitable service point available for the relevant LTU allocate it and cause B103 to occur straight away.

C9 {Land transport waiting for a loading bay}

Conditions:

(1) For each land transport group, is there one or more LTUS of the relevant cargo type waiting to acquire a loading bay?

(2) Are there any loading bays of the relevant cargo type available?

Actions:

(1) Allocate LTUS to suitable loading bays, until either run out of waiting LTUS or loading bays which are available and suitable.
(2) B106 is caused to occur straight away for each LTU that acquires a loading bay.

C10 {Land transport waiting for unloaders}

Conditions:

(1) Has the Boolean variable indicating an LTU is ready to unload been triggered, or has the Boolean indicating an LTU has finished unloading (i.e. resources have become available) been triggered?

Actions:

(1) Make a list of all the LTUS at loading bays which need unloaders, provided the stockpile that the LTU is working at is operating.
(2) Sort the list based on the priority rules.
(3) Go through the whole list and try and allocate any available unloaders.
(4) If an LTU acquired some more unloaders ***and*** has already started unloading, then

- update the throughput of the unloaders and stockpile equipment which the LTU already had.
- remove the LTU from the events calendar.
- calculate the new unloading rate using the extra resources acquired.
- calculate the amount still to be unloaded, and hence the remaining unloading time.
- cause B112 to occur when unloading has finished.
- a Boolean variable is triggered to call C16 as a change in flow rate of one or

more of the stockpiles may have occurred.

C11 {Land transport waiting to get loaders}

Conditions:

(1) Has the Boolean variable indicating an LTU is ready to load been triggered, or has the Boolean indicating an LTU has finished loading (i.e. resources have become available) been triggered?

Actions:

(1) Make a list of all the LTUS at loading bays which need loaders, provided the stockpile that the LTU is working at is operating.

(2) Sort the list based on the priority rules.

(3) Go through the whole list and try and allocate any available loaders.

(4) If an LTU acquired some more loaders ***and*** has already started loading, then

- update the throughput of the loaders and stockpile equipment which the LTU already had.
- remove the LTU from the events calendar.
- calculate the new loading rate using the extra resources acquired.
- calculate the amount still to be loaded, and hence the remaining loading time.
- cause B115 to occur when loading has finished.
- a Boolean variable is triggered to call C16 as a change in flow rate of one or more of the stockpiles may have occurred.

C12 {Land transport waiting for port transport}

Conditions:

(1) Have one or more of the Boolean variables indicating that an LTU waiting to unload or load is ready for port transport been triggered, or have one or more of the Boolean variables indicating that an LTU has finished unloading or loading (i.e. resources have become available) been triggered?

Actions:

(1) Make a list of all the LTUS at loading bays that require port transport.
(2) Sort the list based on the priority rules.
(3) Allocate any available port transport units to suitable LTUS.
(4) If the LTU acquires some more port transport units ***and*** has already started ***unloading*** then

- update the throughput of the unloaders and stockpile equipment which the LTU already had.
- remove the LTU from the events calendar.
- calculate the new unloading rate using the extra resources acquired.
- calculate the amount still to be unloaded, and hence the remaining unloading time.
- cause B112 to occur when unloading has finished.
- a Boolean variable is triggered to call C16 as a change in flow rate of one or more of the stockpiles may have occurred.

(5) If the LTU acquires some more port transport ***and*** has already started ***loading*** then

- update the throughput of the loaders and stockpile equipment which the LTU already had.

- remove the LTU from the events calendar.
- calculate the new loading rate using the extra resources acquired.
- calculate the amount still to be loaded, and hence the remaining loading time.
- cause B115 to occur when loading has finished.
- a Boolean variable is triggered to call C16 as a change in flow rate of one or more of the stockpiles may have occurred.

C13 {Land transport waits to be serviced at gate on departure}

Conditions:

(1) For each gate, are there any LTUS waiting to be serviced?

Actions:

(1) Go through the queue of LTUS and if there is a suitable service point available for the relevant LTU allocate it and cause B126 to occur straight away.

C14 {Ship waiting for stockpile equipment}

Conditions:

(1) Has the Boolean variable indicating that a ship is waiting for stockpile equipment been triggered, or has the Boolean variable indicating that a ship has finished with stockpile equipment been triggered?

Actions:

(1) Make a list of all the ships at berths that require stockpile equipment.

(2) Sort the list based on the priority rules.

(3) Allocate any available stockpile equipment units to suitable ships.

(4) If the ship acquires some more stockpile equipment and has already started unloading or loading then

- remove the ship from the events calendar.
- update the throughput of the unloaders (or loaders) and stockpile equipment units which the ship already had.
- calculate the amount of cargo still to be unloaded (or loaded).

(5) If the ship acquires some stockpile equipment (may or may not have already started unloading or loading) then calculate the new unloading rate (or loading rate) and hence the time to call B37 (B11 if loading) when the unloading (or loading) has been completed.

C15 {Land transport waiting for stockpile equipment}

Conditions:

(1) Has the Boolean variable indicating that an LTU is waiting for stockpile equipment been triggered, or has the Boolean variable indicating that an LTU has finished with stockpile equipment been triggered?

Actions:

(1) Make a list of all the LTUS at loading bays that require stockpile equipment.

(2) Sort the list based on the priority rules.

(3) Allocate any available stockpile equipment units to suitable LTUS.

(4) If the LTU acquires some more stockpile equipment and has already started unloading or loading then

- remove the LTU from the events calendar.
- update the throughput of the unloaders (or loaders) and stockpile equipment units which the LTU already had.

- calculate the amount of cargo still to be unloaded (or loaded).

(5) If the LTU acquires some stockpile equipment (may or may not have already started unloading or loading) then calculate the new unloading rate (or loading rate) and hence the time to call B112 (B115 if loading) when the unloading (or loading) has been completed.

C16 {Storage area}

Conditions:

(1) Has one or more of the Boolean variables indicating that a ship (or LTU), has started (restarted, or finished) unloading (or loading), or has acquired more resources, been triggered?

Actions:

For each stockpile,

(1) calculate the provisional inward batch size, take the present time as the time last updated, and calculate the new inflow rate.
(2) calculate the provisional outward batch size, take the present time as the time last updated, and calculate the new outflow rate.
(3) check if can continue unloading.
(4) check if can continue loading.
(5) reset all Boolean variables which can cause this procedure to be called to false.

C17 {Affect of the work schedules}

Conditions:

(1) For each cargo type, is the relevant work schedule at the start of a duration, and

does the present state of the weather allow cargo movement?

<u>Actions:</u>

If work is being suspended,

(1) update the affected stockpiles.

(2) a Boolean variable declaring work has been suspended at the relevant stockpiles is triggered.

(3) Go through all the ships and LTUS working at the affected stockpiles and

- release all acquired unloaders, loaders, port transport, and stockpile equipment units and update the relevant utilization figures.
- update throughputs of released unloaders, loaders and stockpile equipment units.
- reset entity attributes related to unloading and loading.
- trigger Boolean variables to call relevant C activities (C3, C4, C5, C10, C11, C12, C14, C15) as resources have become available.
- for ships and LTUS which had started unloading or loading, remove from the events calendar and calculate the amount so far unloaded or loaded.

If work is starting up,

(1) the Boolean variable declaring work has been suspended at the relevant stockpiles is cancelled.

(2) trigger Boolean variables to call the relevant C activities (C3, C4, C10, C11), as resources have become available.

C18 {Affect of weather on cargo movement}

Conditions:

(1) Is the weather at the start of a duration, and for each cargo type does the relevant work schedule allow cargo movement?

Actions:

For each cargo type,

(a) If work is being suspended,

(1) update the affected stockpiles.

(2) a Boolean variable declaring work has been suspended at the relevant stockpiles is triggered.

(3) Go through all the ships and LTUS working at the affected stockpiles and

- release all acquired unloaders, loaders, port transport, and stockpile equipment units, and update the relevant utilization figures.
- update throughputs of released unloaders, loaders and stockpile equipment units.
- reset entity attributes related to unloading and loading.
- trigger Boolean variables to call relevant C activities (C3, C4, C5, C10, C11, C12, C14, C15) as resources have become available.
- for ships and LTUS which had started unloading or loading, remove from the events calendar and calculate the amount so far unloaded or loaded.

(b) If work is starting up,

(1) the Boolean variable declaring work has been suspended at the relevant stockpiles is cancelled.

(2) trigger Boolean variables to call relevant C activities (C3, C4, C10, C11), as resources have become available.

3.9 Environmental Conditions

These are several important factors that affect the operation of a port. The environmental conditions included in the model are described in the sections below.

3.9.1 Cargo Schedules

There is one cargo schedule for each of the five cargo types. Each schedule regulates when the relevant cargo type can be worked on. i.e. it affects cargo movement. The user defines for each day of the week the time that work may start, and the time that work must cease. Times must be inputted based on the twenty four hour clock, although minutes must be inputted as fractions of the hour e.g. 6.30pm must be inputted as 18.50. If and when work ceases, all ships and LTUS being worked on which are carrying the relevant cargo type, must release all the resources that they have acquired.

3.9.2 Port Schedule

The port schedule affects ship movement into and out of the port. The port schedule has two states, namely 'open' and 'closed'. If the port is open all ship movement is allowed. If the port is closed, no ship movement is allowed.

The user defines for each day of the week, the time ship movement may commence, and the time that ship movement must cease. Times must be inputted in the same way as the cargo schedules. Note that once a ship has STARTED to enter or exit the port it will complete this activity as the state of the port schedule is not checked again.

3.9.3 Weather

The weather consists of up to six states and affects ship movement and cargo movement. The length of time that the weather spends in a state is known as a period of weather. When the end of a period of weather is reached the weather will begin the next period of weather. The length of the period of weather depends on which state the weather is in. The state of the next period of weather is decided upon by the transition probabilities p_{ij}, where i is the present weather state, j is the next weather state, and p_{ij} is the probability of going from state i to state j. The matrix below gives the possible transition probabilities.

$$\begin{pmatrix} p_{11} & p_{12} & p_{13} & p_{14} & p_{15} & p_{16} \\ p_{21} & p_{22} & p_{23} & p_{24} & p_{25} & p_{26} \\ p_{31} & p_{32} & p_{33} & p_{34} & p_{35} & p_{36} \\ p_{41} & p_{42} & p_{43} & p_{44} & p_{45} & p_{46} \\ p_{51} & p_{52} & p_{53} & p_{54} & p_{55} & p_{56} \\ p_{61} & p_{62} & p_{63} & p_{64} & p_{65} & p_{66} \end{pmatrix}$$

Given that the next weather state has been chosen, each weather state has associated with it a distribution with relevant parameters, from which to sample from, in order to get a duration for the period of weather.

The user defines the transition probabilities of going from one state to another, the distribution (and associated parameters) for each weather state, which states ship movement is allowed in, and for each cargo type which states cargo movement is allowed in.

The user can vary the number of states the weather consists of by the setting the transition probabilities of going into states not needed to zero e.g. if only two states are required, the user could set up the following matrix,

$$\begin{pmatrix} 0.7 & 0.3 & 0 & 0 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

The reason for having up to six states is so that if necessary the first state can allow all cargo movement, the second state can allow movement for all cargo types except one, the third state can allow movement for all cargo types except two etc, up to the sixth state not allowing any cargo movement.

For each state ship movement is either allowed or not allowed. Similarly for cargo movement. If ship movement is allowed, ships may enter and leave the port. If ship movement is not allowed, ships may not START to enter or leave the port. Note that ships only check the weather in the C activities controlling entry and exit to the port, so once a ship has been allowed to proceed down the approach channel (in either direction), the ship will complete this activity even if the weather enters a state which doesn't allow ship movement.

For each cargo type, if the present weather state allows movement of the cargo type in question, all servicing activities on both sides of the port may continue e.g. ship (un)loading, LTU (un)loading. If the weather enters a state which does not allow movement of the particular cargo type, all work on that cargo type must be suspended. All affected ships and LTUS must release all resources acquired, and wait for cargo movement to be allowed to re-start. Entities release resources because the resources may be of use to entities handling other cargo types not affected by the present weather condition.

3.9.4 Tide

The tide is modelled using a modified version of Gooding's tide unit, which in turn is a conversion of a Fortran program written by Halcrow. The tide unit continually calculates the height of the tide during the simulation run using, the amplitude and phase of the four harmonics M2, S2, K1, and O1, the mean sea level (Z0), the minimum chart depth, the minimum clearance level, and a start year and day. All of these are user inputs. The tide affects the hours when ships are allowed to enter and leave the port.

3.10 Model Input

The importance of model input and output are stressed by many authors who have produced simulation models. In particular, without sufficient input, useful output is unobtainable. The following sections explain the vast array of input that the user can set up. See Figure 3.2 for an overview of the model input and output. Model output is discussed in section 3.11.

3.10.1 Ship Variables

The user can have up to five 'shipping fleets', which are known as 'ship groups'. Each ship group carries one and only one 'cargo type', and each cargo type is carried by one and only one ship group i.e. a bijective relationship. It is intended that generally a ship group will comprise of one type of cargo such as coal. However this may not always be the case. It is obviously up to the user to decide which ships categorise each ship group. This will depend on the nature of the project being undertaken. There are numerous input tables for the ship groups and these are described below.

As well as being allocated to a ship group each ship in the simulation belongs to a 'ship size class'. There are up to five ship size classes available. When a ship is created a 'size' is generated based on the relevant ship group size distribution. From this the ship can be allocated to the relevant ship size class, and hence can generate

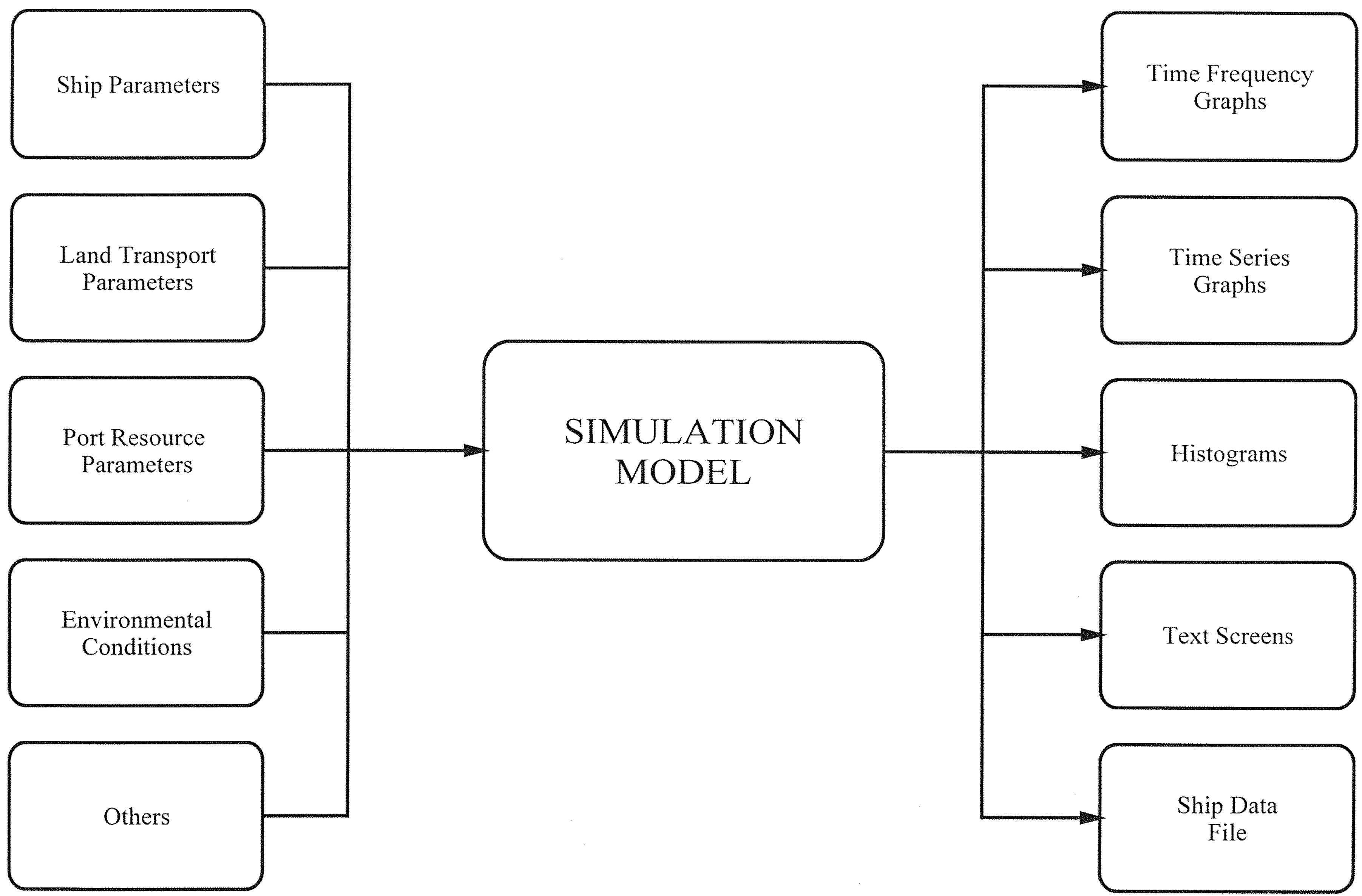


Figure 3.2 Model input and output.

appropriate ship size class attributes for ships in that size range. Ship size class attributes are attributes which relate to the size of the ship rather than the cargo type it is carrying, such as the number of tugs the ship needs to navigate its way into the port.

Ship Groups

The user sets up the ship groups by selecting the 'ship groups' option and the 'ship group priority weightings' option.

Ship group Status

The ship group status table is used to select the number of ship groups required, and to turn the ship groups on and off once set up. For example the user may require four ship groups which are set up in the initial input file. To run the program without 'group three' say, click the mouse on the appropriate check table, rather than setting up a whole new input file.

Arrival Distribution

The user has a choice of five mathematical distributions. These are the Negative Exponential, Erlang, Poisson, Uniform, and Constant distributions. It is most probable that for a particular project the user will have some historic data, and will hence choose the distribution which fits best against the data. Negative Exponential and Poisson distributions are for the common case of random arrivals.

Having chosen the distribution required the user must then input the correct distribution parameters. For the Negative Exponential and Poisson distributions the 'first parameter' is the mean and the 'second parameter' is unused. For the Erlang distribution the 'first parameter' is the mean and the 'second parameter' is 'k', where the random variate E_k is the sum of k Negative Exponential variates. For the Uniform distribution the 'first parameter' is the lower limit, and the 'second parameter' is the upper

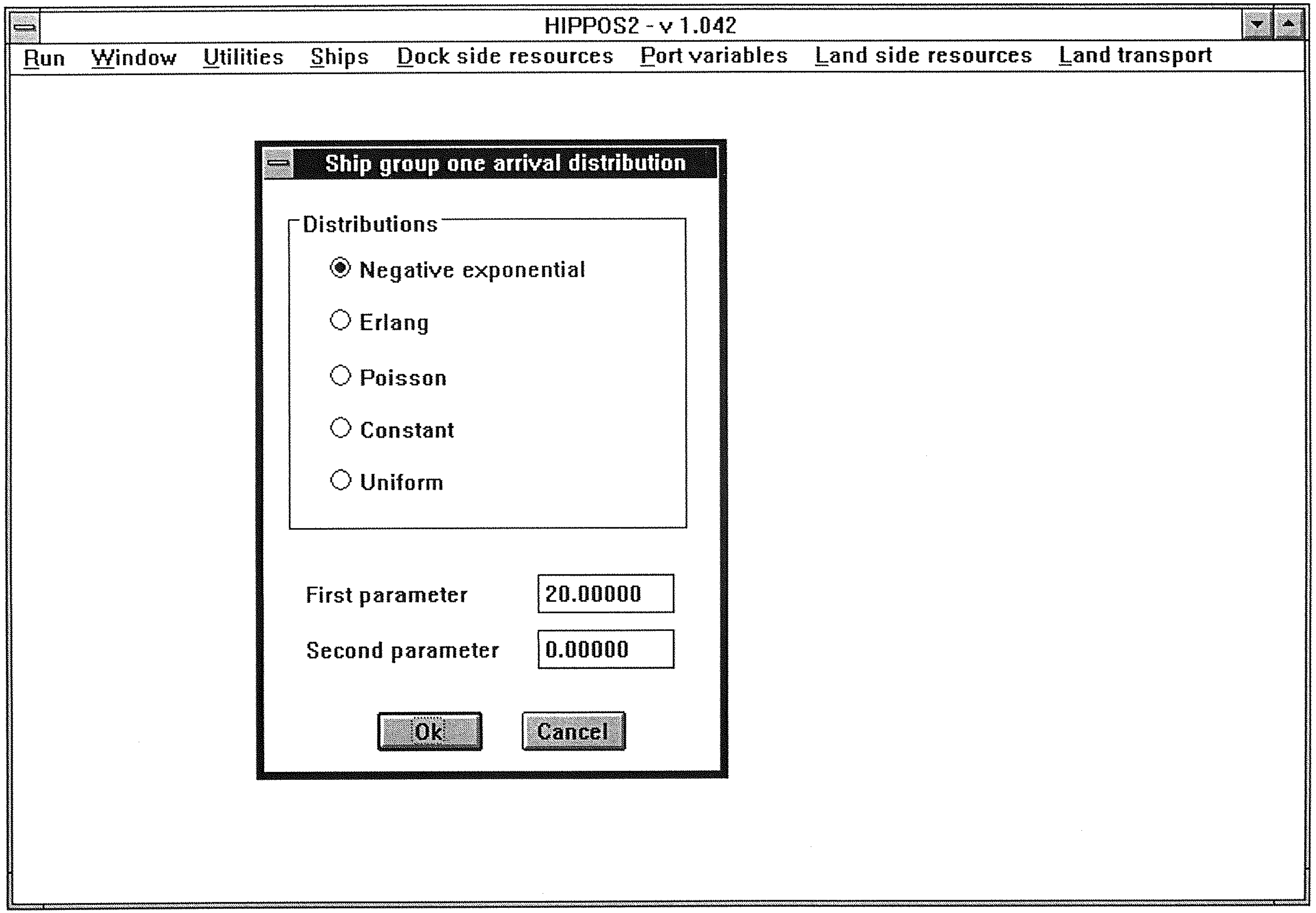


Figure 3.3 Ship group arrival distribution input table.

limit. Finally, for the Constant distribution the 'first parameter' is the constant value at which ships will arrive i.e. its not really a distribution e.g. you may have a ferry which comes to the port the same time every day. The 'second parameter' is unused if the user selects the Constant distribution.

Size Distribution

The user has a choice of six mathematical distributions. These are the Negative Exponential, the Erlang, the Poisson, the Constant, the Uniform, and the Weibull. Having selected the required distribution a second input screen will appear, allowing the user to input the appropriate distribution parameters. These are shown in Table 3.1.

The size (DWT) of the ship is used to calculate the draught of the ship, which in turn is compared with the tide level when the ship wants to enter and leave the port. The size of the ship is also used to allocate the ship to the correct ship size class.

Distribution	**Parameters**
Negative exponential	Mean, upper limit, lower limit
Erlang	Mean, ‘k’, upper limit, lower limit
Poisson	Mean, upper limit, lower limit
Constant	Value
Uniform	Upper limit, lower limit
Weibull	Scale, shape, upper limit, lower limit

Table 3.1 Size distribution choice and appropriate parameters.

Cargo Size Distribution

The user is given the choice of seven mathematical distributions. These are as the ship size distribution, plus the possibility of the ship’s cargo size being a fixed

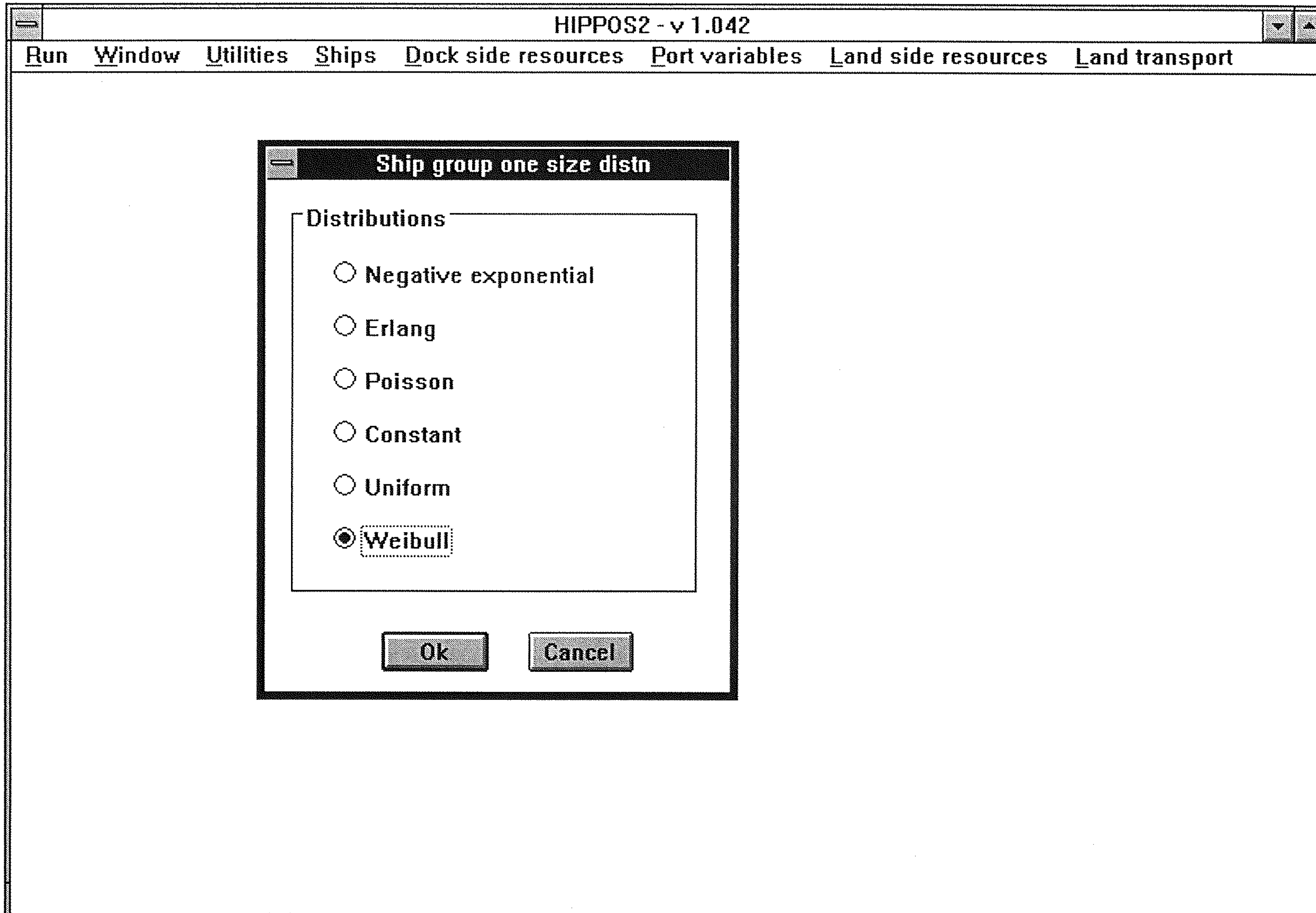


Figure 3.4 Ship group size distribution input table.

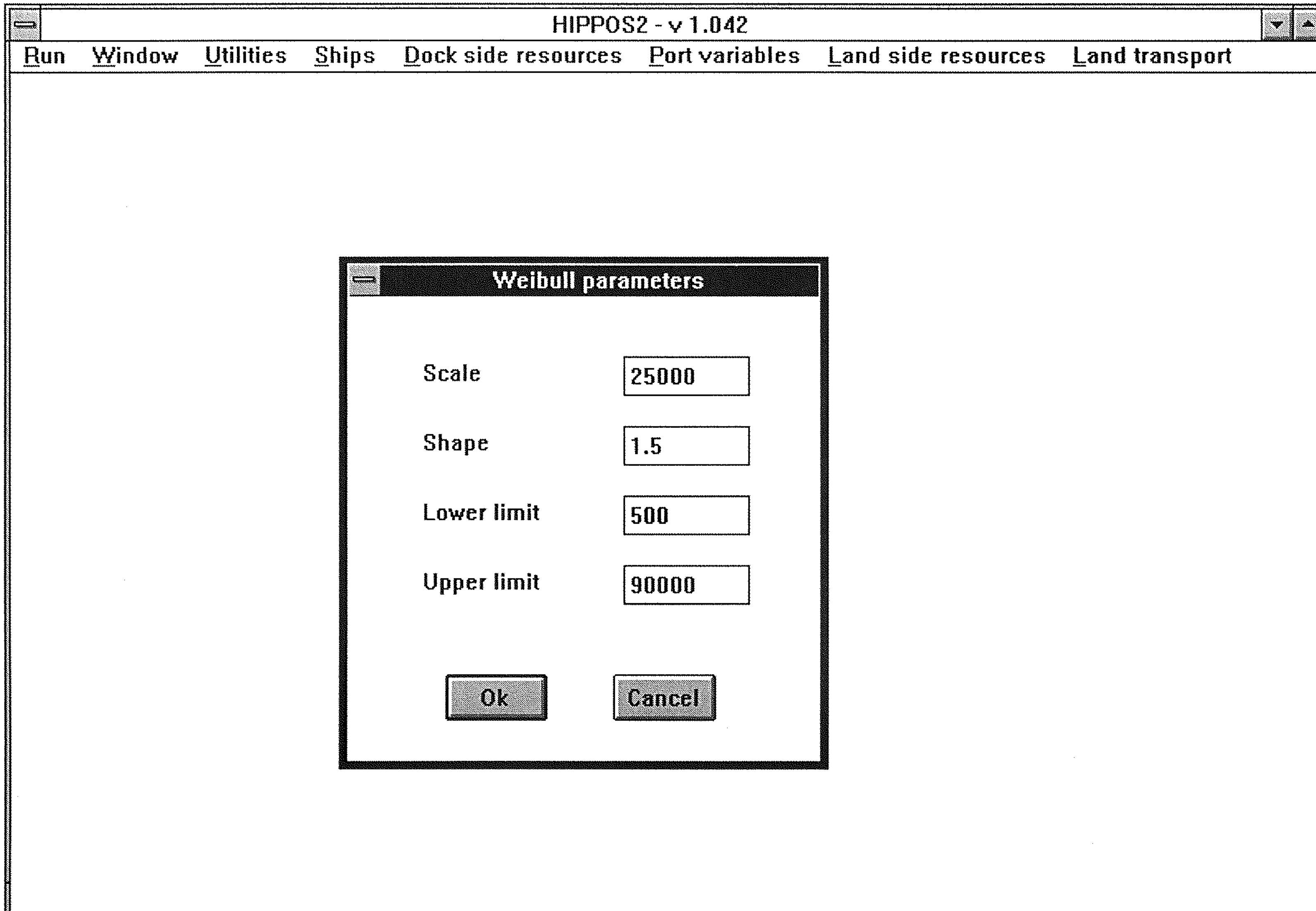


Figure 3.5 Ship group size parameter input table for the Weibull distribution.

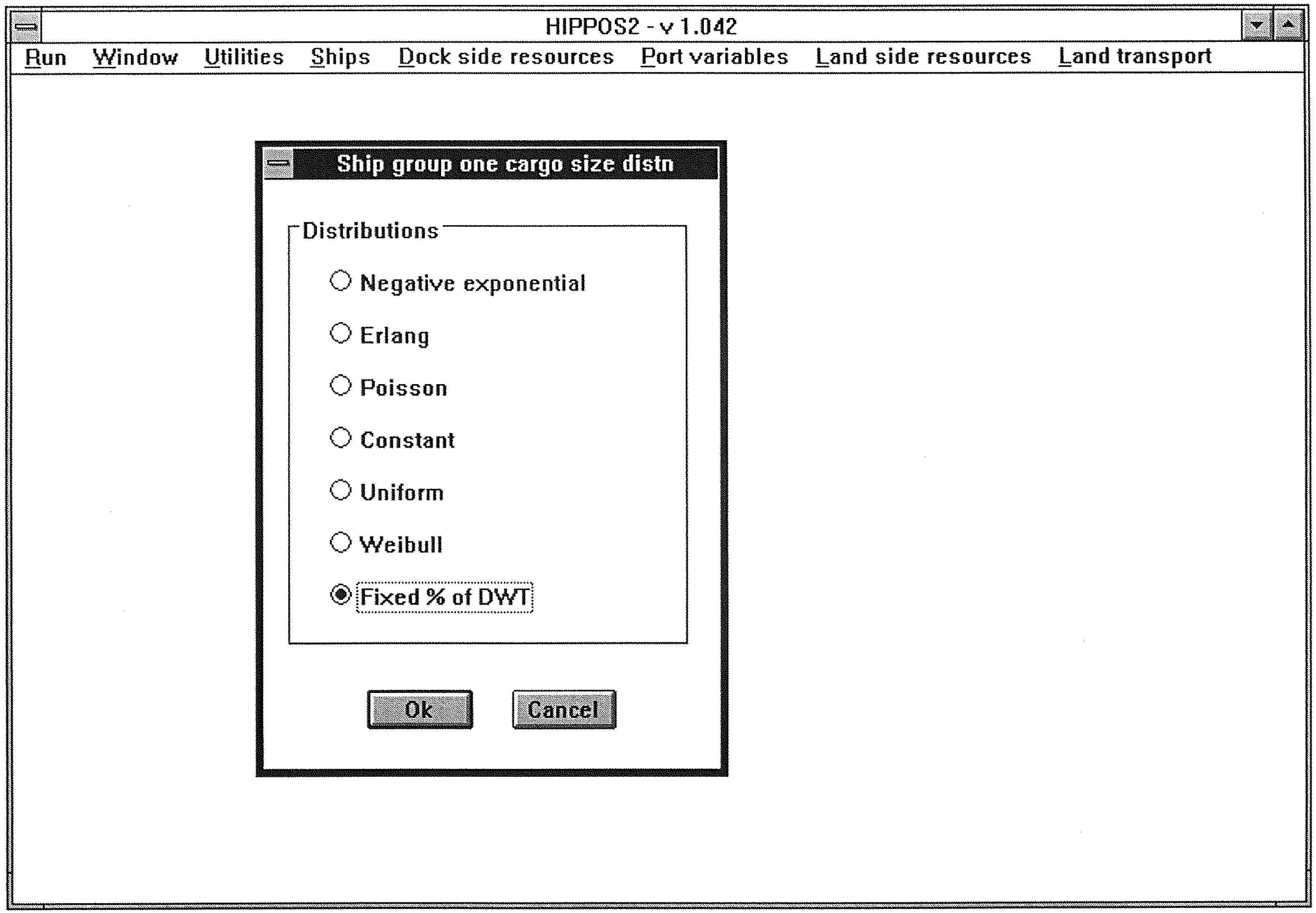


Figure 3.6 Ship group cargo size distribution input table.

percentage of the ship's size.

The cargo size is the amount of cargo a ship unloads and/or loads. The cargo size affects the service time of the ship.

Trading Status Probabilities

A ship can either import cargo, export cargo, or do both. In the trading status table the user inputs the proportion of ships in the ship group that are going to import only as a probability, and the proportion of ships in the ship group that are going to export only as a probability. The remaining probability is for ships importing and exporting cargo.

If a ship is importing only, it will have a loaded draught on entry to the port, and an unloaded draught on leaving the port. If a ship is exporting only, it will have an unloaded draught on entry to the port, and a loaded draught on leaving the port. Finally, if the ship is going to import and export cargo, it will have a loaded draught on entry and on leaving the port.

Pre-unloading Delay

The user can cause ships to be delayed before they are allowed to try and start unloading. For example a ship carrying crude oil may have to have a sample of its cargo tested at a laboratory for some reason e.g. quality, before it is allowed to try and unload. Note that this delay is not related to ships having to wait due to lack of port resources. The distributions on offer are as with the arrival distribution. If no delay is required the user can, for example, select the Constant distribution with a parameter of zero. The length of the pre-unloading delay will affect the length of the ships service time.

Pre-loading Delay

A delay can be caused to ships before they try and load. The distributions available are again as with the arrival distribution. The length of the pre-loading delay will affect the length of the ships service time.

Pre-departure Delay

A delay can be caused before the ships leave the port e.g. for customs. The distributions available are again as with the arrival distribution. The length of the pre-departure delay will affect the length of the ships service time.

Ship group stockpile level checks

Before a ship can enter the port the following condition must be true. If a ship is importing cargo, the ship's cargo size is checked against the relevant stockpile to see if there is room for a specified percentage of the ship's cargo size at the present simulation run time. If the ship is exporting cargo, the ship's cargo size is checked against the relevant stockpile to see if there is a specified percentage of the ship's cargo size available at the stockpile at the present simulation runtime. If a ship is importing and exporting cargo, then both the above statements must be true.

Multiple Unloader Factors

When more than one unloader works on a ship at the same time, it may be that the overall 'effective rate' goes down. For example two unloaders working on their own may have 'effective rates' of 4000 tonnes per hour and 3000 tonnes per hour. But if they were to work on the same ship together, for one reason or another, the combined 'effective rate' may be less than 7000 tonnes per hour. The multiple unloader input table allows the user to allocate factors to the various number of unloaders that may be working on a ship at any one time, up to a maximum of ten unloaders. These inputted

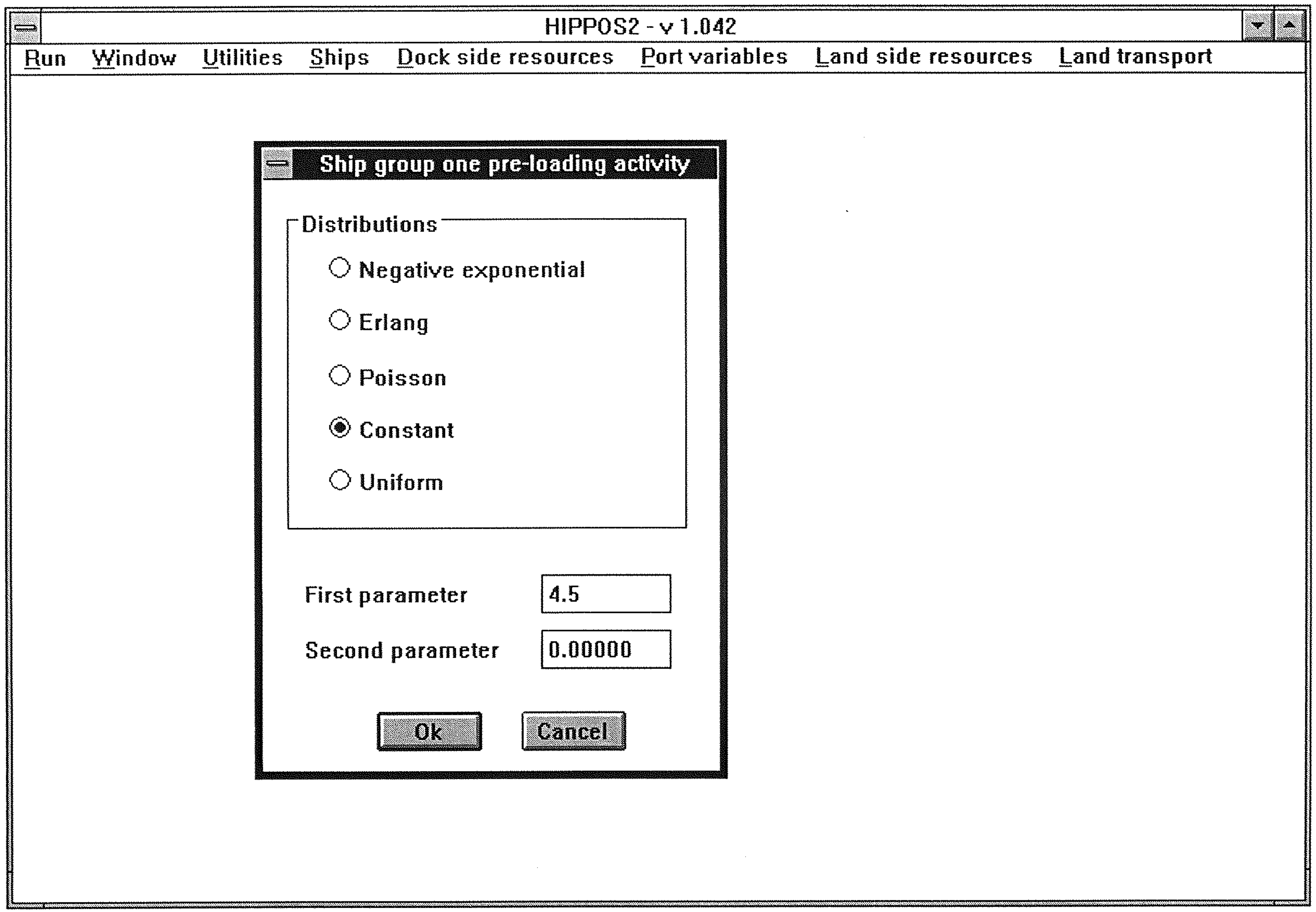


Figure 3.7 Ship group pre-loading delay input table.

factors will then be multiplied against the sum of the 'effective rates' of the unloaders working on a particular ship. So if the above two unloaders were working together on a ship and the user input a factor of 0.9, then the overall 'effective rate' of the two unloaders would be 6300 tonnes per hour.

Multiple Loader Factors

As for the multiple unloader factors, but applied to the loaders.

Ship Group Service Priority Weightings

Under the 'ship group service priority weightings' option, the user can allow certain ship groups priority over others during the service phase. If the user gives a certain ship group priority it means that the ships in this group will have priority in trying to obtain unloaders, loaders, and port transport. All the ship groups have been given a priority weighting of '1' by default i.e. no ship group has priority over any of the others. To give a group priority over the others select an integer value that is larger than the other groups weightings, although this can all be done by just using the numbers 1 to 5.

Ship Group Cargo Size Bands

The cargo size bands are used to decide how many (un)loaders a ship of a certain cargo size and cargo type should ideally have. In the 'cargo size bands' input table the user sets up the ranges for the bands, and the numbers of (un)loaders that the ship should have are set up in the 'max number of unloaders per ship' or 'max number of loaders per ship' options.

Ship Size Classes

The ship size class input tables allow the user to set up the ship attributes which

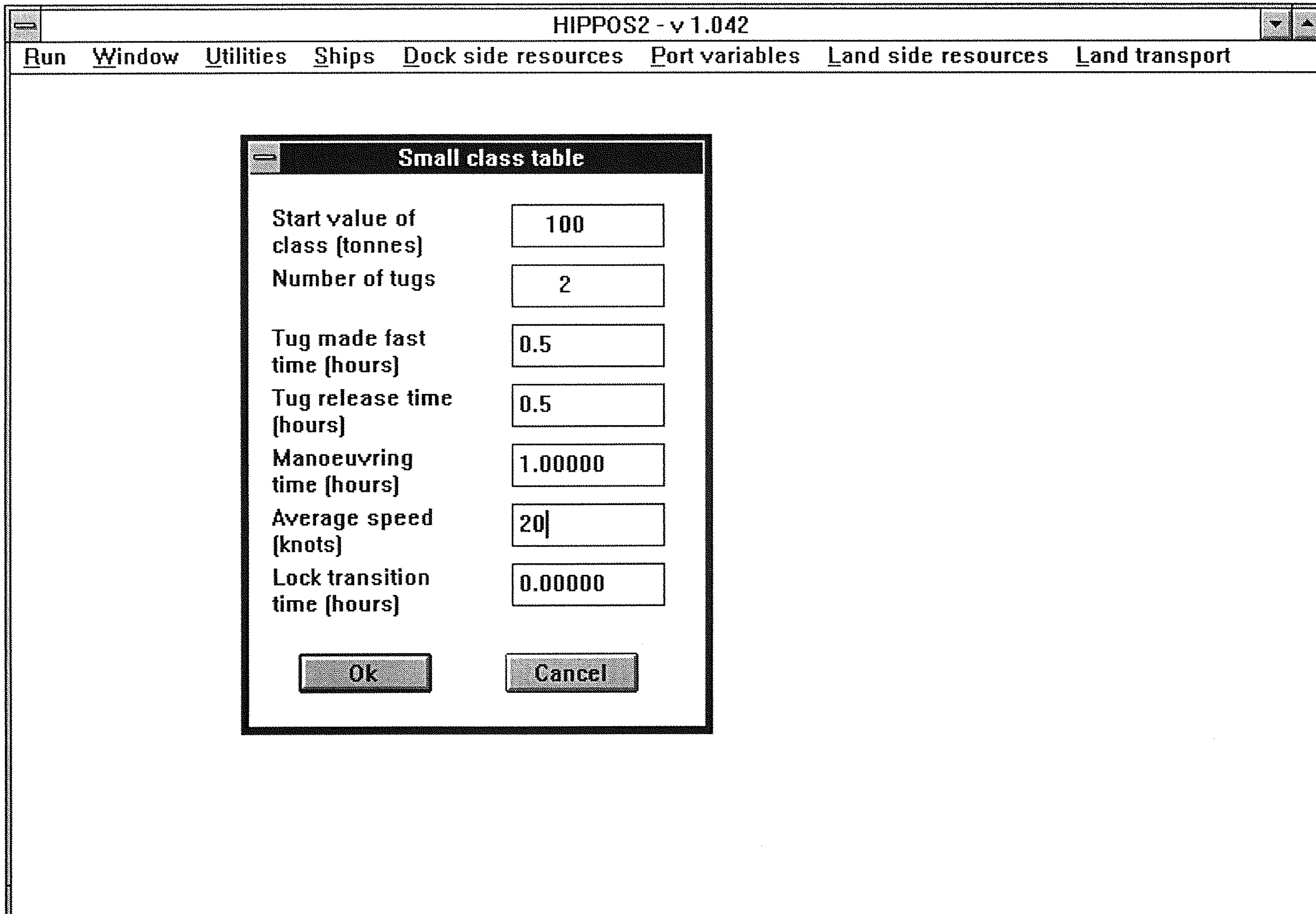


Figure 3.8 Ship size class input table.

relate to size rather than the cargo type it is carrying. The first four ship size classes (small, medium, large and very large) have seven attributes each.

- the number of tugs needed to navigate into and out of the port.
- the tug fasten time, which is the total time to affix all the tugs.
- the tug release time, which is the total time to release all tugs.
- the manoeuvring time, which occurs just before and just after a ship docks.
- the average speed.
- the lock transition time (set to zero if no lock required).

The end of the size range is defined by the start of the next ship size class, except for the 'ultra large ship size class' where there is the additional attribute of the end value of the size class, as there is no other ship size class following this one.

The size classes must cover the entire range of ship sizes possible from the ship groups' size distributions i.e. user awareness is needed.

3.10.2 Dock Side Resources

The resources used on the seaward side of the port are berths, tugs, dock side unloaders, dock side loaders, dock side port transport, and dock side stockpile equipment. The input tables for these resources are described below.

<u>Berths</u>

The berths are used by ships during their stay in port, which will consist of unloading and/or loading and any delays that may be encountered. Only one ship is allowed at a berth at any one time.

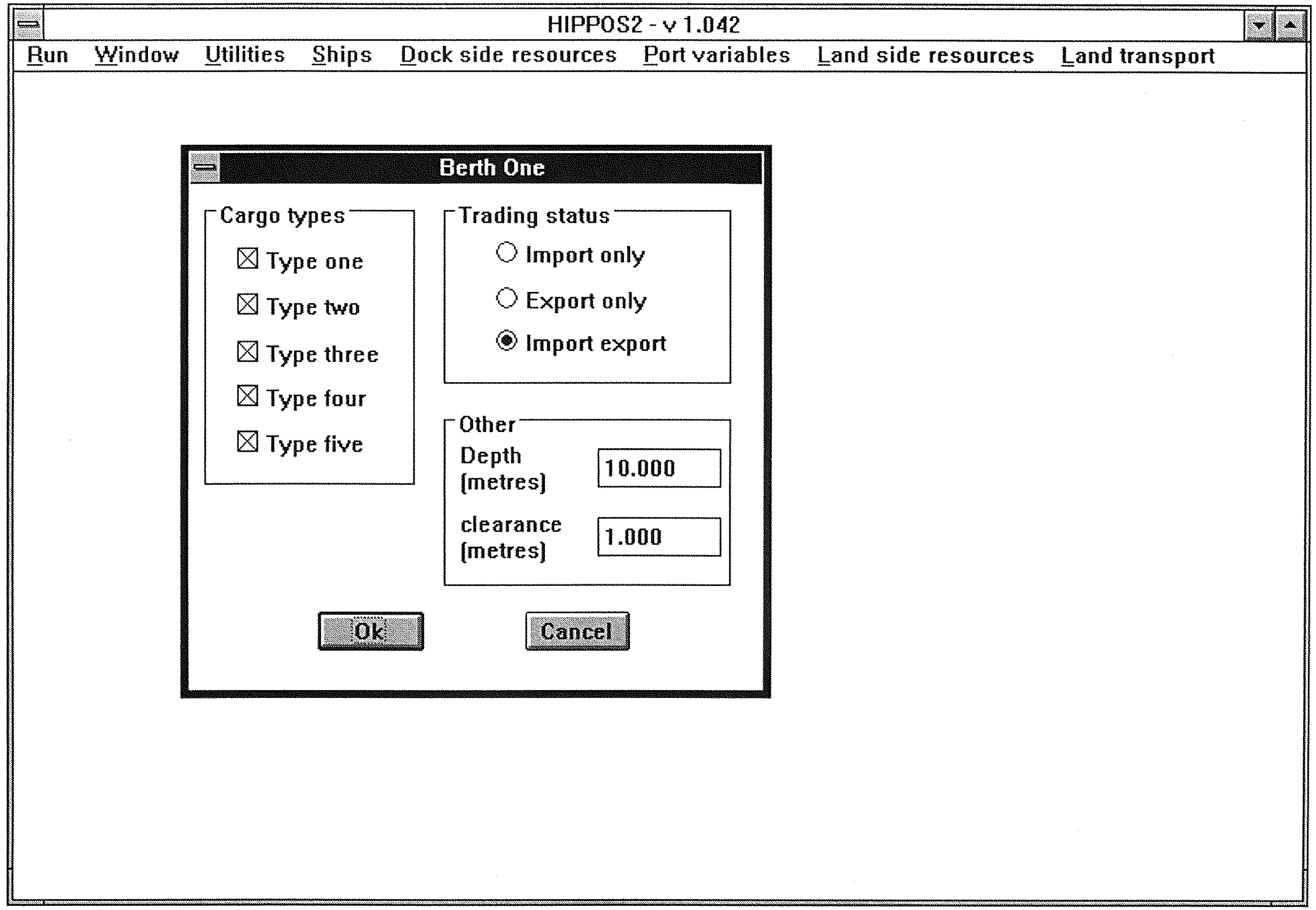


Figure 3.9 Berth input table.

Total number of berths

The user can vary the total number of berths available between **one** and **ten**.

Attributes of berths

The user can alter the attributes of one or more of the berths by selecting the 'Berth - attributes' option. Under this option the user will find one table for each berth. The table for a particular berth lets the user select which cargo types are allowed at the berth. It also lets the user select the trading status of the berth. The trading status of the berth can be 'import only', 'export only', or 'import/export'. If the berth is said to be 'import only', only ships which are just importing are allowed at the berth. Similarly if the berth is said to be 'export only', only ships which are just exporting are allowed at the berth. Note however that a berth which is said to be 'import/export' means that the berth will accept ships which are importing only, exporting only, or ships which are going to do both i.e. import and export. Finally the user can set the depth of the berth, and the minimum level of clearance needed by any ship using the said berth.

User awareness is needed, in that any ship waiting to enter the port must be servicable at, at least one berth.

Tugs

The user can define the total number of tugs available, and the average speed of the tugs (all tugs will have the same speed). If when a ship tries to acquire some tugs enough are available but one or more are at the wrong end of the port e.g. ship is offshore and the tugs are at the dock, then a delay will be incurred by the ship while it waits for tugs to get to it. The tug average speed along with the channel length (the distance from the dock to the offshore waiting area) is used in the calculation of this delay.

Dock Side Unloaders

The unloaders are used to discharge the cargo of ships which are importing.

Total number of dock side unloaders

The user can vary the total number of unloaders available between **one** and **ten**.

Attributes of dock side unloaders

There are two tables of attributes for each unloader. In the first table the user defines which cargo types the unloader can handle, the effective unloading rate of the unloader in cargo units per hour for each of the cargo types, and the efficiency level of the unloader as a percentage for each of the cargo types. The rate at which the unloader will work, will be the 'effective rate' multiplied by the 'efficiency level'. In the second table the user defines which berths the unloader can work at.

Maximum number of dock side unloaders per ship

Under this option the user sets up how many unloaders a ship of a certain cargo type and certain ship cargo size band should have, as a maximum.

Dock Side Loaders

The loaders are used to load the cargo of ships which are exporting.

Total number of dock side loaders

As the dock side unloaders.

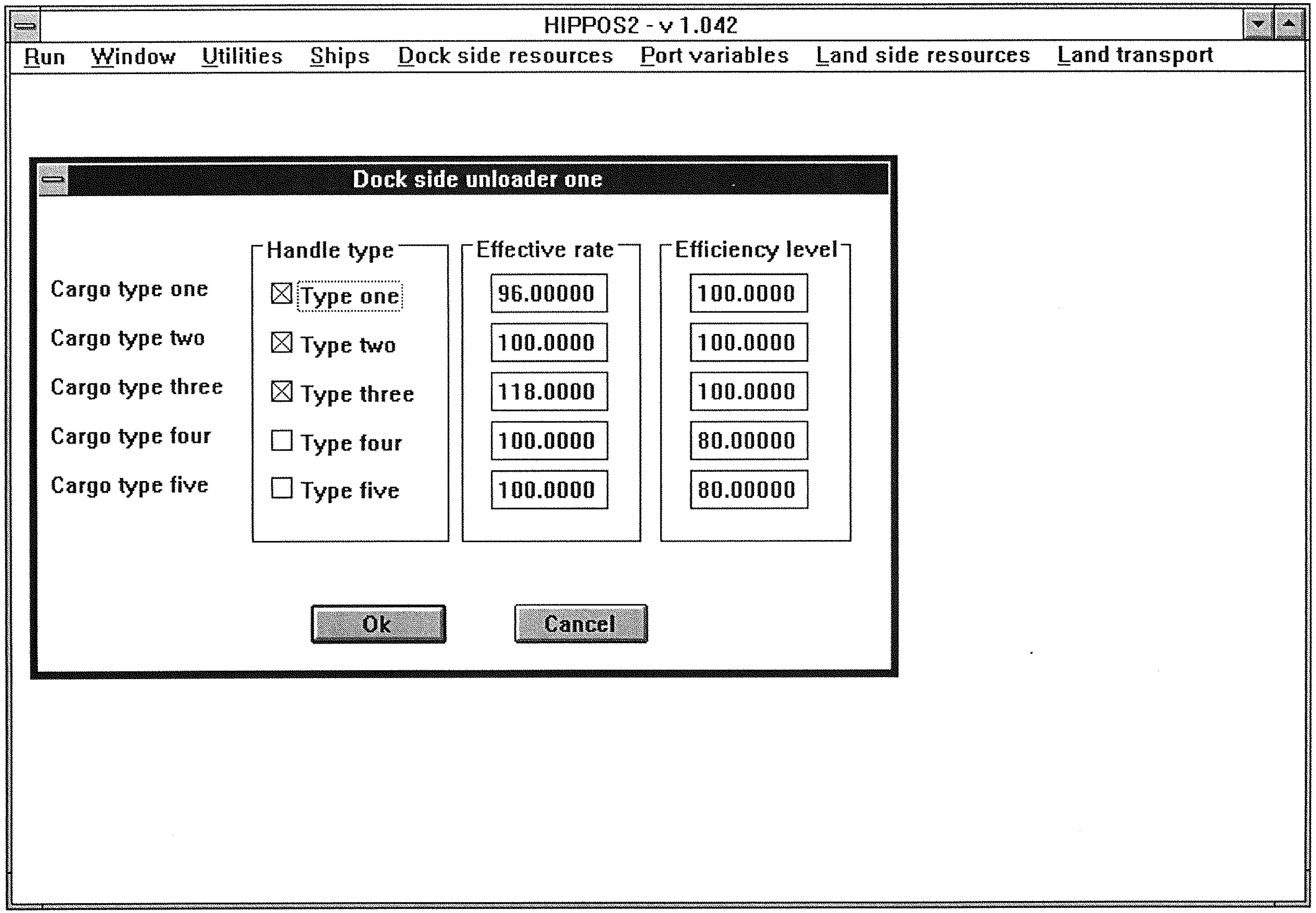


Figure 3.10 Dock side unloader input table (1).

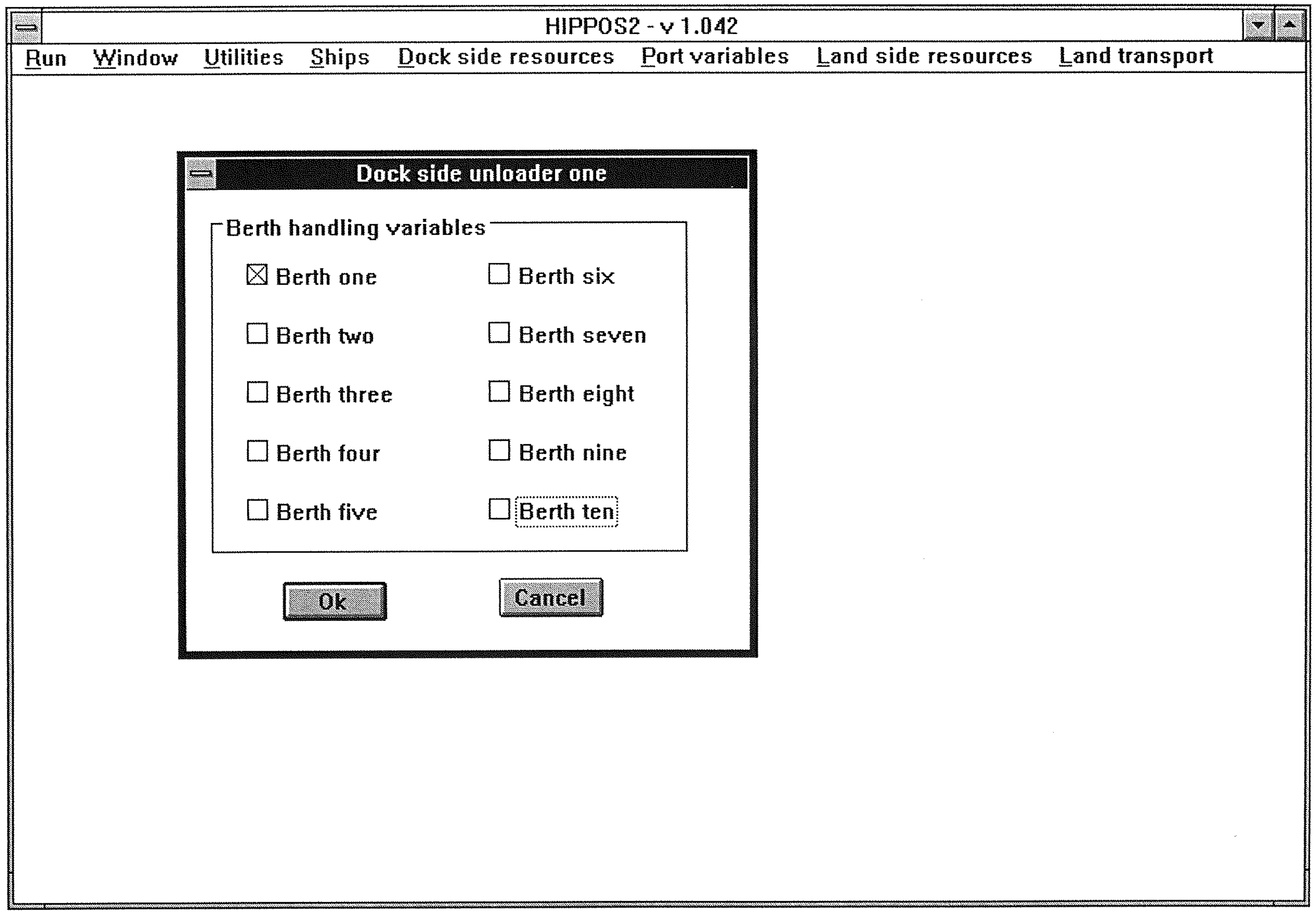


Figure 3.11 Dock side unloader input table (2).

Attributes of dock side loaders

As the dock side unloaders.

Maximum number of dock side loaders per ship

As the dock side unloaders.

Dock Side Port Transport

The port transport is used to carry unloaded cargo from the quayside to the storage area, and cargo which is to be loaded, from the storage area to the quayside. Each ship group has its own group of port transport, with the groups of port transport being numbered so that port transport group one is used to transport cargo from ship group one etc. The attributes of each group are, the total number of port transport units available, the effective rate of each port transport unit, in cargo units per hour, and the efficiency level of each port transport unit, as a percentage. The rate at which each unit will work is the 'effective rate' multiplied by the 'efficiency level'.

Dock Side Stockpile Equipment

The stockpile equipment is used to stack and reclaim cargo from the stockpiles.

Total number of dock side stockpile equipment

The user can vary the total number of dock side stockpile equipment units available between **one** and **twenty**.

Attributes of dock side stockpile equipment

There are two tables of attributes for each unit of stockpile equipment. In the first table the user defines the units type i.e. whether the unit is to be a stacker, a reclaimer or a stacker/reclaimer. In the second table the user defines, for each of the cargo types, which cargo types the unit can handle, the effective unloading rate of the unit in cargo units per hour, and the efficiency level of the unit as a percentage. The rate at which the unit will work, will be the 'effective rate' multiplied by the 'efficiency level'.

3.10.3 Port Variables

Port Schedule

The user defines for each day of the week, the time ship movement may commence and the time it must cease. Times must be inputted based on the twenty four hour clock, although minutes must be inputted as fractions of the hour e.g. 6.30pm must be inputted as 18.50. To have the port open twenty four hours a day, the start time is 0:00, and the finish time is 24:00.

Weather

Under the 'Weather variables' option the user defines the transition probabilities of going from one state to another, the distribution (and associated parameters) for each state. See section 3.9.3 on the weather for further explanation.

Ship Weather States

Under the 'Ship weather states' option the user defines in which weather states ship movement is allowed.

Cargo Type Weather States

Under the 'Cargo type weather states' option, the user defines in which weather states cargo movement is allowed, for each of the five cargo types.

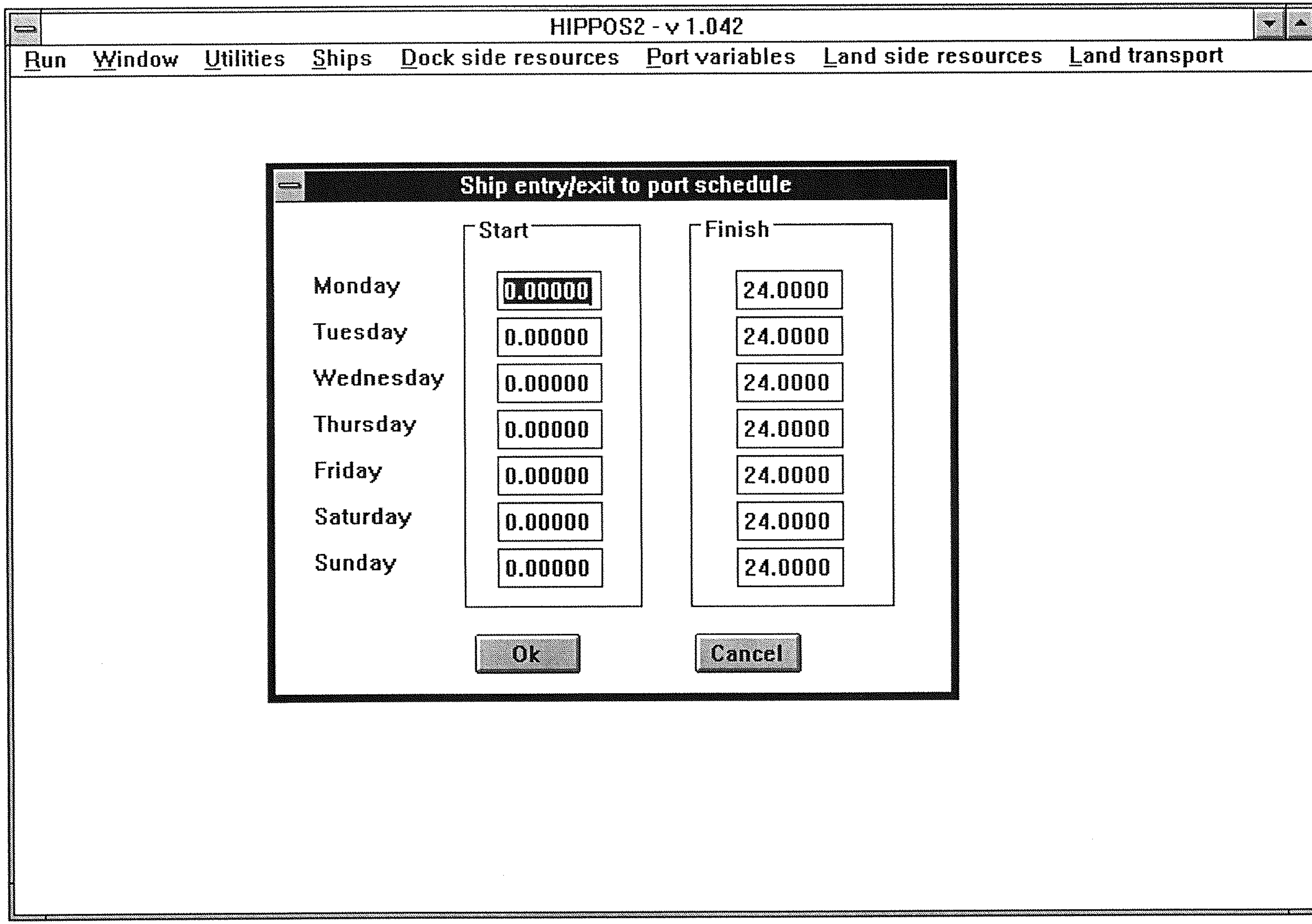


Figure 3.12 Port schedule input table.

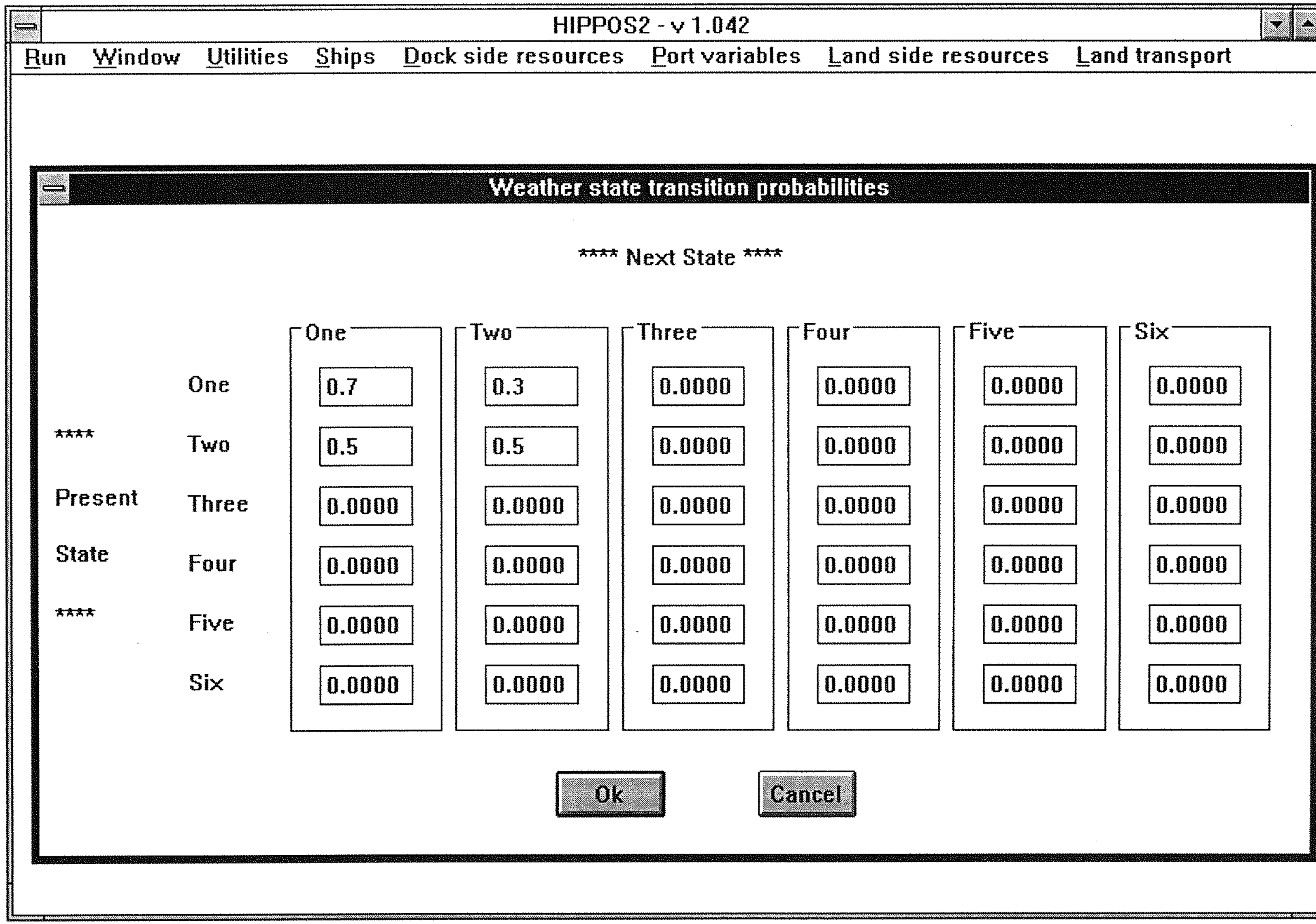


Figure 3.13 Weather state transition probability input table.

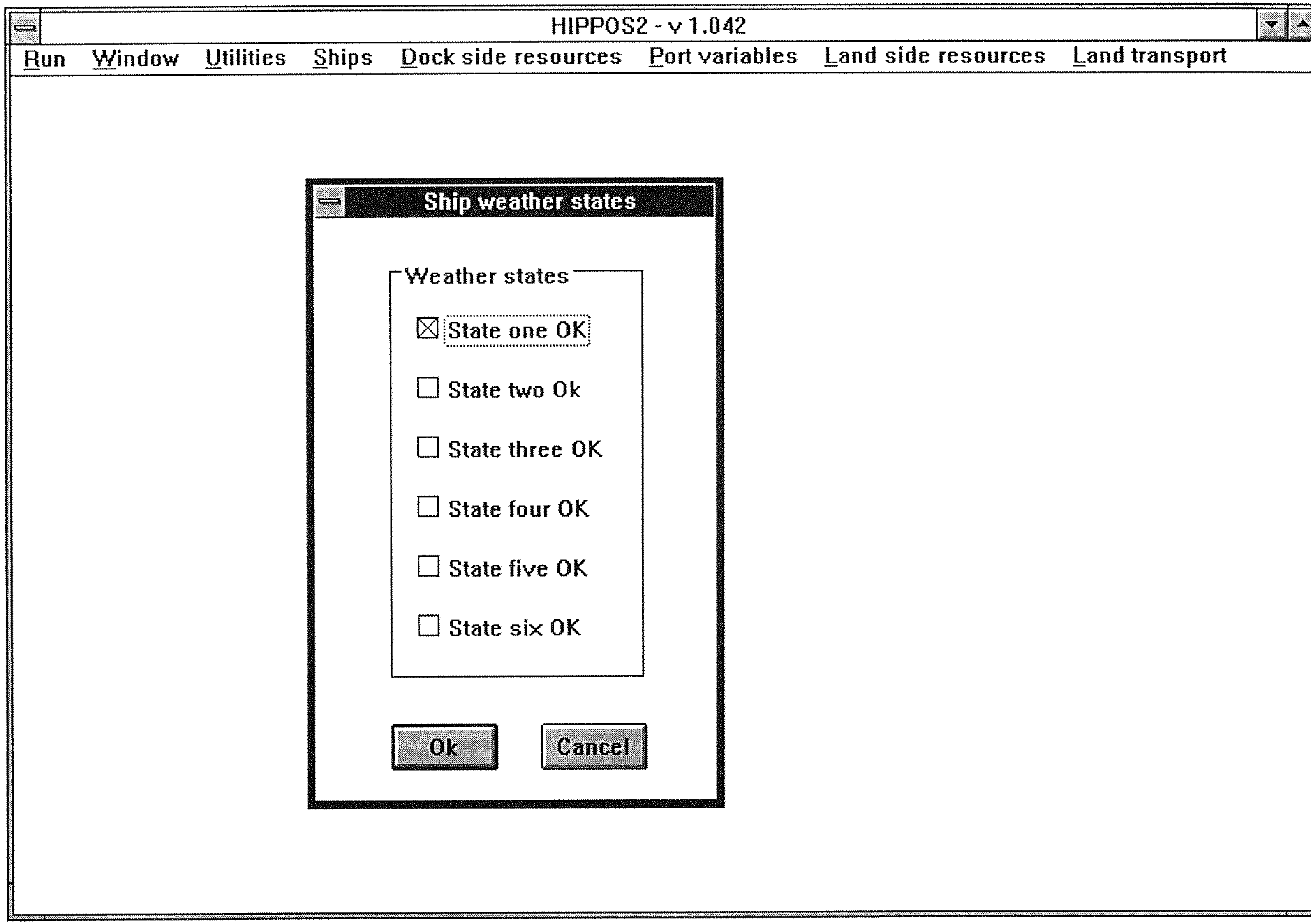


Figure 3.14 Weather affect on ship movement input table.

Tides

see earlier explanation in section 3.9.4.

Channel Parameters

The 'Channel length' parameter is the distance the ships have to travel from the offshore waiting area to the lock, and the 'Distance to manoeuvring area' is the distance from the lock to the manoeuvring area, the manoeuvring area being the area where the ships manoeuvre in order to dock. All distances are in metres.

Simulation Duration

Under the 'Simulation duration' option the user sets the length of the simulation run as a number of hours.

Stockpiles

Under the 'Stockpiles' option the user defines for each cargo type, the total capacity and initial level for the import stockpile and the export stockpile (in cargo units).

3.10.4 Land Transport

Port Gates

Under the 'Port gates' option the user selects how many gates are required, between **one** and **four**. Then for each gate the user selects the number of service points available to arriving LTUS (between one and ten), and the number of service points available to departing LTUS (between one and ten). Finally for each service point, the

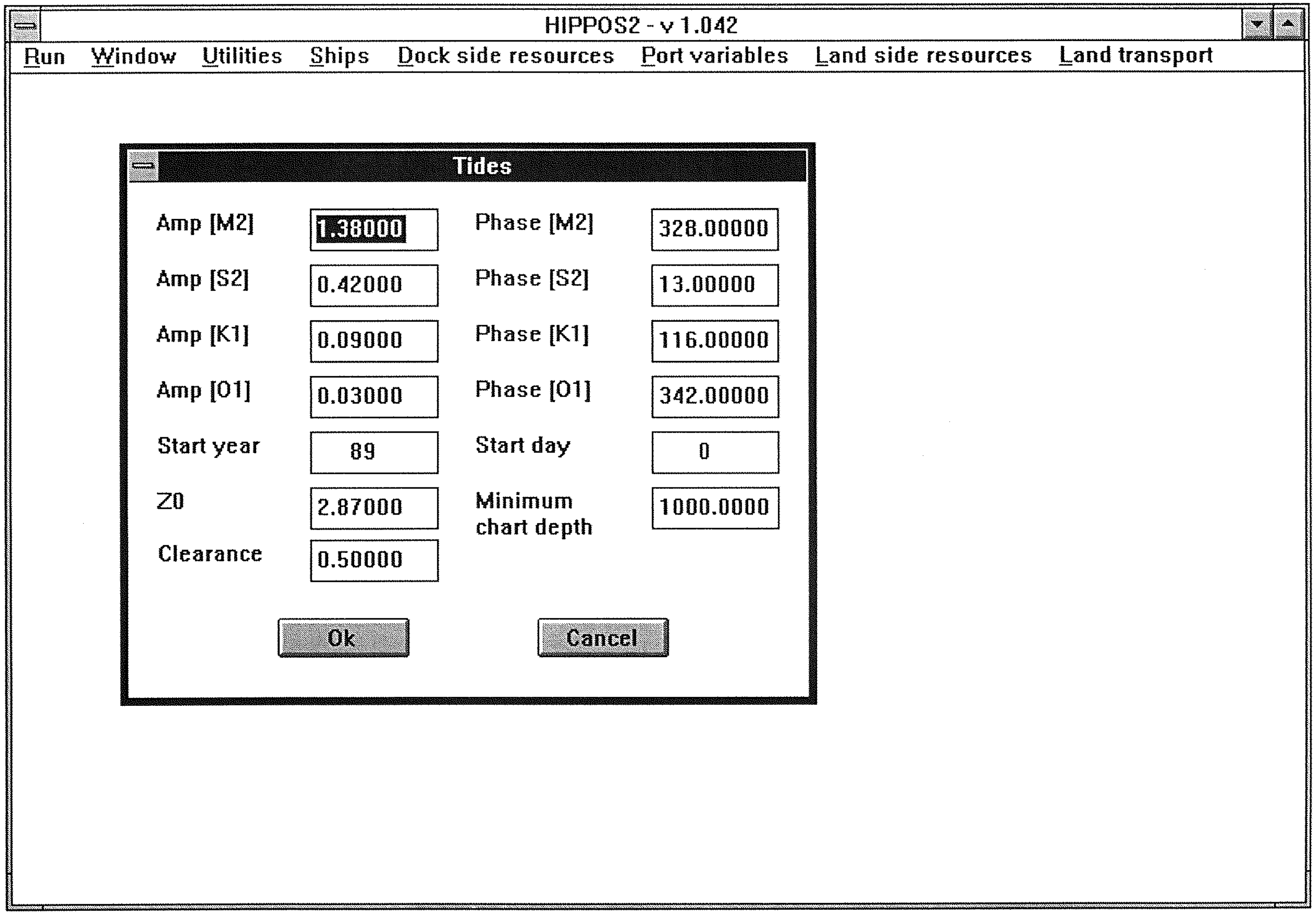


Figure 3.15 Tidal parameters input table.

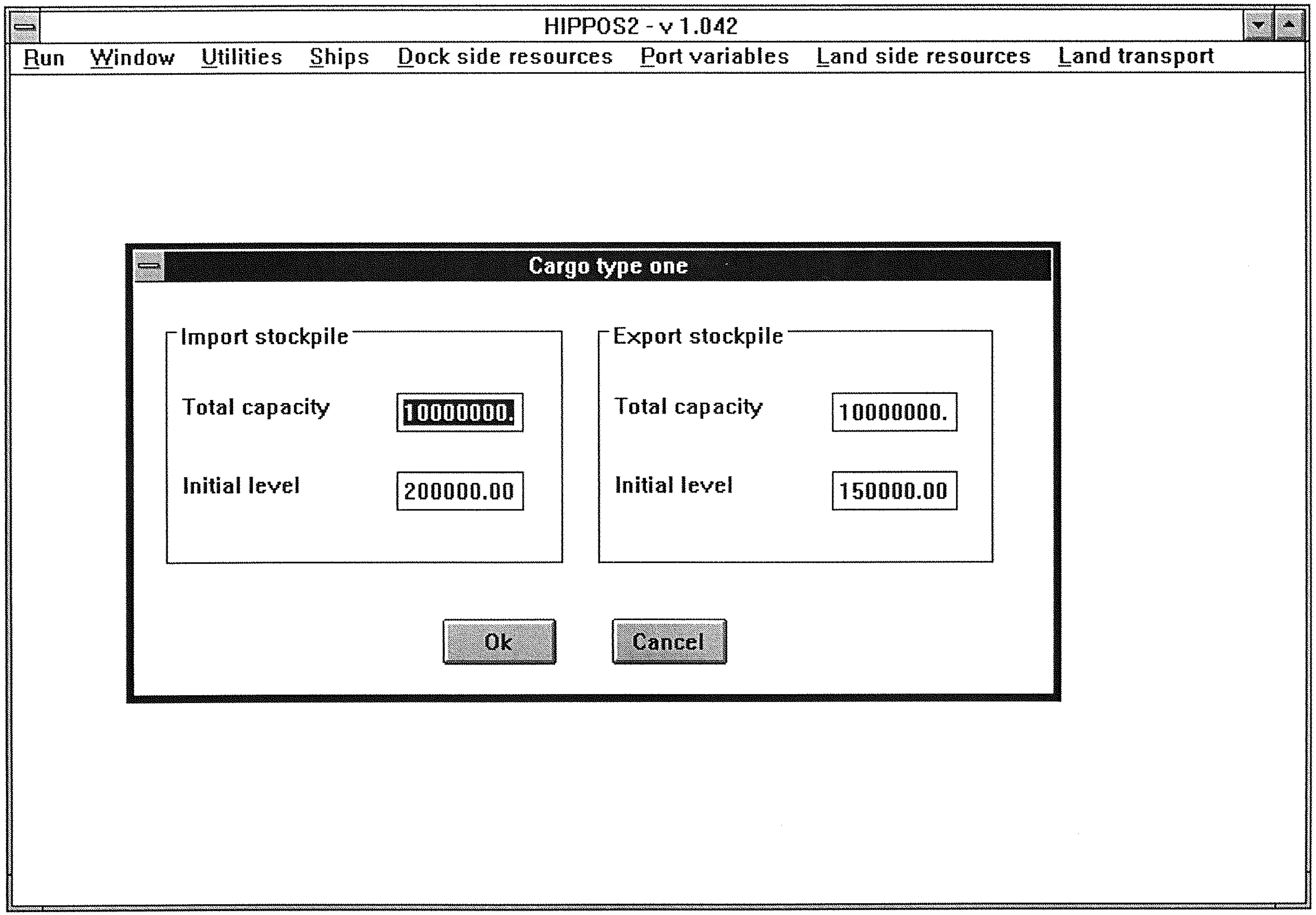


Figure 3.16 Stockpile input table.

user selects which cargo types can be handled at the said service point.

Land Transport Groups

These are as the Ship group input tables except that the LTU's do not have a size, and service times to get through the port gates need to be defined.

Land Side Cargo Size Bands

As ship group cargo size bands.

Land Group Service Priority Weighting

As priority weightings for ships.

3.10.5 Land side resources

Loading Bays

The user can vary the total number of loading bays available for each cargo type, between **one** and **ten**.

Land Side Unloaders

As the dock side unloaders.

Land Side Loaders

As the dock side loaders.

Land Side Port Transport

As the dock side port transport.

Land Side Stockpile Equipment

As the dock side stockpile equipment.

3.11 Model Output

The simulation model provides five sources of output. These are text screens, time frequency graphs, time series graphs, histograms and the ship log data file. The user can save the text screens to one file, all the graphs to a second (see model utilities), and the ship log data to a third.

3.11.1 Text Screens

These contain data in numeric form, as apposed to graphical. There is a large amount of output displayed in these screens, which are explained below.

Timer

This screen shows the present simulation run time. The rate at which the screen is updated is a user input. When the simulation is running in interactive off mode, the user is still able to see the present simulation time displayed on this screen. This is so the user has an idea how the simulation run is progressing.

Dock Side Stockpile Equipment

Shows the present throughput (in cargo units) and utilization (as a percentage) of each dock side stockpile equipment unit in use, up to a maximum of twenty units. Each

HIPPOS2 - v 1.042 - [Dock Side Stockpile Equipment]

Run Window Utilities Ships Dock side resources Port variables Land side resources Land transport

	Throughput	Utilization	Unit type
Dock side S. E. unit one	2199454.96	75.39	stacker/reclaimer
Dock side S. E. unit two	1878476.80	67.78	stacker/reclaimer
Dock side S. E. unit three	1370712.19	51.32	stacker/reclaimer
Dock side S. E. unit four	819290.69	30.96	stacker/reclaimer
Dock side S. E. unit five	442931.42	16.78	stacker/reclaimer
Dock side S. E. unit six	185856.13	6.93	stacker/reclaimer
Dock side S. E. unit seven			stacker/reclaimer
Dock side S. E. unit eight			stacker/reclaimer
Dock side S. E. unit nine			stacker/reclaimer
Dock side S. E. unit ten			stacker/reclaimer
Dock side S. E. unit eleven			stacker/reclaimer
Dock side S. E. unit twelve			stacker/reclaimer
Dock side S. E. unit thirteen			stacker/reclaimer
Dock side S. E. unit fourteen			stacker/reclaimer
Dock side S. E. unit fifteen			stacker/reclaimer
Dock side S. E. unit sixteen			stacker/reclaimer
Dock side S. E. unit seventeen			stacker/reclaimer
Dock side S. E. unit eighteen			stacker/reclaimer
Dock side S. E. unit nineteen			stacker/reclaimer
Dock side S. E. unit twenty			stacker/reclaimer

Figure 3.17 Dock side stockpile equipment results table.

unit is updated whenever it finishes a job. A unit is considered to have finished a job when the ship it is stacking (or reclaiming) cargo for either, finishes unloading, finishes loading, or has its servicing suspended for some reason e.g. affects of the weather, the work schedule for the relevant cargo type, or a stockpile constraint. The screen also shows the unit's type (whether a stacker, a reclaimer or a stacker/reclaimer).

Land Side Stockpile Equipment

See the dock side stockpile equipment.

Land Side Loaders

Shows the present throughput (in cargo units) and utilization (as a percentage) of each land side loader up to the maximum of ten units. Each loader is updated whenever it finishes a job. A loader is considered to have finished a job when the LTU it is loading cargo for either, finishes loading or has its loading suspended for some reason e.g. affects of the weather, the work schedule for the relevant cargo type, or a stockpile constraint.

Land Side Unloaders

See land side loaders.

Dock Side Loaders

See land side loaders.

Dock Side Unloaders

See land side loaders.

Land Group Results

For each of the five LTU groups, this screen shows the import throughput, the export throughput, and the import/export throughput. The import throughput is the amount of cargo taken out of the port by LTUS with an 'import only' trading status. The export throughput is the amount of cargo brought into the port by LTUS with an 'export only' trading status. The import/export throughput is the amount of cargo moved by LTUS with an 'import/export' trading status. To calculate the amount of cargo imported through the port by LTUS, the sum of the import throughput and the import/export throughput is taken, and to calculate the amount of cargo exported through the port by LTUS, the sum of the export throughput and the import/export throughput is taken.

The screen also shows for each LTU group, the number of import calls, the number of export calls, and the number of import/export calls. As with the throughput, the calls relate to the trading status of the LTUS. This screen is updated whenever an LTU leaves its loading bay.

Ship Group Results

This screen shows, for each of the five ship groups, the import throughput, the export throughput, the import/export throughput, the number of import calls, the number of export calls, and the number of import/export calls.

The import throughput is the amount of cargo unloaded by ships with an 'import only' trading status, the export throughput is the amount of cargo loaded by ships with an 'export only' trading status, and the import/export throughput is the amount of cargo unloaded and loaded by ships with an 'import/export' trading status. So the amount of imported cargo from ships is the import throughput plus the import/export throughput, and the amount of exported cargo from ships is the export throughput plus the import/export throughput.

HIPPOS2 - v 1.042 - [Ship cargo type results table]

Run Window Utilities Ships Dock side resources Port variables Land side resources Land transport

Cargo type	Ship calls	finished	servicing	Total cargo			Throughput	
	Imp	Exp	Imp/Exp	Imp	Exp	Imp/Exp	Imported	Exported
Type one	0	811	0	0.00	3119291.60	0.00	0.00	3119291.60
Type two	0	81	0	0.00	624644.60	0.00	0.00	624644.60
Type three	383	257	0	1866876.24	1272869.41	0.00	1866876.24	1272869.41
Type four								
Type five								
Total	383	1149	0	1866876.24	5016805.61	0.00	1866876.24	5016805.61

Figure 3.18 Ship group results table.

The number of call refers to the number of ships with the relevant trading status that have visited the port. This screen is updated whenever a ship leaves its berth.

<u>LTU Average Service Times</u>

This screen shows, for each of the five LTU groups, the full service time, the unloading service time, and the loading service time.

The full service time is the time the LTU spent at the loading bay. The program takes the simulation time when the LTU arrives at the loading bay (done in B106), the time that the LTU leaves the loading bay (done in B117), and then calculates the difference to get the full service time.

The unloading service time is the time that the LTU spends in the unloading phase of its servicing. The program takes the time that the LTU starts the phase (done in B110 at the start of the pre - unloading delay), the time that the LTU finishes the phase (done in B112 when unloading is finished), and then calculates the difference to get the unloading service time.

The loading service time is the time that the LTU spends in the loading phase of its servicing. The program takes the time that the LTU starts the phase (done in B113 at the start of the pre - loading delay), the time that the LTU finishes the phase (done in B115 when loading is finished), and then calculates the difference to get the loading service time.

The screen also shows, the full service count, the unloading service count, and the loading service count.

All LTUS fall into the full service category, while only LTUS with 'export only' or 'import/export' trading status' fall into the unloading service category, and only LTUS with 'import only' or 'import/export' trading status' fall into the loading service category.

HIPPOS2 - v 1.042 - [LTU average service times]

Run Window Utilities Ships Dock side resources Port variables Land side resources Land transport

	Full service time	Unloading service time	Loading service time
Type one	47.85	47.85	0.00
Type two	83.41	83.41	0.00
Type three	55.45	50.16	58.97
Type four			
Type five			
	Full service count	Unloading service count	Loading service count
Type one	763	763	0
Type two	79	79	0
Type three	698	279	419
Type four			
Type five			

Figure 3.19 LTU average service times results table.

This screen is updated whenever an LTU leaves its loading bay.

Ship Average Journey Times

This screen shows, for each of the five size classes of each of the five ship groups, the average approach time, the average departure time, the average passage time, and the total calls. The approach time for a ship is the difference in time between the ship's creation time (taken in B22 when the ship arrives) and the time that the ship arrives at its berth (taken in B7). The departure time for a ship is the difference in time between the time the ship leaves its berth (taken in B13) and the time the ship is disposed of (taken in B18 when the ship leaves). The passage time for a ship is the difference in time between the creation time and disposal time of the ship. This screen is updated whenever a ship leaves the system.

Berth Results

This screen shows, for each berth in use (up to the maximum of ten), the import throughput, the export throughput, the utilization, the number of import calls, the number of export calls, and the number of import/export calls.

The import throughput is the amount of cargo unloaded at the berth. This will be by ships with an import only or an import/export trading status. The export throughput is the amount of cargo loaded at the berth by ships with an export only or import/export trading status.

The number of import calls is the number of ships visiting the berth with an 'import only' trading status. The number of export calls in the number of ships visiting the berth with an 'export only' trading status. The number of import/export calls is the number of ships visiting the berth with an 'import/export' trading status.

The berth utilization is the percentage of time that the berth is **occupied**. Note

HIPPOS2 - v 1.042 - [Ship average journey times]

Run Window Utilities Ships Dock side resources Port variables Land side resources Land transport

		Avg approach time	Avg departure time	Avg passage time	Total calls
Cargo type one	Class one	9.58	1.01	57.12	811.00
	Class two	0.00	0.00	0.00	0.00
	Class three	0.00	0.00	0.00	0.00
	Class four	0.00	0.00	0.00	0.00
	Class five	0.00	0.00	0.00	0.00
Cargo type two	Class one	15.63	1.00	102.69	81.00
	Class two	0.00	0.00	0.00	0.00
	Class three	0.00	0.00	0.00	0.00
	Class four	0.00	0.00	0.00	0.00
	Class five	0.00	0.00	0.00	0.00
Cargo type three	Class one	10.11	1.01	59.22	640.00
	Class two	0.00	0.00	0.00	0.00
	Class three	0.00	0.00	0.00	0.00
	Class four	0.00	0.00	0.00	0.00
	Class five	0.00	0.00	0.00	0.00
Cargo type four	Class one				
	Class two				
	Class three				
	Class four				
	Class five				
Cargo type five	Class one				
	Class two				
	Class three				
	Class four				
	Class five				

Figure 3.20 Ship average journey times results table.

HIPPOS2 - v 1.042 - [Berth results table]

Run Window Utilities Ships Dock side resources Port variables Land side resources Land transport

	Throughput		Util (%)	Ship calls		
Berth No.	Imp	Exp		Imp	Exp	Imp/Exp
One	249147.82	788126.65	43.98	52	193	0
Two	263971.64	926420.85	49.87	56	215	0
Three	318705.94	723690.42	43.21	65	166	0
Four	300791.70	700079.96	41.55	64	165	0
Five	289633.94	659164.15	40.17	64	163	0
Six	446927.12	1230062.00	69.09	83	249	0
Seven						
Eight						
Nine						
Ten						
Total	1869178.17	5027544.02		384	1151	0

Figure 3.21 Berth results table.

that the percentage of time that the berth is occupied differs from the percentage of time that the berth is **allocated**. Allocating a berth to a ship is one of the conditions that must be satisfied before the ship can proceed down the approach channel. So a berth is allocated to a ship (done in C1) from when it leaves the offshore area in order to enter the port up to when the ship leaves the berth (B13), whereas a berth is only occupied by a ship while the ship is being serviced (B7 to B13).

This screen is updated whenever a ship leaves its berth.

Loading Bays

There is one screen for each LTU group being used in the present simulation run. Each screen shows for each loading bay (up to a maximum of ten), the import throughput, the export throughput, the import/export throughput, the utilization, the number of import calls, the number of export calls, and the number of import/export calls.

The import throughput is the amount of cargo loaded. This will be by LTUS with an import only or import/export trading status. The export throughput is the amount of cargo unloaded by LTUS with an export only or import/export trading status.

The number of call refers to the number of LTUS with the relevant trading status that have visited the loading bay. The utilization is the percentage of time the loading bay is occupied. LTUS are only allocated a loading bay immediately before occupation so the percentage of time allocated can be said to be the same as the percentage of time occupied, and hence the percentage of time unused can be obtained. This screen is updated whenever an LTU leaves its loading bay.

Gate Average Service Times

There is one screen for each gate. Each screen shows, for each of the five LTU groups, the average service time on arrival, and the average service time on departure. These screens are updated every time an LTU has finished being serviced at a gate.

Current Status Statistics Two

This screen shows the lock utilization, the average wait for ships to enter the port, the average wait to enter the lock on entry to the port, the average wait to leave the berths, and the average wait to enter the lock on departure from the port.

Stockpile Status Report

For each of the ten stockpiles this screen shows, the average dwell time, the percentage full, and the amount full in terms of cargo units. Each stockpile is updated every hour in B190.

Dock Status

This screen shows, for each berth (up to the maximum of ten), details about the ship presently situated at the said berth. The cargo type, the trading status, the cargo size, the present activity (loading, unloading etc.), the number of unloaders acquired, the number of loaders acquired, the number of port transport acquired, and the number of stockpile equipment units acquired, for the ship are shown.

Loading Bay (LTU group one) Status

This screen was used to aid validation and debugging. The screen shows, the arrival number, the trading status, the cargo size, the present activity (e.g. waiting to unload, unloading etc.), the number of unloaders acquired, the number of loaders acquired, the number of port transport acquired, and the number of stockpile equipment units acquired, for the LTU at each loading bay.

Inland Transport Status Report

This screen shows, the number of arrivals, the number of departures (and hence the difference is the number in the system), the state of the five cargo type work schedules. The screen also shows the memory available, which was useful to know when debugging the program. A continual fall in the amount of memory available as the simulation runs, implied there are bugs in the program e.g. not disposing of entities correctly. This screen was used to aid validation and debugging.

Current Status Statistics Screen One

This screen shows some miscellaneous statistics about the present state of the simulation model. These are, the number of tugs in use, the departure released tugs (the number of tugs waiting at the offshore area), the berth released tugs (the number of tugs waiting at the docking area), the total number of ship arrivals, the total number of ships turned away, the total number of ships which have entered the port, the total number which have left the system, the present weather state, the lock sill level (the tide level), the present port schedule state, the present simulation time (only updated whenever a ship leaves the system), and the memory available. This screen was used to aid validation and debugging.

3.11.2 Time Frequency Graphs

Time frequency graphs show the amount of time spent in each state (y - axis) against each state (x - axis). The time frequency graphs available in the simulation model all show utilizations of resources, where the states along the x - axis are the amounts of the resource being used. The graphs displayed are,

- dock side stacker/reclaimer utilization.
- dock side reclaimer utilization.
- dock side stacker utilization.

- dock side loader utilization.
- dock side unloader utilization.
- dock side port transport utilization.
- land side stacker/reclaimer utilization.
- land side reclaimer utilization.
- land side stacker utilization.
- land side unloader utilization.
- land side loader utilization.
- land side port transport utilization.
- berth utilization.
- tug utilization.
- LTU group loading bay utilization (one graph for each cargo type in use).

These graphs are updated whenever resources are acquired or released.

3.11.3 Time Series Graphs

Time series graphs show how a variable changes over time, with the variable level shown on the y - axis, and time shown on the x - axis. The time series graphs available in the simulation model are updated at regular intervals during a simulation run. Each graph is updated fifty times, so the time between each successive update depends on the simulation run length. The graphs displayed are,

- stockpile level graphs which show the percentage full (one for each stockpile whose cargo type is in use).
- gate queue length graphs (one graph for each gate's arrival queue and one graph for each gate's departure queue).
- Port Queue - Arrivals (shows queue length).
- Lock Queue - Arrivals (shows queue length).
- Berth Queue - Departures (shows queue length).
- Lock Queue - Departures (shows queue length).

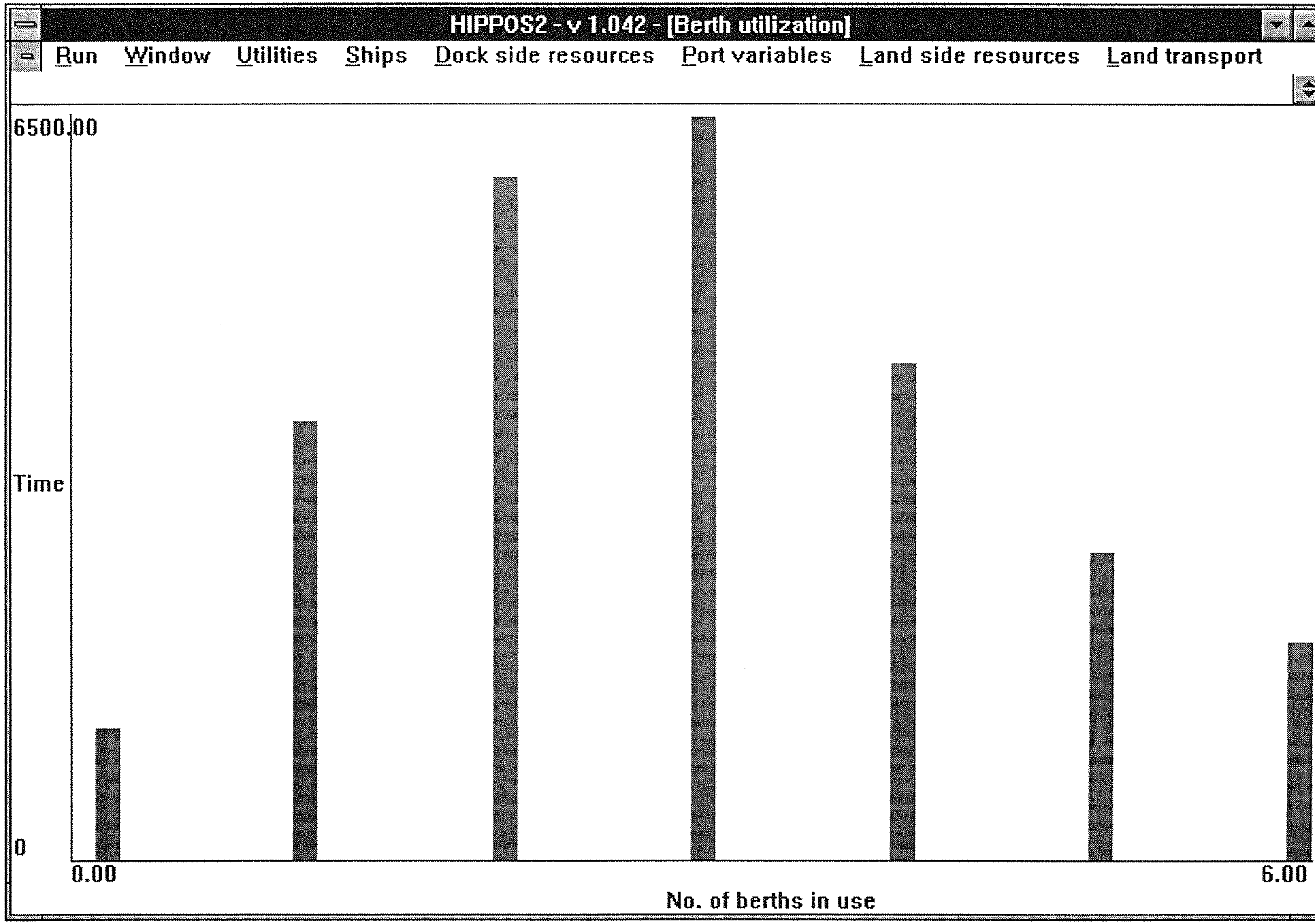


Figure 3.22 Berth utilisation graph.

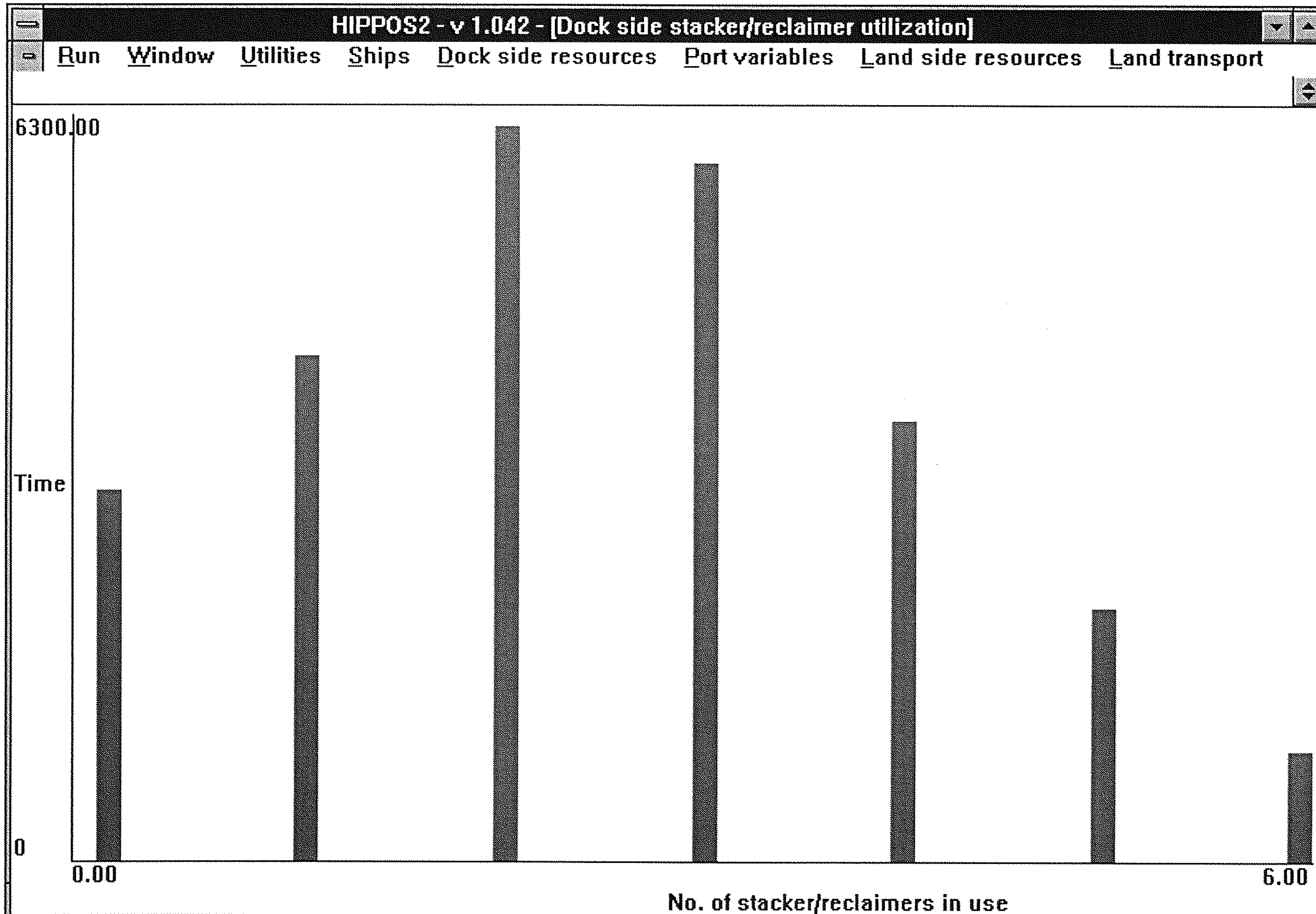


Figure 3.23 Dock side stacker/reclaimer utilisation graph.

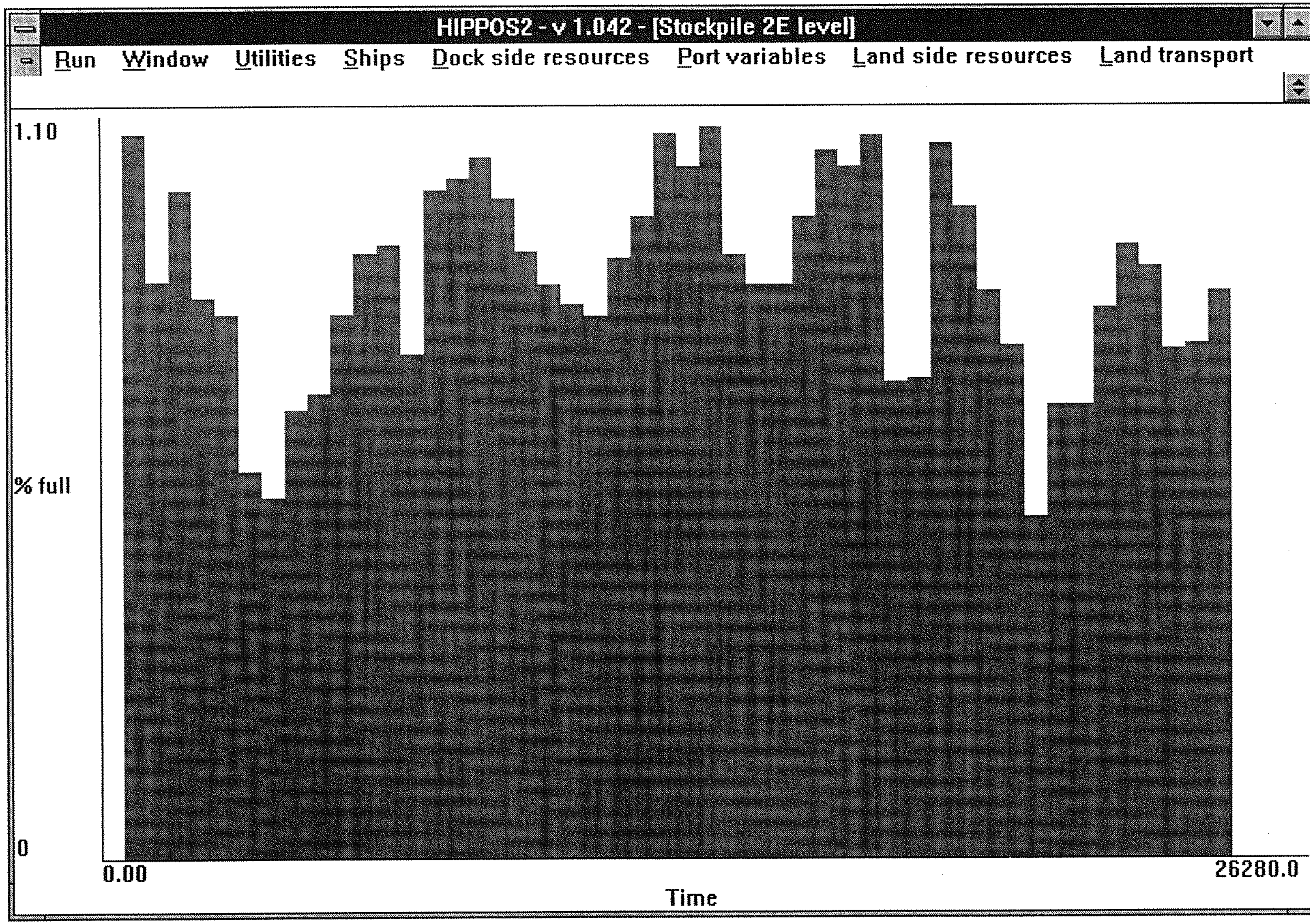


Figure 3.24 Stockpile level graph.

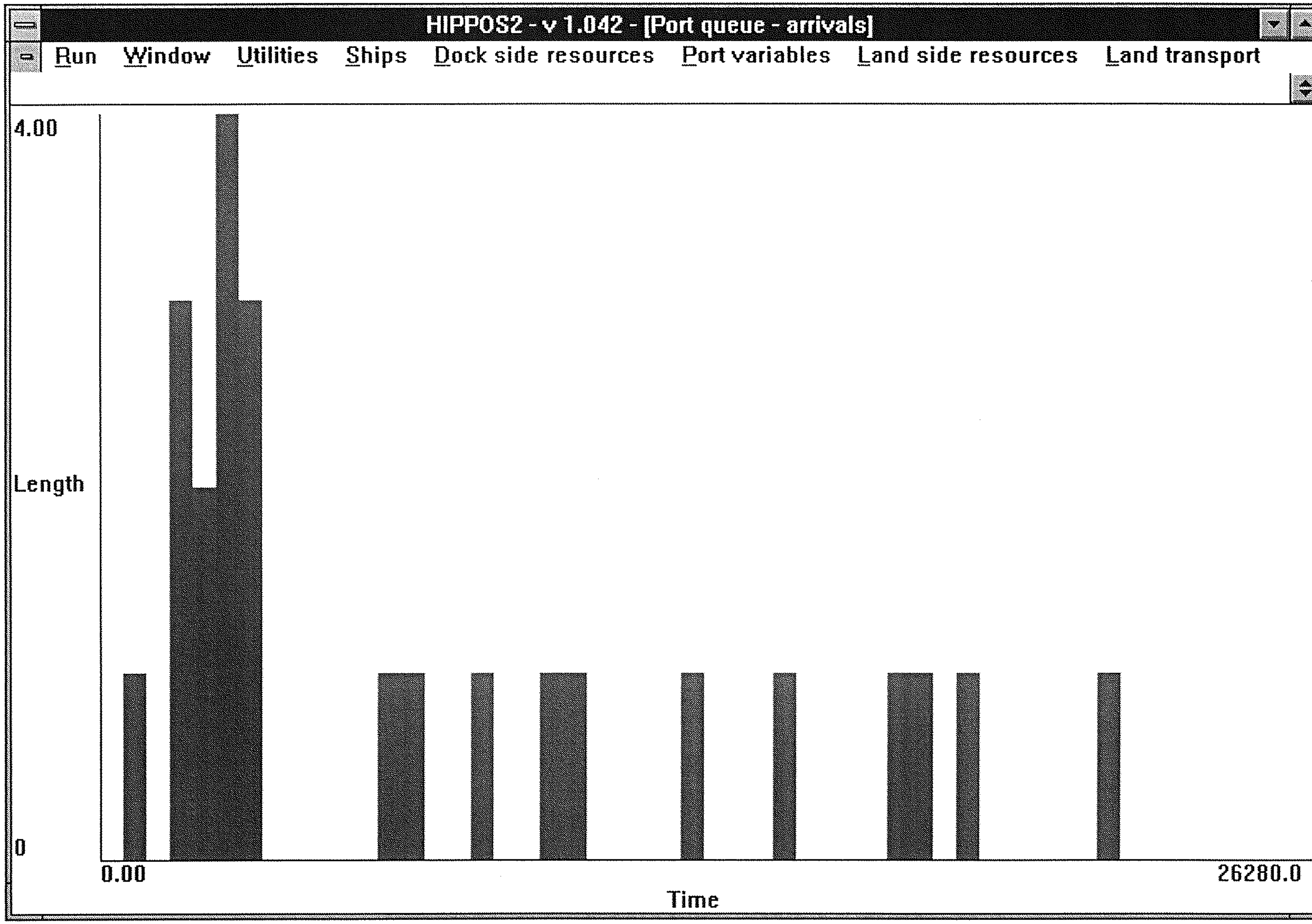


Figure 3.25 Port queue graph.

3.11.4 Histograms

Histograms show the frequency of occurrence of levels of a variable plotted against the variable. The histograms available in the simulation model are,

- Land transport cargo size.
- Ship size.
- Inter arrival time (for all ships).
- Ship cargo size.

These graphs are updated whenever a ship or LTU arrives in the system.

3.12 Model Utilities

The following features of the model allow the user to load and save the various types of file available with the model. Also described is how to vary the updating rate of the timer screen.

3.12.1 Save Variables

Once the user has set up an input file it can be saved using the 'save variables' option. The file will be given a '.var' extension by default. A sample from a file can be found in Appendix F.

3.12.2 Load Variables

A previously saved input file can be retrieved using the 'load variables' option.

3.12.3 Save Text Screens

The 'save text screens' option saves the text screens in a file with a '.txt' extension

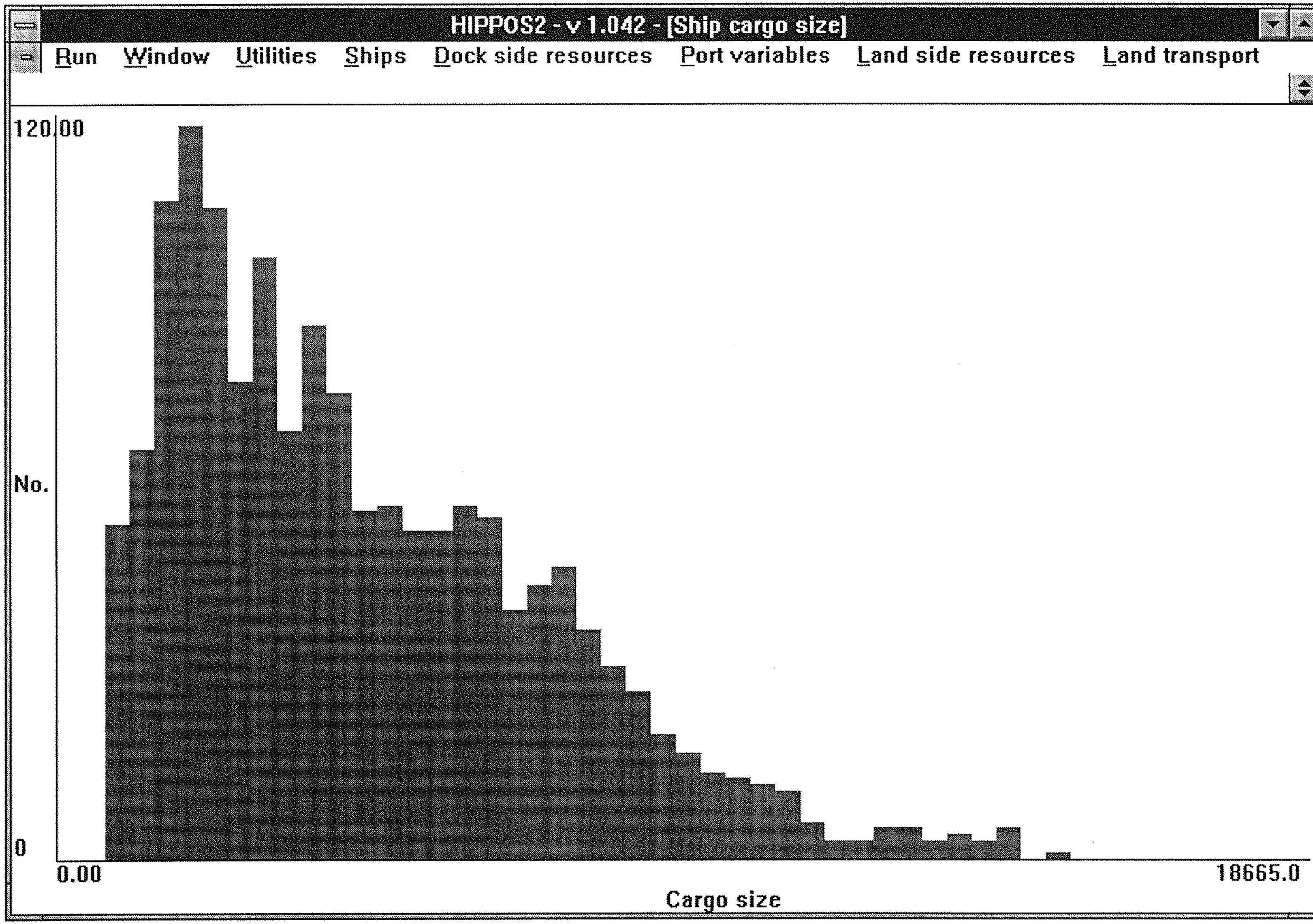


Figure 3.26 Ship cargo size graph.

by default. The text screens are saved in a separate option from the graphs so that the text screen data can be easily used further e.g. if it needs to be loaded into a spreadsheet.

3.12.4 Load Text Screens

The user can load previously saved text screens if required, using the 'load text screens' option.

3.12.5 Save Graphs

As stated above, the graphs are saved in a separate file from the text screens. The graphs can be saved using the 'save graph' option in a file which has a '.grf' extension by default.

3.12.6 Load Graphs

Previously saved graphs can be reloaded using the 'load graphs' option.

3.12.7 Animation - updating frequency

Defines the number of times the animation screens are updated in an hour. The higher the number input the more realistic the animation will look, but the slower the program will run.

3.12.8 Animation - realistic screen

This option allows the user to load in a '.SHP' file which the user has previously set up in WANIMAT.EXE. The user needs to load in a *.SHP file if he/she wants to run the program with the realistic animation screen.

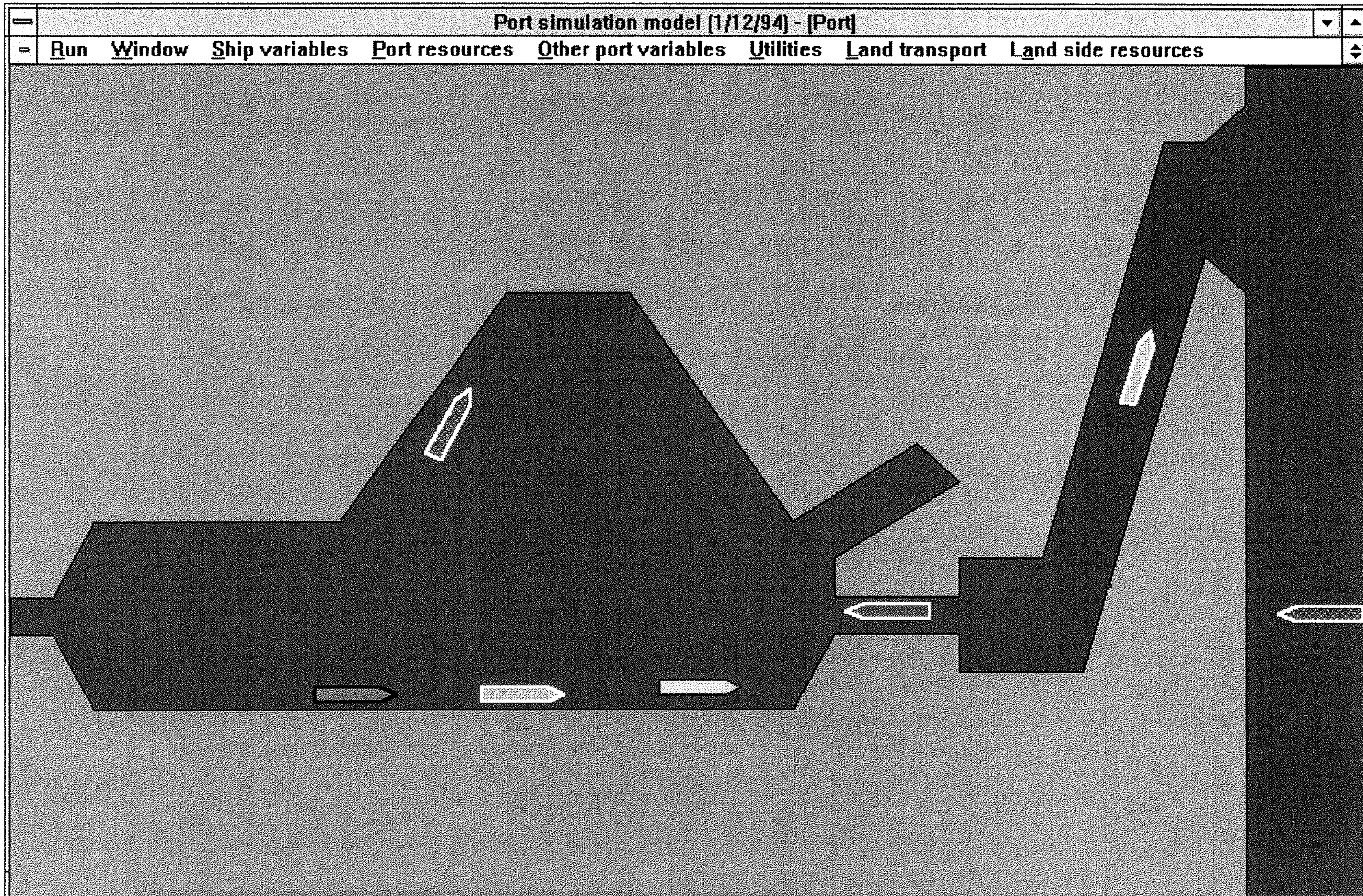


Figure 3.27 Realistic animation screen - set up for part of the Port of Grangemouth.

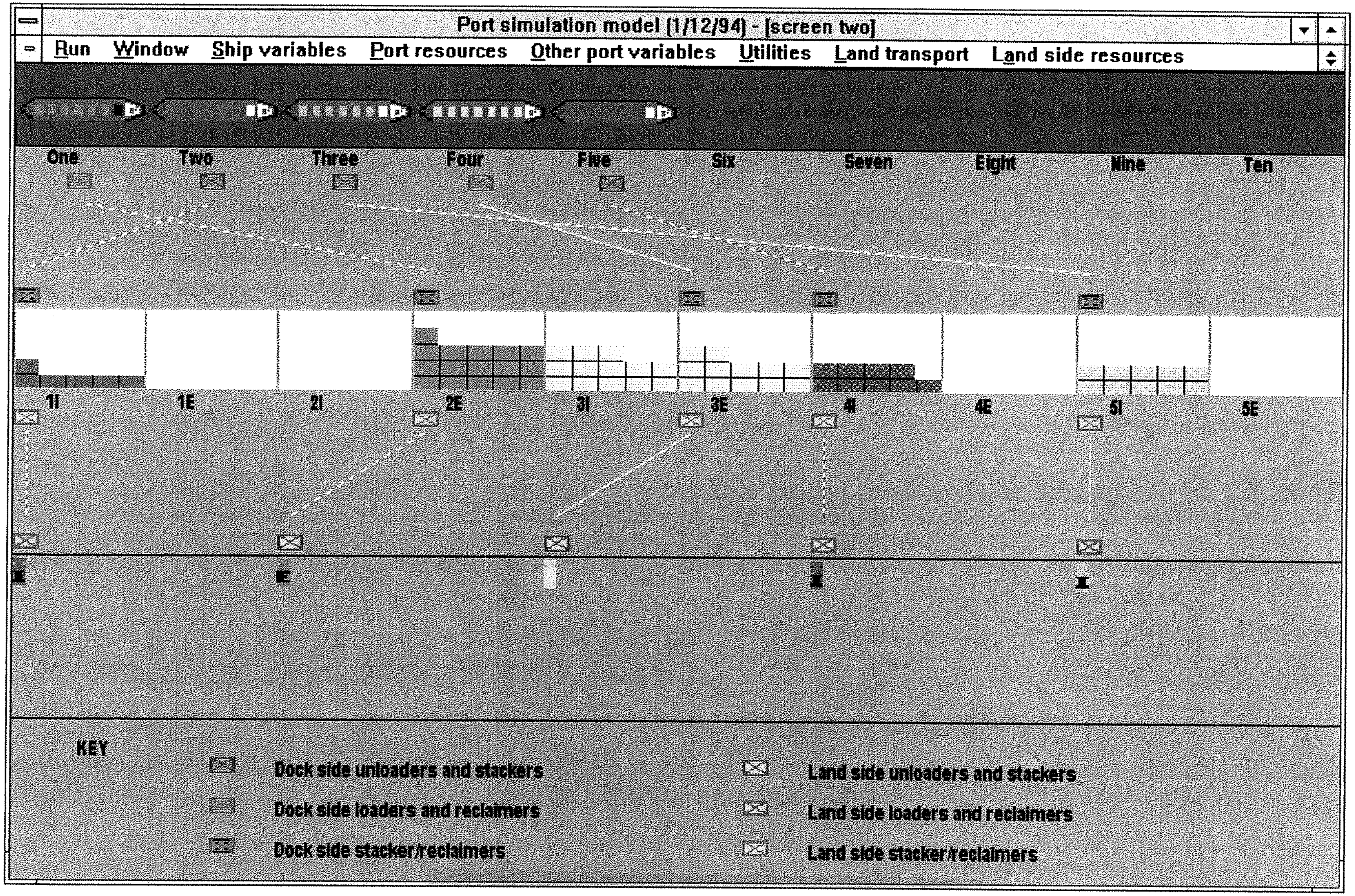


Figure 3.28 Schematic animation screen.

3.12.9 Animation - schematic screen

The user can load in the SCREEN_2.SHA file which is needed if the user wants to run the program with the schematic animation screen.

3.12.10 Timer screen

The user inputs the updating frequency of the timer screen (in hours). See the model output section for further details.

3.12.11 Save ship data

The user can save a '.DAT' file of the ship data collected during the simulation run.

3.12.12 Ship data collection

The user defines the start and end times, in simulation run hours, of when ship data should be collected. Any ship which completes its passage through the simulation system in between the start and end times will have some of its attributes saved in a data record. There is an upper limit of 800 records. The file has been designed so that it can be easily imported into any of the main spreadsheet packages. A sample from a file can be found in Appendix F. Each ship record consists of the following fields:

1. record number.
2. run time the record was created.
3. ship number.
4. cargo type.
5. trading status.
6. size (DWT).
7. creation time.
8. time arrived at berth.

9. time left berth.
10. disposal time.
11. approach time.
12. departure time.
13. passage time.
14. berth number.

CHAPTER FOUR
VERIFICATION AND VALIDATION

4.1 Literature review

4.1.1 Introduction

Verification and validation will be defined as follows. Sargent[27] uses Schlesinger's definition of model validation which is,

> *"Substantiation that a computerised model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model."*

In this author's opinion the simplest definition of model verification is defined by Chau[5] as,

> *"The process of ensuring that the computer code is a correct implementation of the conceptual model."*

A vast amount of literature has been produced in the field of simulation model verification and validation. Many differing opinions have been expressed, giving various alternative approaches to the process of verification and validation. However, many authors seem to agree that there are areas of commonality in these ideas.

The main area of commonality is the idea that verification and validation should be a continuous process, carried out throughout all stages of the model development process, and not just once the computer program has been completed. In order to achieve this objective, a modelling process must be defined. Section 4.1.2 discusses the concept of a modelling process.

Many author's go further and define the purpose of model verification and validation (and the associated model process) as gaining an acceptable level of model credibility and user confidence. Sargent defines model credibility as,

> *"developing in the (potential) users of information from the models, sufficient confidence in the information that they are willing to use it."*

Specifically he refers to the relationship between cost and model validation, and the value of the model to the user as a function of model confidence (see Figure 4.1).

Model verification is discussed in section 4.1.3, and model validation is discussed in section 4.1.4.

4.1.2 Model process

While many differing modelling processes have been put forward, Banks[3] states that he believes there are some common threads to all of them. These threads consist of 5 phases which form the basic outline of the modelling process, namely,

- initialisation
- a plan
- a detailed design
- testing
- operation and maintenance.

The initialisation phase is where, the feasibility of the simulation is determined, and the problem is thoroughly defined. The plan phase is where a method of approaching the problem is developed. The detailed design phase is where the plan is converted into a detailed design for the computer program. The testing phase looks at testing the computer program, and the operation and maintenance phase is performed once the model is ready for use. Banks re-iterates the need for verification and validation throughout the modelling

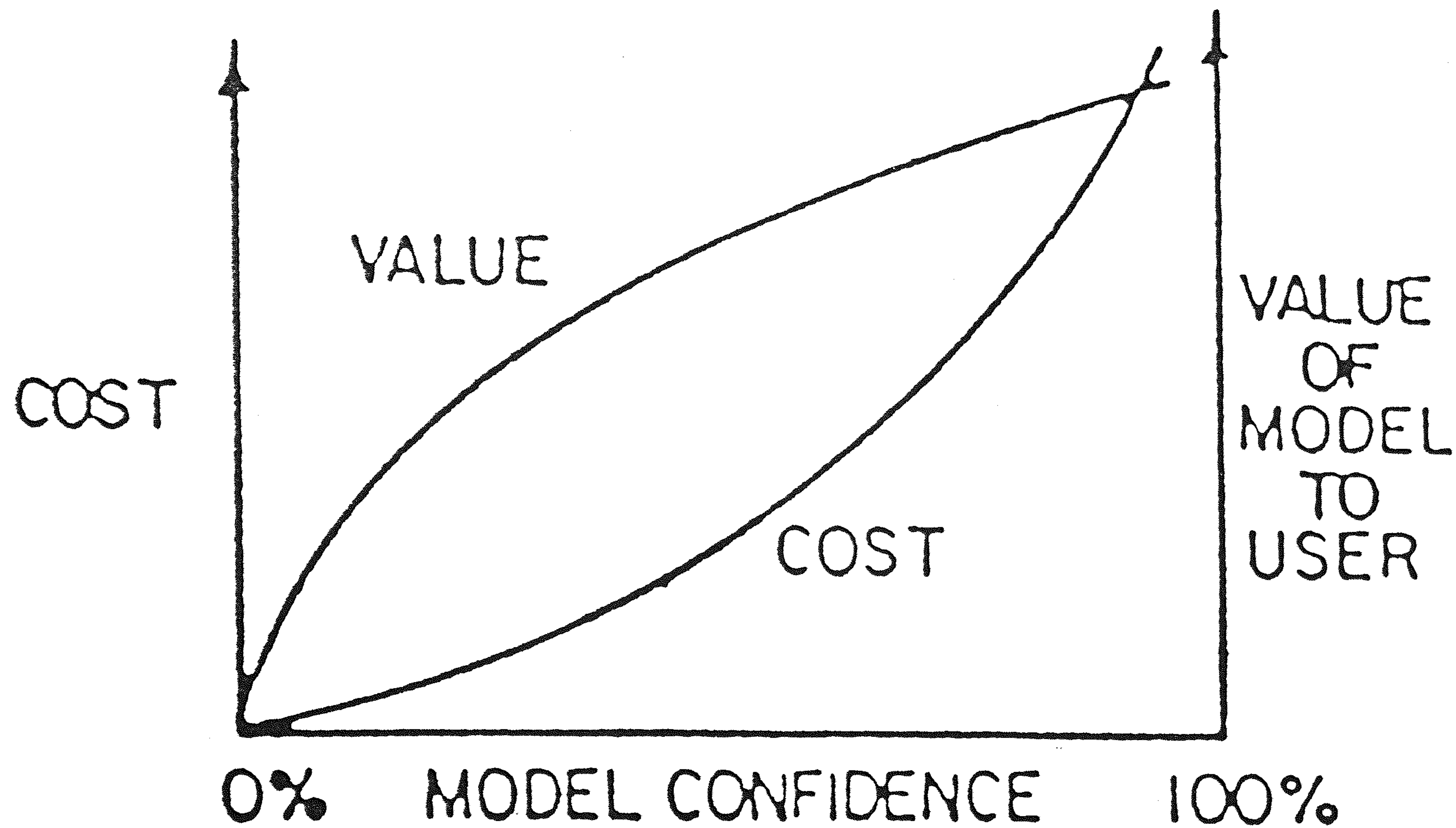


Figure 4.1 Sargent's diagram of model confidence.

process, and not just in the testing phase.

Sargent puts forward a simple modelling process, which Banks considers to be one of the best to follow, and which Banks states conforms to his 5 common threads. The simple modelling process put forward by Sargent is shown in Figure 4.2. The problem entity is the system to be modelled, the conceptual model is the mathematical representation of the system, and the computerised model is the computer program of the conceptual model. Sargent splits verification and validation down into several parts covering the whole of the process. These are conceptual model validity, computerised model verification, operational validity, and data validity. Conceptual model validity is defined by Sargent as,

> *"Determining that the theories and assumptions underlying the conceptual model are correct, and that the model representation of the problem entity is reasonable for the intended purpose of the model."*

Computerised model verification can be defined as stated earlier in section 4.1.1 by Chau. Operational validity is defined by Sargent as,

> *"Determining that the model's output behaviour has sufficient accuracy for its intended applicability."*

Finally, data validity is defined by Sargent as,

> *"Ensuring that the data necessary for model building, model evaluation and testing, and conducting the modelling experiments to solve the problem are adequate and correct."*

Sargent states that usually several versions of a model are needed before a valid one is achieved, and that verification and validation will be needed in each iteration.

Other similar such processes are put forward by Shannon[29].

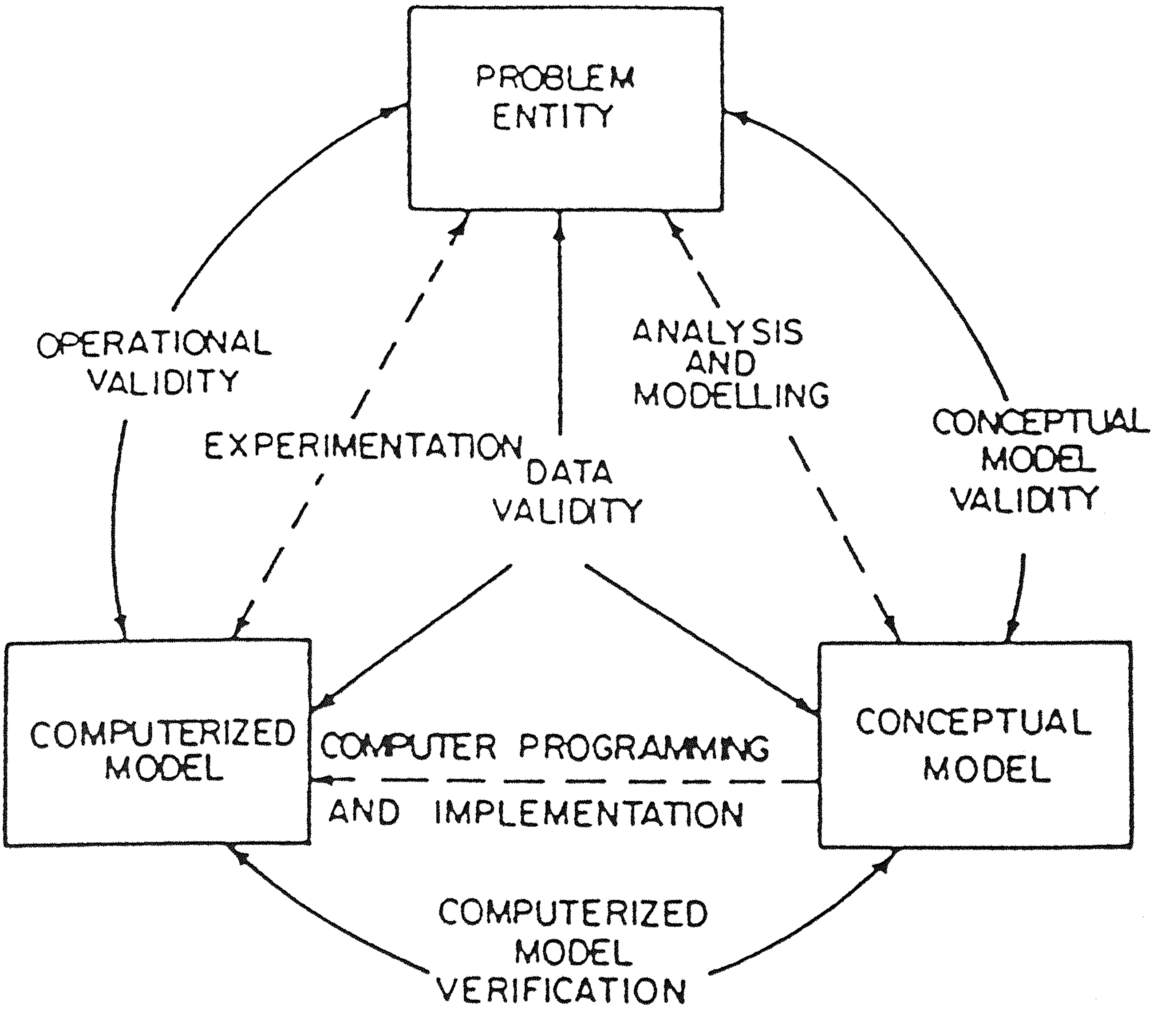


Figure 4.2 Sargent's simplified version of the modelling process.

Alternative approaches are suggested by Gass & Joel[15] and Schruben[28] .

Gass & Joel present a scoring approach to model credibility. They say that,

"We argue that confidence in a model is a result of the accumulation of information, the sum total of which leads to a judgemental statement by the decision maker."

They define seven criteria against which information collected throughout the project can be interpreted. For each criterion, a minimum level of what they call "information satisfaction" is required to achieve the decision makers threshold value for that criterion. The meeting of all the criteria thresholds informs the decision maker that the model results can be used with an acceptable level of confidence. The seven criteria that they use are,

- model definition
- model structure
- model data
- computer model verification
- model validation
- model usability
- model pedigree.

They state that not all the criteria can be considered to be quantitative. Sargent states that he does not believe in such a method for determining the validity of a model. Four reasons are given,

- the subjective nature of the method
- how are "passing scores" to be determined?
- a model may receive a passing score and yet have a defect that needs fixing
- the score for a model may cause over confidence in a model, or may be used to argue that one model is better than another.

Schruben's process to achieve acceptance for a simulation model consists of an iterative process based on the use of Turing tests. Turing tests are where a person knowledgable with the system modelled is asked to discriminate between output from the real system, and output from the model. Schruben gives an example of the process where a director of major surgery was asked to compare simulation data and genuine data about the daily management of the operating rooms at a hospital. The first time round the director was able to tell the two sets of results apart. Using the comments made by the director about how she was able to distinguish between the two sets of data, changes to the models logic, and other corrections, were able to be made. At the second attempt the director was still able to tell the two sets of data apart. However, after some more adjustments to the model, the director was unable to identify the simulated documents at the third attempt. Schruben also presents some statistical methods for the analysis of results from Turing tests.

Finally a word of warning about the many pitfalls that can occur during the course of a simulation project. Many authors comment on the substantial number of simulation models that fail to ever produce useful results. Annino & Russell[1] have written an excellent paper, describing what they believe are the 10 most common causes of simulation analysis failure, and how to avoid them. These causes of failure are,

- failure to define an achievable goal
- incomplete mix of essential skills
- inadequate level of user participation
- inappropriate level of detail
- poor communication
- using the wrong computer language
- obsolete or non existent documentation
- using an unverified model
- failure to use modern tools and techniques to manage the development of a large, complex computer program
- using mysterious results.

4.1.3 Model verification

As has been stated above, while validation refers to the whole of the modelling process, verification is only used in reference to the computer model. Generally authors suggest the use of Software Engineering techniques to ensure the correct implementation of the conceptual model. Shannon refers to the 40 - 20 - 40 rule. This rule states that 40% of the time should be devoted to problem evaluation and model design, 20% of the time should be devoted to coding the model, and 40% of the time should be devoted to testing the model. He states that,

> *"Most errors are the result of starting to write computer code too soon and not leaving enough time for the testing of the model."*

During the design and coding of the model, techniques such as top down design, structured programming and program modularity should be used.

4.1.4 Validation techniques

There is a huge range of validation techniques suggested by authors. The following is a summary of the 11 most commonly used techniques.

(a) Animation: the model's operational behaviour is displayed graphically as the model moves through time.

(b) Comparison with other models: various results of the simulation model being validated are compared to results of other valid models. Note that sometimes the simulation model being validated requires modification to allow comparisons to be made.

(c) Degenerate tests: the degeneracy of the model's behaviour is tested by removing portions of the model, or by appropriate selection of values of the input and internal parameters e.g. does the average number in the queue of a single server continue to increase with respect to time, when the arrival rate is larger than the service rate.

(d) Extreme condition tests: the model structure and output should be plausible for any extreme and unlikely combination of events within the system.

(e) Fixed values: fixed values are used for all model input and internal variables. This should allow checking the model results against hand calculated values.

(f) Internal validity: several replications (runs) of a stochastic model are made in order to ascertain the amount of internal stochastic variability within the model. A high amount of variability (lack of consistency) may cause the model's results to be questionable, and, if typical of the problem entity, may question the appropriateness of the policy or system being investigated.

(g) External validity (historical data validation): if historical data exists, part of the data is used to build the model, and the remaining data is used to determine if the model behaves as the system does.

(h) Sensitivity analysis: this validation technique consists of changing the values of the input and internal parameters of the model, to determine the effect upon the model behaviour and its output. The same relationships should occur in the model as in the real system.

(i) Traces: the progression of entities through the modelled system is checked to determine if the models logic is correct and has obtained the necessary accuracy.

(j) Face validity: People knowledgable about the system modelled are asked whether the model and its behaviour is reasonable. This technique can be used to determine whether the logic in the conceptual model is correct, and whether the model's input - output transformations are reasonable.

(k) Turing tests: People knowledgeable about the system modelled are asked whether they can discriminate between output from the real system, and output from the model.

Some alternatives methods of validation have been discussed by Chau. He discusses the work of Pidd[26], Velayes & Levary[31], Balci & Nance[2], and Friedman & Friedman[14].

Chau states that Pidd suggests two basic approaches to validation, namely a black box approach and a white box approach. The black box approach ignores the detailed internal workings of the model, and just asks whether or not the output from the simulation model accurately reflects the situation of the real system. The white box approach involves looking at some of the internal parameters of the model. For example, the probability distributions of certain dependent variables could be checked to see if they match with the expected theoretical ones.

Velayes & Levary propose the use of decision theory to validate a model. They suggest measures such as the Expected Value of Perfect Information from Simulation (EVPIS), the Expected Value of Information from Simulation (EVIS), and the Expected Net Gain from Additional Validation (ENGAV). Grieg[18] who also suggests an approach using decision theory states that,

> *"This approach involves trading off the chances of incurring the cost of using an invalid model, against the costs of additional modelling to increase the likelihood that the model will fulfil its intended purpose."*

However, he warns that the use of decision theory should only be done with other tests, in order to give a balanced approach.

Balci & Nance suggest a procedure which guides a modeller through the process of formulating a problem. They argue that an explicit requirement of model credibility is formulated problem verification.

Finally, Friedman & Friedman suggest two statistical validation procedures to test the validity of simulation metamodels. They state that a metamodel is a simpler model which is built and used as a device to help understand and explore the more complex simulation model.

4.2 The port simulation model process

The model was constructed in four modules. These were:

- ship arrivals and departures
- ship unloading and loading
- storage areas
- inland transportation.

The first module was developed under the MSc. project. For information on the modelling process undertaken for this module the reader should refer to that document.

For the other three modules, Statements of Requirements were produced by Sir William Halcrow & Partners Ltd. In response to these, firstly Functional Specification documents were produced, and when these had been agreed by all parties, Detailed Design documents were produced. Copies of the Functional Specification and Detailed Design documents are contained in Appendix B. The verification and validation undertaken during and after model development is discussed in section 4.3.

The stages of the modelling process used to develop the simulation model conform to Banks' five common threads as discussed in section 4.1.2. Banks' initialisation phase is contained in the Statements of Requirements documents, the plan phase is contained in the Functional Specification documents, and the detailed design phase is contained in the Detailed Design documents. The other 2 phases of testing, and operation and maintenance have also been conformed to.

4.3 The port simulation model verification and validation

Verification of the model has been achieved by using the Software Engineering techniques described in section 4.1.3. By using Borland Pascal for Windows and constructing the model using object oriented programming, the task of conforming with the techniques recommended was made a lot easier. Also, tracing was used to thoroughly check the logic of the model.

Validation of the computer program was carried out by the software developer (the author) continually throughout the models development, using many of the techniques recommended in section 4.1.4. Once the first completed version of the model had been developed, a software tester undertook a comprehensive testing programme. This involved setting up very simple test input files, which allowed elements of the model to be tested one at a time. An iterative process then occurred. When a bug was found an error report would be filed. Then the bug would be investigated and fixed by the software developer, and then the original test file run by the software tester would be re-run to confirm that the bug had been correctly fixed.

4.4 Case study

4.4.1 Introduction

The case study undertaken is completely hypothetical. The purpose of the case study was to consider a present set up for the port, known as the Base Case, and then look at 5 future scenarios. These future scenarios looked at possible alternatives to maintain the ports present level of performance, based on future traffic predictions.

4.4.2 The Base Case

The following sections explain how the Base Case was set up. Not all of the simulation model parameters were used. Those which are not mentioned in the sections below were redundant for the case study.

4.4.2.1 General

There were five cargo types. For each cargo type there was a corresponding ship group and land transport group.

4.4.2.2 Ships

Arrival distribution

A negative exponential distribution was used, for all five ship groups. The inter arrival times (times between successive arrivals) are shown in the Table 4.1.

Ship group	**1**	**2**	**3**	**4**	**5**
Inter arrival time (hrs)	30.2	151.0	27.2	134.2	151.0

Table 4.1. Ship group inter arrival times.

Size distribution

All ships were assumed to have a size of 100 000 tonnes.

Cargo size distribution

The distribution selected for each ship group and the associated parameter value are shown in Table 4.2. Also shown is the lower and upper limit.

Ship group	Distribution type	Parameter	Lower limit	Upper limit
1	Poisson	2803	0	100000
2	Poisson	3073	0	100000
3	Poisson	3591	0	100000
4	Poisson	1235	0	100000
5	Poisson	6691	0	100000

Table 4.2. Cargo size distributions

Trading status

The proportions for each trading status, for each ship group are shown in the Table 4.3.

Ship group	1	2	3	4	5
Import (%)	20	0	0	100	50
Export (%)	20	75	0	0	17
Both (%)	60	25	100	0	33

Table 4.3. Trading status proportions.

Service delays

There was a 4 hour pre-unloading delay, a 4 hour pre-loading delay, and a 4 hour pre-departure delay.

4.4.2.3 Dock Side Resources

Berths

Seven berths were modelled. Table 4.4 shows which cargo types could be handled at each berth. All berths handled importing and exporting ships (including vessels which import and export).

Cargo types		1	2	3	4	5
Berths	1	✗	✗	✓	✗	✗
	2	✗	✓	✓	✓	✗
	3	✗	✓	✓	✓	✗
	4	✓	✓	✗	✗	✓
	5	✓	✓	✗	✗	✓
	6	✓	✓	✗	✗	✓
	7	✓	✓	✗	✗	✓

Table 4.4. Cargo type handling by berths.

Dock side unloaders

Cargo transfer was done using general cargo handling rates. There was one rate per cargo type. There were then seven hypothetical unloaders, one for each berth, which worked at these general cargo handling rates. The general cargo handling rates, are shown in Table 4.5. As each ship was unloaded by a hypothetical unloader, the option which allows the user to specify upper limits on the number of unloaders a ship can use was effectively redundant.

Cargo types	**1**	**2**	**3**	**4**	**5**
Cargo handling rate	139.1	99.8	234.6	105.9	167.6

Table 4.5. General cargo handling rates for unloading (tonnes/hr)

<u>Dock side loaders</u>

Dock side loaders were modelled in the same way as the dock side unloaders. The general cargo handling rates for loading were the same as those for unloading and are shown in Table 4.5.

<u>Dock side port transport</u>

When a ship is unloading it uses three types of resource. These are unloaders, port transport, and stockpile equipment. The rate at which the ship unloads is limited by which ever resource works the slowest. As a general cargo handling rate was used by the unloaders, the port transport needed setting up so that its work rate was higher than this and was therefore effectively redundant. A work rate of 4000 tonnes/hr was used for all the port transport groups. The same applied to when port transport was working in conjunction with loaders.

<u>Dock side stockpile equipment</u>

As indicated by the above, stockpile equipment also needed to be made redundant. A work rate of 4000 tonnes/hr was also used for all stockpile equipment units. There were 7 units all of which were be stacker/reclaimers (i.e. do both). One unit was then effectively mapped to each of the berths.

4.4.2.4 Port Variables

Port schedule

The port was open 24 hours a day, 7 days a week.

Cargo schedules

All types of cargo were worked 24 hours a day, 7 days a week.

Simulation duration

A simulation year consisted of 8688 hours, with the model being run for 2 simulation years (i.e. 17376 hours). This assumed a 3 day shutdown per year.

4.4.3 The future scenarios

Each scenario used the same data as the Base Case except for the information stated in Tables 4.6 - 4.9 and in the sections that follow.

Cargo type	**1**	**2**	**3**	**4**	**5**
Base Case	30.2	151.0	27.2	134.2	151
Future Sc.	30.2	151.0	25.0	134.2	75.0

Table 4.6. Average inter arrival times (Hrs).

Cargo type	**1**	**2**	**3**	**4**	**5**
Base Case	2803	3073	3591	1235	6691
Future Sc.	3533	3212	9066	2919	14825

Table 4.7. Average cargo size (tonnes).

Cargo type	1	2	3	4	5	Total
Base Case	1,290	221	2,294	80	512	4,277
Future Sc.	1626	231	6,301	189	2,284	10,632

Table 4.8. Expected cargo throughputs (000's tonnes).

cargo type	future handling rate
1	250
2	100
3	ships gear 250 2 specialised cranes 592
4	150
5	275

Table 4.9. Cargo handling rates for ship loaders and ship unloaders (tonnes/hr)

<u>Scenario 1</u>

This scenario had 2 specialised cranes for cargo type 3 on berth 1.

<u>Scenario 2</u>

This scenario had nine berths, and 2 specialised cranes for cargo type 3 on berth 1. The extra berths handled all cargo types.

<u>Scenario 3</u>

This scenario had ten berths, and 2 specialised cranes for cargo type 3 on berth 1. The extra berths handled all cargo types.

Scenario 4

This scenario had ten berths, and 2 specialised cranes for cargo type 3 on berths 1 and 2. The extra berths handled all cargo types.

Scenario 5

This scenario had ten berths, and 2 specialised cranes for cargo type 3 on berths 1 and 2. The extra berths handled all cargo types. There were alternative berth handling rules for this scenario as specified by Table 4.10. Also, the cargo handling rate for cargo type 5 was 425 tonnes/hr at berths 8 and 9, which were dedicated to this cargo type, and 275 tonnes/hr at berth 10, where cargo type 1 was also worked.

Cargo types		**1**	**2**	**3**	**4**	**5**
Berths	**1**	×	×	✓	×	×
	2	×	×	✓	×	×
	3	×	✓	✓	✓	×
	4	×	✓	✓	✓	×
	5	✓	✓	×	✓	×
	6	✓	✓	×	✓	×
	7	✓	✓	×	✓	×
	8	×	×	×	×	✓
	9	×	×	×	×	✓
	10	✓	×	×	×	✓

Table 4.10. Alternative cargo type handling by berths for Scenario 5.

4.4.4 Results and conclusions

The results from the six model runs are shown in Figure 4.3. Due to the vast increase in the expected throughput for cargo type 3, this cargo type was the key to the problem, and which is why specialised cranes were included in the future scenarios. Inspection of the waiting time expected for cargo type 3 under Scenario 1 shows that merely installing 2 specialised cranes at berth 1 is completely inadequate. This option can be immediately discounted. The other 4 scenarios however, all give reasonably similar values for the average waiting times over all the cargo types. A cost - benefit analysis would have to be done to consider whether the reduction in waiting times is worth the expenditure needed to implement the scenarios. For example would a reduction of 3.23 hours per ship between Scenario 2 and Scenario 3 be worth the cost of the extra berth included in Scenario 3, given that we would be probably planning for a 20 year period.

MODEL RESULTS COMPARISON	SCENARIOS Base Case	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
INPUT						
Arrival distribution						
cargo type 1	Neg Exp	Neg Exp	Neg Exp	Neg Exp	Neg Exp	Neg Exp
cargo type 2	Neg Exp	Neg Exp	Neg Exp	Neg Exp	Neg Exp	Neg Exp
cargo type 3	Neg Exp	Neg Exp	Neg Exp	Neg Exp	Neg Exp	Neg Exp
cargo type 4	Neg Exp	Neg Exp	Neg Exp	Neg Exp	Neg Exp	Neg Exp
cargo type 5	Neg Exp	Neg Exp	Neg Exp	Neg Exp	Neg Exp	Neg Exp
Cargo size distribution						
cargo type 1	Poisson	Poisson	Poisson	Poisson	Poisson	Poisson
cargo type 2	Poisson	Poisson	Poisson	Poisson	Poisson	Poisson
cargo type 3	Poisson	Poisson	Poisson	Poisson	Poisson	Poisson
cargo type 4	Poisson	Poisson	Poisson	Poisson	Poisson	Poisson
cargo type 5	Poisson	Poisson	Poisson	Poisson	Poisson	Poisson
Simulation duration (yrs)	2	2	2	2	2	2
Number of berths	7	7	9	10	10	10
Specialised cranes for cargo type 3						
2 on berth 1S?	No	Yes	Yes	Yes	Yes	Yes
2 on berth 2?	No	No	No	No	Yes	Yes
OUTPUT						
Berth utilization (%)						
berth 1	63.34	91.76	59.48	50.41	45.86	59.08
berth 2	64.39	95.46	74.66	68.99	50.16	55.86
berth 3	65.43	96.06	71.05	62.3	59.86	69.5
berth 4	50.29	61.19	52.01	46.71	41.65	68.11
berth 5	50.23	61.43	51.44	44.41	45	43.27
berth 6	49.22	62.5	51.37	46.31	47.07	43.04
berth 7	51.45	61.24	50.87	41.44	42.5	43.76
berth 8	N/A	N/A	78.2	71.99	70.68	27.16
berth 9	N/A	N/A	79.97	73.18	70.17	31.07
berth 10	N/A	N/A	N/A	72.27	67.53	49.78
average over all berths	56.34	75.66	63.23	57.8	54.04	49.06
Cargo delivered (1 yr)						
cargo type 1	1,276,544	1,682,641	1,693,672	1,666,494	1,668,384	1,711,730
cargo type 2	186,729	216,536	214,800	209,909	205,010	210,003
cargo type 3	2,507,088	6,579,130	6,615,916	6,634,333	6,634,333	6,634,333
cargo type 4	86,751	177,419	177,419	177,419	177,419	177,419
cargo type 5	519,608	2,215,996	2,320,939	2,343,439	2,335,870	2,350,908
total	4,576,720	10,871,722	11,022,746	11,031,594	11,021,016	11,084,393
Number of ships (1 yr)						
cargo type 1	283	296	296	296	296	296
cargo type 2	48	51	51	51	51	51
cargo type 3	343	359	361	362	362	362
cargo type 4	68	60	60	60	60	60
cargo type 5	57	117	117	117	117	117
Waiting time (1 yr)						
cargo type 1	846	2611	710	272	186	299
cargo type 2	91	615	58	13	17	64
cargo type 3	2130	61418	3046	1222	662	2523
cargo type 4	611	12148	587	243	179	29
cargo type 5	190	1561	270	62	33	122
total	3868	78353	4671	1812	1077	3037
Waiting time per ship						
cargo type 1	2.99	8.82	2.40	0.92	0.63	1.01
cargo type 2	1.90	12.06	1.14	0.25	0.33	1.25
cargo type 3	6.21	171.08	8.44	3.38	1.83	6.97
cargo type 4	8.99	202.47	9.78	4.05	2.98	0.48
cargo type5	3.33	13.34	2.31	0.53	0.28	1.04
average over all cargo types	4.84	88.73	5.28	2.05	1.22	3.43

Figure 4.3 Case study simulation model results.

CHAPTER FIVE
CONCLUDING REMARKS

The main purpose of this report has been to present the work carried out during the development of a simulation model of total port operations. This work involved a large amount of background reading in the fields of port modelling and, verification and validation of simulation models. The most useful parts of this research have been presented as literature reviews in Chapters 2 and 4. The actual development of the port simulation model has been presented in Chapters 3 and 4.

The model that has been produced covers the operations of all aspects of a port system in some detail. This has been achieved despite the differences that occur between individual ports. In particular the approaches to ports can differ substantially i.e. the natural parts of the port system vary a lot more than the man made parts of the port system. However, there are commonalities in all ports, and generalisations can be made. It cannot be stressed enough that any user of this, or any other simulation model, must remember that a simulation model is an approximate mathematical representation of a real life system.

In a project such as this, there are always extra features that can be added to the model. However, it is a matter of obtaining the appropriate level of detail. There is also the matter of the time scales involved with the project which limit the amount of work that can be done. As the model is used, lessons will undoubtably be learned about, which are the most important features of the model, which features are generally redundant and perhaps ought to be removed, and which features are missing and need to be added.

At the time of writing Sir William Halcrow & Partners Ltd. have used the model in two projects. Both projects looked at planning the future capability of a port by considering various possible alternatives. Both projects were successfully completed, achieving the stated objectives. From these projects, lessons have already been learned, and time and money permitting, the necessary changes will be made. Many other enquiries about the model have been made, and several proposals for work have been submitted by Sir William Halcrow and Partners Ltd. At the present time, the future for the model looks optimistic.

APPENDIX A

USER MANUAL

USER MANUAL

1. GETTING STARTED

1.1 Introduction

The following two sections, which explain how to install and run the Port Simulation Model, are primarily written for people who know little or nothing about the Windows 3.1 operating system. If you are already familiar with Windows 3.1 the following sections should be very easy to follow.

1.2 Installing the program (In Windows 3.1)

It may be necessary for the user to install the program from a diskette. If so the following instructions tell the user how to set up a directory on the C:\ drive, and how to copy the program from the diskette to the correct directory (Note that only the left mouse button needs to be used).

1. Enter Windows 3.1 if not already there.
2. Insert the diskette into the A:\ drive.
3. In the Program Manager double click the mouse on the Main option.
4. In the Main option double click the mouse on the File Manager option.
5. In the File Manager double click the mouse on the C:\ icon, found near the top left corner of the screen. This is so that you are at the root directory.
6. Select File from the File Manager menu. Select Create Directory. At the prompt type 'PORTSIM'. Click the mouse on the OK button.
7. Now click the mouse on PORTSIM to open the folder for the PORTSIM directory (should now be highlighted).
8. Click the mouse on A:\ drive symbol located just below the menu. You should now have a list of all the files on the diskette.
9. Click the mouse button on 'HSIM.EXE' and WITHOUT releasing the button, drag the mouse 'ARROW' over to the C:\ drive icon located below the File Manager menu.
10. You should now receive a prompt asking you to confirm your decision. It should say that you are moving a file to C:\PORTSIM. If so click on the YES button. If not you need to go back to step 7 and select C:\PORTSIM.
11. The file will then be copied to C:\PORTSIM.
12. Click on the C:\ drive icon to see what is on the C:\ drive. Then click on PORTSIM to confirm that HSIM.EXE is now there.

If at any stage you have any problems either start again or ask for assistance from someone who knows how to use Windows 3.1.

1.3 Running the program

There are several ways of running the program. One way is as follows.

1. Select the File option from the Program Manager menu.
2. Select the Run option from the File menu.
3. At the prompt type 'C:\PORTSIM\HSIM.EXE' and then click the mouse on the OK button.

Having done the above three steps the computer should run the program. If not try again, or ask for assistance from someone who knows how to use Windows 3.1.

2. RUNNING A MODEL

Having entered the simulation program, the following steps guide you through the process of running a particular model.

1. Either load a previously prepared input file using the 'utilities/load variables' option from the main menu, or create a new input variables file (see section 3).
2. If ship data collection is required use the utilities menu to set up the start and end times of collection.
3. If either of the animation screens are required, load in the appropriate animation screen files, using the utilities menu.
4. Make sure the simulation duration option found under the 'port variables' menu option has been set up correctly.
5. Run the model, using the 'Run/Run' menu option. Switch 'interactive off' to run the model in fast mode. However, interactive must be set to 'on' if animation is required.
6. When the model has finished running, save the text screens, graphs, and ship data (if required), using the appropriate options found under the utilities menu option.
7. The graphs and text screens can be reviewed at any time within the model. The ship data, which is a comma separated data file, can be reviewed and analysed, by importing it into any spreadsheet package.

For further details on the options under the utilities menu option see section 5.

3 MODEL INPUT

The following sections describe the input tables found under each main menu option.

3.1 Ship Variables

The user can have up to five 'shipping fleets', which are known as 'ship groups'. Each ship group carries one and only one 'cargo type', and each cargo type is carried by one and only one ship group i.e. a bijective relationship. It is intended that generally a ship group will comprise of one type of cargo such as coal. However this may not always be the case. It is obviously up to the user to decide which ships categorise each ship group. This will depend on the nature of the project being undertaken. There are numerous input tables for the ship groups and these are described below.

As well as being allocated to a ship group each ship in the simulation belongs to a 'ship size class'. There are up to five ship size classes available. When a ship is created a 'size' is generated based on the relevant ship group size distribution. From this the ship can be allocated to the relevant ship size class, and hence can generate appropriate ship size class attributes for ships in that size range. Ship size class attributes are attributes which relate to the size of the ship rather than the cargo type it is carrying, such as the number of tugs the ship needs to navigate its way into the port.

<u>Ship Groups</u>

The user sets up the ship groups by selecting the 'ship groups' option and the 'ship group priority weightings' option.

<u>Ship group Status</u>

The ship group status table is used to select the number of ship groups required, and to turn the ship groups on and off once set up. For example the user may require four ship groups which are set up in the initial input file. To run the program without 'group three' say, click the mouse on the appropriate check table, rather than setting up a whole new input file.

<u>Arrival Distribution</u>

The user has a choice of five mathematical distributions. These are the Negative Exponential, Erlang, Poisson, Uniform, and Constant distributions. It is most probable that for a particular project the user will have some historic data, and will hence choose the distribution which fits best against the data. Generally speaking the Negative Exponential distribution gives the best fit.

Having chosen the distribution required the user must then input the correct distribution parameters. For the Negative Exponential and Poisson distributions the 'first parameter' is the mean and the 'second parameter' is unused. For the Erlang distribution the 'first parameter' is the mean and the 'second parameter' is 'k', where the random variate E_k is the sum of k Negative Exponential variates. For the Uniform distribution the 'first parameter' is the lower limit, and the 'second parameter' is the upper limit. Finally, for the Constant distribution the 'first parameter' is the constant value at which ships will arrive i.e. its not really a distribution e.g. you may have a ferry which comes to the port the same time every day. The 'second parameter' is unused if the user selects the Constant distribution.

<u>Size Distribution</u>

The user has a choice of six mathematical distributions. These are the Negative Exponential, the Erlang, the Poisson, the Constant, the Uniform, and the Weibull. Having selected the required distribution a second input screen will appear, allowing the user to input the appropriate distribution parameters. These are shown in Table 3.1.

The size (DWT) of the ship is used to calculate the draught of the ship, which in turn is compared with the tide level when the ship wants to enter and leave the port. The size of the ship is also used to allocate the ship to the correct ship size class.

Distribution	Parameters
Negative exponential	Mean, upper limit, lower limit
Erlang	Mean, 'k', upper limit, lower limit
Poisson	Mean, upper limit, lower limit
Constant	Value
Uniform	Upper limit, lower limit
Weibull	Scale, shape, upper limit, lower limit

Table 3.1 Size distribution choice and appropriate parameters.

Cargo Size Distribution

The user is given the choice of seven mathematical distributions. These are as the ship size distribution, plus the possibility of the ship's cargo size being a fixed percentage of the ship's size.

The cargo size is the amount of cargo a ship unloads and/or loads. The cargo size affects the service time of the ship.

Trading Status Probabilities

A ship can either import cargo, export cargo, or do both. In the trading status table the user inputs the proportion of ships in the ship group that are going to import only as a probability, and the proportion of ships in the ship group that are going to export only as a probability. The remaining probability is for ships importing and exporting cargo.

If a ship is importing only, it will have a loaded draught on entry to the port, and an unloaded draught on leaving the port. If a ship is exporting only, it will have an unloaded draught on entry to the port, and a loaded draught on leaving the port. Finally, if the ship is going to import and export cargo, it will have a loaded draught on entry and on leaving the port.

Pre-unloading Delay

The user can cause ships to be delayed before they are allowed to try and start unloading. For example a ship carrying crude oil may have to have a sample of its cargo tested at a laboratory for some reason e.g. quality, before it is allowed to try and unload. Note that this delay is not related to ships having to wait due to lack of port resources. The distributions on offer are as with the arrival distribution. If no delay is required the user can, for example, select the Constant distribution with a parameter of zero. The length of the pre-unloading delay will affect the length of the ships service time.

Pre-loading Delay

A delay can be caused to ships before they try and load. The distributions available are again as with the arrival distribution. The length of the pre-loading delay will affect the length of the ships service time.

Pre-departure Delay

A delay can be caused before the ships leave the port e.g. for customs. The distributions available are again as with the arrival distribution. The length of the pre-departure delay will affect the length of the ships service time.

Ship group stockpile level checks

Before a ship can enter the port the following condition must be true. If a ship is importing cargo, the ship's cargo size is checked against the relevant stockpile to see if there is room for a specified percentage of the ship's cargo size at the present simulation run time. If the ship is exporting cargo, the ship's cargo size is checked against the relevant stockpile to see if there is a specified percentage of the ship's cargo size available at the stockpile at the present simulation runtime. If a ship is importing and exporting cargo, then both the above statements must be true.

Multiple Unloader Factors

When more than one unloader works on a ship at the same time, it may be that the overall 'effective rate' goes down. For example two unloaders working on their own may have 'effective rates' of 4000 tonnes per hour and 3000 tonnes per hour. But if they were to work on the same ship together, for one reason or another, the combined 'effective rate' may be less than 7000 tonnes per hour. The multiple unloader input table allows the user to allocate factors to the various number of unloaders that may be working on a ship at any one time, up to a maximum of ten unloaders. These inputted factors will then be multiplied against the sum of the 'effective rates' of the unloaders working on a particular ship. So if the above two unloaders were working together on a ship and the user input a factor of 0.9, then the overall 'effective rate' of the two unloaders would be 6300 tonnes per hour.

Multiple Loader Factors

As for the multiple unloader factors, but applied to the loaders.

Ship Group Service Priority Weightings

Under the 'ship group service priority weightings' option, the user can allow certain ship groups priority over others during the service phase. If the user gives a certain ship group priority it means that the ships in this group will have priority in trying to obtain unloaders, loaders, and port transport. All the ship groups have been given a priority weighting of '1' by default i.e. no ship group has priority over any of the others. To give a group priority over the others select an integer value that is larger than the other groups weightings, although this can all be done by just using the numbers 1 to 5.

Ship Group Cargo Size Bands

The cargo size bands are used to decide how many (un)loaders a ship of a certain cargo size and cargo type should ideally have. In the 'cargo size bands' input table the user sets up the ranges for the bands, and the numbers of (un)loaders that the ship should have are set up in the 'max number of unloaders per ship' or 'max number of loaders per ship' options.

Ship Size Classes

The ship size class input tables allow the user to set up the ship attributes which relate to size rather than the cargo type it is carrying. The first four ship size classes (small, medium, large and very large) have seven attributes each.

- the number of tugs needed to navigate into and out of the port.
- the tug fasten time, which is the total time to affix all the tugs.
- the tug release time, which is the total time to release all tugs.
- the manoeuvring time, which occurs just before and just after a ship docks.
- the average speed.
- the lock transition time (set to zero if no lock required).

The end of the size range is defined by the start of the next ship size class, except for the 'ultra large ship size class' where there is the additional attribute of the end value of the size class, as there is no other ship size class following this one.

The size classes must cover the entire range of ship sizes possible from the ship groups' size distributions i.e. user awareness is needed.

3.2 Dock Side Resources

The resources used on the seaward side of the port are berths, tugs, dock side unloaders, dock side loaders, dock side port transport, and dock side stockpile equipment. The input tables for these resources are described below.

Berths

The berths are used by ships during their stay in port, which will consist of unloading and/or loading and any delays that may be encountered. Only one ship is allowed at a berth at any one time.

Total number of berths

The user can vary the total number of berths available between **one** and **ten**.

Attributes of berths

The user can alter the attributes of one or more of the berths by selecting the 'Berth - attributes' option. Under this option the user will find one table for each berth. The table for a particular berth lets the user select which cargo types are allowed at the berth. It also lets the user select the trading status of the berth. The trading status of the berth can be 'import only', 'export only', or 'import/export'. If the berth is said to be 'import only', only ships which are just importing are allowed at the berth. Similarly if the berth is said to be 'export only', only ships which are just exporting are allowed at the berth. Note however that a berth which is said to be 'import/export' means that the berth will accept ships which are importing only, exporting only, or ships which are going to do both i.e. import and export. Finally the user can set the depth of the berth, and the minimum level of clearance needed by any ship using the said berth.

User awareness is needed, in that any ship waiting to enter the port must be serviceable at, at least one berth.

Tugs

The user can define the total number of tugs available, and the average speed of the tugs (all tugs will have the same speed). If when a ship tries to acquire some tugs enough are available but one or more are at the wrong end of the port e.g. ship is offshore and the tugs are at the dock, then a delay will be incurred by the ship while it waits for tugs to get to it. The tug average speed along with the channel length (the distance from the dock to the offshore waiting area) is used in the calculation of this delay.

Dock Side Unloaders

The unloaders are used to discharge the cargo of ships which are importing.

Total number of dock side unloaders

The user can vary the total number of unloaders available between **one** and **ten**.

Attributes of dock side unloaders

There are two tables of attributes for each unloader. In the first table the user defines which cargo types the unloader can handle, the effective unloading rate of the unloader in cargo units per hour for each of the cargo types, and the efficiency level of the unloader as a percentage for each of the cargo types. The rate at which the unloader will work, will be the 'effective rate' multiplied by the 'efficiency level'. In the second table the user defines which berths the unloader can work at.

Maximum number of dock side unloaders per ship

Under this option the user sets up how many unloaders a ship of a certain cargo type and certain ship cargo size band should have, as a maximum.

Dock Side Loaders

The loaders are used to load the cargo of ships which are exporting.

Total number of dock side loaders

As the dock side unloaders.

Attributes of dock side loaders

As the dock side unloaders.

Maximum number of dock side loaders per ship

As the dock side unloaders.

Dock Side Port Transport

The port transport is used to carry unloaded cargo from the quayside to the storage area, and cargo which is to be loaded, from the storage area to the quayside. Each ship group has its own group of port transport, with the groups of port transport being numbered so that port transport group one is used to transport cargo from ship group one etc. The attributes of each group are, the total number of port transport units available, the effective rate of each port transport unit, in cargo units per hour, and the efficiency level of each port transport unit, as a percentage. The rate at which each unit will work is the 'effective rate' multiplied by the 'efficiency level'.

Dock Side Stockpile Equipment

The stockpile equipment is used to stack and reclaim cargo from the stockpiles.

Total number of dock side stockpile equipment

The user can vary the total number of dock side stockpile equipment units available between **one** and **twenty**.

Attributes of dock side stockpile equipment

There are two tables of attributes for each unit of stockpile equipment. In the first table the user defines the units type i.e. whether the unit is to be a stacker, a reclaimer or a stacker/reclaimer. In the second table the user defines, for each of the cargo types, which cargo types the unit can handle, the effective unloading rate of the unit in cargo units per hour, and the efficiency level of the unit as a percentage. The rate at which the unit will work, will be the 'effective rate' multiplied by the 'efficiency level'.

3.3 Port Variables

Port Schedule

The user defines for each day of the week, the time ship movement may commence and the time it must cease. Times must be inputted based on the twenty four hour clock, although minutes must be inputted as fractions of the hour e.g. 6.30pm must be inputted as 18.50. To have the port open twenty four hours a day, the start time is 0:00, and the finish time is 24:00.

Weather

The weather consists of up to six states and affects ship movement and cargo movement. The length of time that the weather spends in a state is known as a period of weather. When the end of a period of weather is reached the weather will begin the next period of weather. The length of the period of weather depends on which state the weather is in. The state of the next period of weather is decided upon by the transition probabilities p_{ij}, where i is the present weather state, j is the next weather state, and p_{ij} is the probability of going from state i to state j. Under the 'Weather variables' option the user defines the transition probabilities of going from one state to another, and the distribution (and associated parameters) for each state.

Ship Weather States

Under the 'Ship weather states' option the user defines in which weather states ship movement is allowed.

Cargo Type Weather States

Under the 'Cargo type weather states' option, the user defines in which weather states cargo movement is allowed, for each of the five cargo types.

Tides

The tide is modelled using a modified version of Gooding's tide unit, which in turn is a conversion of a Fortran program written by Halcrow. The tide unit continually calculates the height of the tide during the simulation run using, the amplitude and phase of the four harmonics M2, S2, K1, and O1, the mean sea level (Z0), the minimum chart depth, the minimum clearance level, and a start year and day. All of these are user inputs. The tide affects the hours when ships are allowed to enter and leave the port.

Channel Parameters

The 'Channel length' parameter is the distance the ships have to travel from the offshore waiting area to the lock, and the 'Distance to manoeuvring area' is the distance from the lock to the manoeuvring area, the manoeuvring area being the area where the ships manoeuvre in order to dock. All distances are in metres.

Simulation Duration

Under the 'Simulation duration' option the user sets the length of the simulation run as a number of hours.

Stockpiles

Under the 'Stockpiles' option the user defines for each cargo type, the total capacity and initial level for the import stockpile and the export stockpile (in cargo units).

3.4 Land Transport

Port Gates

Under the 'Port gates' option the user selects how many gates are required, between **one** and **four**. Then for each gate the user selects the number of service points available to arriving LTUS (between one and ten), and the number of service points available to departing LTUS (between one and ten). Finally for each service point, the user selects which cargo types can be handled at the said service point.

Land Transport Groups

These are as the Ship group input tables except that the LTU's do not have a size, and service times to get through the port gates need to be defined.

Land Side Cargo Size Bands

As ship group cargo size bands.

Land Group Service Priority Weighting

As priority weightings for ships.

3.5 Land side resources

Loading Bays

The user can vary the total number of loading bays available for each cargo type, between **one** and **ten**.

Land Side Unloaders

As the dock side unloaders.

Land Side Loaders

As the dock side loaders.

Land Side Port Transport

As the dock side port transport.

Land Side Stockpile Equipment

As the dock side stockpile equipment.

4. MODEL OUTPUT

The simulation model provides five sources of output. These are text screens, time frequency graphs, time series graphs, histograms and the ship log data file. The user can save the text screens to one file, all the graphs to a second (see model utilities), and the ship log data to a third.

4.1 Text Screens

These contain data in numeric form, as apposed to graphical. There is a large amount of output displayed in these screens, which are explained below.

Timer

This screen shows the present simulation run time. The rate at which the screen is updated is a user input. When the simulation is running in interactive off mode, the user is still able to see the present simulation time displayed on this screen. This is so the user has an idea how the simulation run is progressing.

Dock Side Stockpile Equipment

Shows the present throughput (in cargo units) and utilization (as a percentage) of each dock side stockpile equipment unit in use, up to a maximum of twenty units. Each unit is updated whenever it finishes a job. A unit is considered to have finished a job when the ship it is stacking (or reclaiming) cargo for either, finishes unloading, finishes loading, or has its servicing suspended for some reason e.g. affects of the weather, the work schedule for the relevant cargo type, or a stockpile constraint. The screen also shows the unit's type (whether a stacker, a reclaimer or a stacker/reclaimer).

Land Side Stockpile Equipment

See the dock side stockpile equipment.

Land Side Loaders

Shows the present throughput (in cargo units) and utilization (as a percentage) of each land side loader up to the maximum of ten units. Each loader is updated whenever it finishes a job. A loader is considered to have finished a job when the LTU it is loading cargo for either, finishes loading or has its loading suspended for some reason e.g. affects of the weather, the work schedule for the relevant cargo type, or a stockpile constraint.

Land Side Unloaders

See land side loaders.

Dock Side Loaders

See land side loaders.

Dock Side Unloaders

See land side loaders.

Land Group Results

For each of the five LTU groups, this screen shows the import throughput, the export throughput, and the import/export throughput. The import throughput is the amount of cargo taken out of the port by LTUS with an 'import only' trading status. The export throughput is the amount of cargo brought into the port by LTUS with an 'export only' trading status. The import/export throughput is the amount of cargo moved by LTUS with an 'import/export' trading status. To calculate the amount of cargo imported through the port by LTUS, the sum of the import throughput and the import/export throughput is taken, and to calculate the amount of cargo exported through the port by LTUS, the sum of the export throughput and the import/export throughput is taken.

The screen also shows for each LTU group, the number of import calls, the number of export calls, and the number of import/export calls. As with the throughput, the calls relate to the trading status of the LTUS. This screen is updated whenever an LTU leaves its loading bay.

Ship Group Results

This screen shows, for each of the five ship groups, the import throughput, the export throughput, the import/export throughput, the number of import calls, the number of export calls, and the number of import/export calls.

The import throughput is the amount of cargo unloaded by ships with an 'import only' trading status, the export throughput is the amount of cargo loaded by ships with an 'export only' trading status, and the import/export throughput is the amount of cargo unloaded and loaded by ships with an 'import/export' trading status. So the amount of imported cargo from ships is the import throughput plus the import/export throughput, and the amount of exported cargo from ships is the export throughput plus the import/export throughput.

The number of call refers to the number of ships with the relevant trading status that have visited the port. This screen is updated whenever a ship leaves its berth.

LTU Average Service Times

This screen shows, for each of the five LTU groups, the full service time, the unloading service time, and the loading service time.

The full service time is the time the LTU spent at the loading bay. The program takes the simulation time when the LTU arrives at the loading bay, the time that the LTU leaves the loading bay, and then calculates the difference to get the full service time.

The unloading service time is the time that the LTU spends in the unloading phase of its servicing. The program takes the time that the LTU starts the phase (done at the start of the pre - unloading delay), the time that the LTU finishes the phase (done when unloading is finished), and then calculates the difference to get the unloading service time.

The loading service time is the time that the LTU spends in the loading phase of its servicing. The program takes the time that the LTU starts the phase (done at the start of the pre - loading delay), the time that the LTU finishes the phase (done when loading is finished), and then calculates the difference to get the loading service time.

The screen also shows, the full service count, the unloading service count, and the loading service count.

All LTUS fall into the full service category, while only LTUS with 'export only' or 'import/export' trading status' fall into the unloading service category, and only LTUS with 'import only' or 'import/export' trading status' fall into the loading service category. This screen is updated whenever an LTU leaves its loading bay.

Ship Average Journey Times

This screen shows, for each of the five size classes of each of the five ship groups, the average approach time, the average departure time, the average passage time, and the total calls. The approach time for a ship is the difference in time between the ship's creation time and the time that the ship arrives at its berth. The departure time for a ship is the difference in time between the time the ship leaves its berth and the time the ship is disposed of. The passage time for a ship is the difference in time between the creation time and disposal time of the ship. This screen is updated whenever a ship leaves the system.

Berth Results

This screen shows, for each berth in use (up to the maximum of ten), the import throughput, the export throughput, the utilization, the number of import calls, the number of export calls, and the number of import/export calls.

The import throughput is the amount of cargo unloaded at the berth. This will be by ships with an import only or an import/export trading status. The export throughput is the amount of cargo loaded at the berth by ships with an export only or import/export trading status.

The number of import calls is the number of ships visiting the berth with an 'import only' trading status. The number of export calls in the number of ships visiting the berth with an 'export only' trading status. The number of import/export calls is the number of ships visiting the berth with an 'import/export' trading status.

The berth utilization is the percentage of time that the berth is **occupied**. Note that the percentage of time that the berth is occupied differs from the percentage of time that the berth is **allocated**. Allocating a berth to a ship is one of the conditions that must be satisfied before the ship can proceed down the approach channel. So a berth is allocated to a ship from when it leaves the offshore area in order to enter the port up to when the ship leaves the berth, whereas a berth is only occupied by a ship while the ship is being serviced.

This screen is updated whenever a ship leaves its berth.

Loading Bays

There is one screen for each LTU group being used in the present simulation run. Each screen shows for each loading bay (up to a maximum of ten), the import throughput, the export throughput, the import/export throughput, the utilization, the number of import calls, the number of export calls, and the number of import/export calls.

The import throughput is the amount of cargo loaded. This will be by LTUS with an import only or import/export trading status. The export throughput is the amount of cargo unloaded by LTUS with an export only or import/export trading status.

The number of call refers to the number of LTUS with the relevant trading status that have visited the loading bay. The utilization is the percentage of time the loading bay is occupied. LTUS are only allocated a loading bay immediately before occupation so the percentage of time allocated can be said to be the same as the percentage of time occupied, and hence the percentage of time unused can be obtained. This screen is updated whenever an LTU leaves its loading bay.

Gate Average Service Times

There is one screen for each gate. Each screen shows, for each of the five LTU groups, the average service time on arrival, and the average service time on departure. These screens are updated every time an LTU has finished being serviced at a gate.

Current Status Statistics Two

This screen shows the lock utilization, the average wait for ships to enter the port, the average wait to enter the lock on entry to the port, the average wait to leave the berths, and the average wait to enter the lock on departure from the port.

Stockpile Status Report

For each of the ten stockpiles this screen shows, the average dwell time, the percentage full, and the amount full in terms of cargo units. Each stockpile is updated every hour.

Dock Status

This screen shows, for each berth (up to the maximum of ten), details about the ship presently situated at the said berth. The cargo type, the trading status, the cargo size, the present activity (loading, unloading etc.), the number of unloaders acquired, the number of loaders acquired, the number of port transport acquired, and the number of stockpile equipment units acquired, for the ship are shown.

Loading Bay (LTU group one) Status

This screen was used to aid validation and debugging. The screen shows, the arrival number, the trading status, the cargo size, the present activity (e.g. waiting to unload, unloading etc.), the number of unloaders acquired, the number of loaders acquired, the number of port transport acquired, and the number of stockpile equipment units acquired, for the LTU at each loading bay.

Inland Transport Status Report

This screen shows, the number of arrivals, the number of departures (and hence the difference is the number in the system), the state of the five cargo type work schedules. The screen also shows the memory available, which was useful to know when debugging the program. A continual fall in the amount of memory available as the simulation runs, implied there are bugs in the program e.g. not disposing of entities correctly. This screen was used to aid validation and debugging.

Current Status Statistics Screen One

This screen shows some miscellaneous statistics about the present state of the simulation model. These are, the number of tugs in use, the departure released tugs (the number of tugs waiting at the offshore area), the berth released tugs (the number of tugs waiting at the docking area), the total number of ship arrivals, the total number of ships turned away, the total number of ships which have entered the port, the total number which have left the system, the present weather state, the lock sill level (the tide level), the present port schedule state, the present simulation time (only updated whenever a ship leaves the system), and the memory available. This screen was used to aid validation and debugging.

4.2 Time Frequency Graphs

Time frequency graphs show the amount of time spent in each state (y - axis) against each state (x - axis). The time frequency graphs available in the simulation model all show utilizations of resources, where the states along the x - axis are the amounts of the resource being used. The graphs displayed are,

- dock side stacker/reclaimer utilization.
- dock side reclaimer utilization.
- dock side stacker utilization.
- dock side loader utilization.
- dock side unloader utilization.
- dock side port transport utilization.
- land side stacker/reclaimer utilization.
- land side reclaimer utilization.
- land side stacker utilization.
- land side unloader utilization.

- land side loader utilization.
- land side port transport utilization.
- berth utilization.
- tug utilization.
- LTU group loading bay utilization (one graph for each cargo type in use).

These graphs are updated whenever resources are acquired or released.

4.3 Time Series Graphs

Time series graphs show how a variable changes over time, with the variable level shown on the y - axis, and time shown on the x - axis. The time series graphs available in the simulation model are updated at regular intervals during a simulation run. Each graph is updated fifty times, so the time between each successive update depends on the simulation run length. The graphs displayed are,

- stockpile level graphs which show the percentage full (one for each stockpile whose cargo type is in use).
- gate queue length graphs (one graph for each gate's arrival queue and one graph for each gate's departure queue).
- Port Queue - Arrivals (shows queue length).
- Lock Queue - Arrivals (shows queue length).
- Berth Queue - Departures (shows queue length).
- Lock Queue - Departures (shows queue length).

4.4 Histograms

Histograms show the frequency of occurrence of levels of a variable plotted against the variable. The histograms available in the simulation model are,

- Land transport cargo size.
- Ship size.
- Inter arrival time (for all ships).
- Ship cargo size.

These graphs are updated whenever a ship or LTU arrives in the system.

4.5 Ship data collection

The user defines the start and end times, in simulation run hours, of when ship data should be collected. Any ship which completes its passage through the simulation system in between the start and end times will have some of its attributes saved in a data record. There is an upper limit of 800 records. The file, which is saved under the utilities menu option (see section 5), has been designed so that it can be easily imported into any of the main spreadsheet packages. Each ship record consists of the following fields:

1. record number.
2. run time the record was created.

3. ship number.
4. cargo type.
5. trading status.
6. size (DWT).
7. creation time.
8. time arrived at berth.
9. time left berth.
10. disposal time.
11. approach time.
12. departure time.
13. passage time.
14. berth number.

5. MODEL UTILITIES

The following features of the model allow the user to load and save the various types of file available with the model. Also described is how to vary the updating rate of the timer screen.

5.1 Save Variables

Once the user has set up an input file it can be saved using the 'save variables' option. The file will be given a '.var' extension by default.

5.2 Load Variables

A previously saved input file can be retrieved using the 'load variables' option.

5.3 Save Text Screens

The 'save text screens' option saves the text screens in a file with a '.txt' extension by default. The text screens are saved in a separate option from the graphs so that the text screen data can be easily used further e.g. if it needs to be loaded into a spreadsheet.

5.4 Load Text Screens

The user can load previously saved text screens if required, using the 'load text screens' option.

5.5 Save Graphs

As stated above, the graphs are saved in a separate file from the text screens. The graphs can be saved using the 'save graph' option in a file which has a '.grf' extension by default.

5.6 Load Graphs

Previously saved graphs can be reloaded using the 'load graphs' option.

5.7 Animation - updating frequency

Defines the number of times the animation screens are updated in an hour. The higher the number input the more realistic the animation will look, but the slower the program will run.

5.8 Animation - realistic screen

This option allows the user to load in a '.SHP' file which the user has previously set up in WANIMAT.EXE. The user needs to load in a *.SHP file if he/she wants to run the program with the realistic animation screen.

5.9 Animation - schematic screen

The user can load in the SCREEN_2.SHA file which is needed if the user wants to run the program with the schematic animation screen.

5.10 Timer screen

The user inputs the updating frequency of the timer screen (in hours).

5.11 Save ship data

The user can save a '.DAT' file of the ship data collected during the simulation run.

5.12 Ship data collection

See section 4.5.

APPENDIX B

MODEL PROCESS DOCUMENTS

MODEL PROCESS DOCUMENTS

This appendix contains the Functional Specification and Detailed Design documents for the three modules of the Port Simulation Model that were designed under this project, namely,

- Ship unloading and loading
- Storage areas
- Inland transportation.

The design of the Ship arrivals and departures module was carried out under the M.Sc. project. Refer to this document for details.

Where there are inconsistencies between the design documents and the main report, the main report should be taken as the correct version. In particular certain aspects of the inland transportation module were decided to be too ambitious, within the project timescales, and also to a certain extent, unnecessary.

PORT SIMULATION MODEL

SHIP UNLOADING/LOADING MODULE

FUNCTIONAL SPECIFICATION

REVISED 15th DECEMBER 1993

(1) When a ship has docked at a berth, the main purpose of it's visit to the port is to either, unload, load, or, unload and load. To do this it must use, port unloaders and/or port loaders to actually transfer the cargo off and on the ship, and what will be known as port transport, to take unloaded cargo to the relevant storage area(s), and bring from the relevant storage area(s) cargo that needs loading.

(2) The number of unloaders/loaders that a ship needs will vary from ship to ship. Certain factors about the ship will be used to decide how many unloaders/loaders an individual ship needs, if in fact it needs any at all.

(3) The amount of port transport that a ship needs will also vary from ship to ship. The amount an individual ship needs will depend on how many unloaders/loaders are being used by the ship, and how fast they are working. The ship needs to obtain enough port transport so that all the unloaders/loaders working on the ship, can work at full capacity. However, as with the port unloaders/loaders, it may be that the ship doesn't actually require any port transport at all. This possibility will be catered for.

(4) The port unloaders for a port will not all be the same. Different types of unloaders are used for different types of cargo. For example, cranes may be used to unload general cargo, while conveyor belts or bucket unloaders may be used to unload bulk materials such as coal. And even for one particular cargo type such as coal, the port manager might have several unloaders that he/she can use, all of which might have different unloading rates. The above also applies to the port loaders. To achieve this, the port unloaders and port loaders will be given identities.

(5) Within a port, there will also be several types of port transport. For example you can have tractors and trailers, fork lift trucks etc. It will need to be possible to distinguish between the different types of port transport.

(6) A set of rules needs to be formulated to decide for each ship which unloaders/loaders should be allocated to it. These rules will need to take into account the fact that, if a ship needs several unloaders/loaders, it may not be able to acquire them all at once, and hence initially, unloading/loading will take place at less than the desired level. Also, there will need to be some method for continually checking when further unloaders/loaders have become available that the ship can use.

(7) A set of allocation rules will also need to be formulated for the port transport. These will be similar to the port unloader/loader allocation rules.

(8) Whenever a ship acquires either more port unloaders/loaders, or port transport, the rate at which it is unloading/loading will increase and hence its unloading/loading time will decrease. Some method of recalculating the unloading/loading time needs to be formulated. The unloading/loading time will be used so that you know when the ship wants to leave the berth.

(9) It should be noted that while the overall unloading/loading rate of a ship will increase if it acquires more equipment, the individual work rates will go down.

(10) Delays may be incurred by ships at various stages during it's stay at the port. The ones to be modelled will be before a ship unloads, before it loads, and before it is allowed to leave its berth.

(11) There needs to be a method to check that the cargo size of a ship is not greater than the DWT of the ship, bearing in mind that the unit of cargo may not be 'tonnes'.

PORT SIMULATION MODEL

SHIP UNLOADING/LOADING MODULE

DETAILED DESIGN

REVISED 15th DECEMBER 1993

1. Introduction

Throughout the following document no mention will be made of the port loaders and related design issues. This is because the port loaders will be designed in exactly the same way as the port unloaders. Therefore every time you read the word unloader, you can read the word loader.

In this new revised version of the detailed design there are three new sections, one on the various delays that can be encountered by the ships, one on a ship's unloading rate, and one on cargo sizes.

2. Port unloaders

These are one of the resources, that are acquired by the ships in order that they may unload. Each unloader will have its own identity. This will consist of,

(a) five effective rates: the average unloading rate of the unloader (assuming no breakdowns) for each of the cargo groups.

(b) five efficiency levels: the percentage of time that the unloader is in a working condition. There is one efficiency level for each of the five cargo groups.

(c) five final rates: the effective rate of an unloader, for a particular cargo group, is multiplied by the efficiency level of the unloader, for the same cargo group, to give an overall average unloading rate for the unloader, for that cargo group.

(d) A 'mega final rate': when an unloader is acquired by a ship, the rate at which the unloader works is the final rate for that ships cargo group. This is called the 'mega final rate'. This attribute will be updated every time the unloader is going to start a new job.

(e) five cargo handling variables: each cargo handling variable is a boolean variable which says whether the unloader can handle the cargo from a particular cargo group.

(f) berth handling variables: the berth handling variables are again boolean variables, and say which berths the unloader can be used at.

(g) availability: says whether the unloader is being used at the present simulation runtime or not.

The effective rates, efficiency levels, cargo handling variables, and berth handling variables are all user inputs. The total number of unloaders is also a user input.

2. Port transport

These are the other resources that are acquired by ships in order that they may unload/load. They are needed to transport cargo to an from the storage area(s). There will be five groups of port transport (PT), one group for each of the cargo groups. Each PT group will have its own identity. This will consist of,

(a) an effective rate: the rate at which one unit of PT in the group works. This rate will take into account the distance the unit of PT has to travel to and from the storage area.

(b) an efficiency level: the percentage of time that each unit will be operational.

(c) a final rate: the effective rate of the PT group is multiplied by the efficiency level of the PT group, to find the overall work rate of each PT unit in the group.

The effective rate and efficiency level for each PT group are user inputs, as are the total number of PT units in each group.

3. The number of unloaders and amount of PT a ship requires

These two seemingly separate issues will be discussed together because this section could have an additional title, namely 'Does the ship require any unloaders and/or PT ?'. There are four possible cases that need examining.

(a) ship requires unloaders and PT.

(b) ship requires just unloaders.

(c) ship requires just PT.

(d) ship requires neither.

Case (a)

(i) The number of unloaders required

In deciding how many unloaders a ship requires, we need to consider the ship's cargo size and the ship's cargo type. For each cargo group the cargo size will be split up into five continuous bands. By continuous bands I mean that Band 2 starts where Band 1 finishes etc. The start point for each band will be a user input, as will the end point of Band 5. Note that the start point of Band 1 will be the lower limit of the cargo size, and the end point of Band 5 will be the upper limit of the cargo size. This is important to remember for when altering the cargo size generation attributes in the cargo group tables. For each of the twenty five user inputs (i.e. five cargo groups each having five cargo size bands), there is a lower limit of one unloader, and an upper limit of four unloaders.

(ii) The amount of PT required

This depends on the number of unloaders that the ship is using and their work rates. To find out how many units of PT a ship needs at a particular time, sum the 'mega final rates' of the unloaders presently working on the ship, and divide this figure by the work rate of the PT units in the relevant PT group. The result (which may need rounding up) gives the number of PT units required.

Case (b)

If for a particular cargo group no PT is needed just set that groups PT group total number to such a high level as not to cause any waiting time for PT. Also, make the final rates very high.

Case (c)

To turn the unloaders off, set the amount the ship needs to one in the input table. To fix the amount of PT units needed, set the unloader's final rate to give the required value. Then just need to make sure that enough dummy unloaders are dedicated to the relevant group, so that ships aren't left waiting for unloaders.

Case (d)

Set up the PT as in case (b). Then the unloading time will be based on the cargo size of the ship, and the final rate of the dummy unloader (both of which are user inputs).

4. Port unloader allocation rules

There will be one c_activity which deals with the unloader allocation. It will be called whenever a ship arrives at a berth and starts preparing to unload, or if an unloader becomes available. It will do the following:

(1) check all the berths to see which are busy i.e. finds where the ships are.

(2) create an order in which to check all the ships based on the following priority rules:

(a) check the group weightings, placing the ships with the highest group weightings first. The group weighting for each cargo group can be any integer, and will be a user input in the cargo group tables. By default all the group weightings will be set to one i.e. no group has priority over another.

(b) For all ships with the same weighting, order the ships so the one with the least number of unloaders at the present time has priority.

(c) In case there are ships still with equal priority, the time at which the ships berthed will also be taken, and the ships will be ordered so that the one which has been there the longest will be placed first.

(3) go through the ships in the required order, and if a ship requires any more unloaders call the unloader allocation procedure which,

(a) for all the available unloaders, checks whether they are suitable i.e. whether they can handle the ships cargo type, and they can go to the ships berth.

(b) for a ship requiring X unloaders, the ship will be allowed to acquire the smallest of, X and the number of suitable unloaders available.

(c) having worked out how many unloaders the ship can acquire, the relevant number of unloaders is selected by choosing the ones with the best 'mega final rates'.

(d) calculates how many units of PT the ship now needs to obtain to unload at the full rate.

5. Port transport allocation

This will also be done using a c_activity, which will be called every time the c_activity involved in unloader allocation is called (or the loader allocation c_activity).

This c_activity will

(a) obtain a list of the berths with ships at them.

(b) obtain a list of the ships in their priority order. The priority rules for ordering the ships will be the same as those used to order the ships when acquiring unloaders, the only difference being that we will be looking for ships with the least amount of port transport rather than the least number of unloaders.

(c) if a ship requires more PT, a PT allocation procedure will be called, which will,

  (i) compare the amount of PT that the ship wants and how much is available for that PT group, and give the ship the smaller of these two amounts.

  (ii) update how much the ship still needs.

(d) the ships unloading time (or loading time) will be updated if necessary. See below for an explanation of how this is done.

6. Delays

Three main areas of delay that ships may encounter have been identified. These are

(a) before being allowed to unload.

(b) before being allowed to load.

(c) before being allowed to leave the berth.

Delays depend on the cargo type. Hence the delays will be group attributes, like the arrival or size distributions.

For a particular ship group there will be, for each of the three delay areas, an input table giving the user a choice of distributions from which to create the delay.

There will also be boxes to input the parameters of the selected distribution. It will all be set up much like the arrival distribution has been set up, except that all the input for a particular delay will be displayed in the same input table. The probable distributions that the user will be able to choose from will be,

(a) Constant.

(b) Negative exponential.

(c) Poisson.

(d) Erlang.

(e) Normal.

(f) Uniform.

(g) Weibull.

If no delay is required this can be done by, for example, selecting the constant distribution and giving it a parameter of zero.

7. Ship unloading rate

The unloading rate of a ship at any time will be the sum of the 'mega final rates' of the port unloaders that are working on it, multiplied by some factor to take into account the fact that individual work rates go down for the unloaders even though the total work rate is obviously going up. These factors will be input variables.

8. Calculation of the unloading time

If a ship acquires more unloaders and/or port transport, its unloading rate will increase and hence its unloading time will decrease. To alter the unloading time of the ship, several things need to be done. First of all remove the ship from the event calendar. Then find the time difference between the present simulation time and the last time the ship's unloading time was updated i.e. the last time it went through this c_activity, and multiply this time by the ship's old unloading rate to find how much cargo has been unloaded since its last update and hence calculate how much cargo still needs to be unloaded. Divide the amount of cargo still to be unloaded by the new unloading rate to find the new unloading time and then place the ship back on the events calendar.

9. Effect of the port schedule

If the port status changes to 'stops work', all unloading and loading must be temporarily halted. This will be done by removing all the relevant ships from the events calendar and storing them somewhere temporarily. When the port status changes to 'open' or 'closed to arrivals', the ships will be placed back on the events calendar.

10. Cargo size

When creating the size of the cargo shipment being carried by a ship, it is obviously necessary to check that the cargo size created is not larger than the ship can possibly carry. As the unit of cargo carried can take many forms, conversion factors need to be created so that the cargo size of the ship can be compared with the DWT of the ship. These conversion factors will be user inputs.

PORT SIMULATION MODEL

STORAGE AREA MODULE

FUNCTIONAL SPECIFICATION

Revised 10th August 1994

3.1 General

3.1.1 The flow of cargo to and from the storage area has been covered by the modelling of port transport in the Ship Unloading/Loading Module and the Inland Transportation Module.

3.1.2 When a ship is unloading it may be that the cargo is taken away immediately by inland transport, rather than being put in a storage area. In this module all cargo will be assumed to be taken to a storage area, and the possibility of cargo being taken away immediately will be dealt with in the inland transport module. Similarly for ships when they are loading.

3.1.3 In modelling terms I do not believe that the fact that there are two types of storage (namely those controlled by the port manager and those controlled by the consignee) is relevant.

3.1.4 Each cargo group will need a specific storage area, which will be a user input. See section 3.6.2.

3.1.5 All of the constraints on cargo handling specified (paragraph 1, page 4, Statement of Requirements), have been dealt with. The design of the port (un)loaders and the port transport in the Ship Unloading/Loading Module took into account plant efficiency, plant breakdown, skill of the labour force, and industrial disputes. Similarly for the land side resources designed in the Inland Transportation Module. The working hours constraint is taken care of by the port schedule for ship movements, designed in the Ship Arrival/Departure Module, and the work schedules for cargo movements, designed in the Inland Transportation Module.

While the effect of the weather was included in the Ship Arrival/Departure Module, at present this effect doesn't extend to cargo movements. There will be a user input to say which cargo groups are affected by weather. If a cargo group is affected by the weather in the movement of its cargo, (un)loading will be suspended until the end of the bad weather. The affected ships and inland transport units will lose their port equipment during spells of bad weather.

'Special needs such as segregation or special care in handling' is taken care in the previous paragraph.

3.1.6 The dwell time of a unit of cargo is defined as the time that the unit of cargo spends in storage, and will be calculated by taking the time that it left storage less the time that it entered storage. Each *stockpile* (see section 3.6.1) will be updated hourly. Cargo which has been put on the stockpile during the previous hour will be grouped together and given the same entry time i.e. a stockpile will consist of 'batches' of cargo. The batches of cargo will be ordered so that the cargo that has been there the longest will be removed first. At the end of each hour, any batch of cargo which has had some or all of its units of cargo removed will be updated. Given we know the time that the cargo was put into storage (the creation time of the batch), the present time, and the amount of cargo removed from the batch in the last hour, we can calculate a total dwell time for those units of cargo. So when a batch of cargo has been exhausted, we will be left with a total dwell time for the batch and the original size of the batch, so that we can calculate an average dwell time. An average dwell time will be calculated for each stockpile.

3.2 Transportation

3.2.1 The transportation of cargo to and from the storage area has been covered in the Ship Unloading/Loading Module and the Inland Transportation Module. See the relevant sections on port transport of the said modules' detailed designs. For the present time being it has been agreed that this method of modelling the port transport is appropriate (LMC meeting 10/2/94). See 3.5.1.

3.3 Rate of working

3.3.1 The rate of working of port transport units was designed (in the Ship Unloading/Loading Module and the Inland Transportation Module) to take account of things like stoppages, distances to storage area(s), speeds and package sizes. To give either importing or exporting ships (or inland transport units(itu)) priority, the present priority rules for acquiring port transport will need to be modified. The present priority rules are, in decreasing order of priority, the cargo group priority weighting, the amount of equipment already acquired (the ship/itu with the least has priority), and the time at which the ship berthed /itu arrived at the loading bay (the one which has been there the longest has priority). These rules will be modified so that after checking the cargo group priority weighting, there will be a check to see if the ship/itu is importing or exporting. The rules will then continue as before.

3.4 Cargo Handling Equipment

3.4.1 From the dock side of a port, cargo is brought to and taken from the storage areas by the port transport described in the Ship Unloading/Loading Module.

On the land side of a port, if a land transport unit is being serviced at a loading bay, the cargo is brought to and taken from the storage area by the land side port transport described in the Functional Specification of the Inland Transportation Module.

Cargo will be put on and taken off *stockpiles* (see section 3.6.1) by *stackers*, *reclaimers*, and *stacker/reclaimers* i.e. can do both, but only one thing at a time. This group of equipment will be known collectively as stockpile equipment. The user will specify the total numbers of stockpile equipment for the land side and dock side of the port. Attributes for the stockpile equipment will be similar to those of the port unloaders and port loaders in the Ship Unloading/Loading Module.

3.5 Distance

3.5.1 The port transport which has been designed in the Ship Unloading/Loading Module (and the Inland Transportation Module) is given an 'effective rate' in cargo units per hour. This work rate was designed so that it takes into account the distance the port transport has to travel between the quay (or loading bay) and the storage area. So for example if two units of port transport with the same capacity have different distances to travel for each journey they make, the one with the longer journey would be given a lower 'effective rate'. Package size and speed of port transport units are also covered by the 'effective rate' of the unit. For the present time being it has been agreed that this method of modelling the port transport is appropriate (LMC meeting 10/2/94). The possibility of having port transport whose work rates are based partly on the distances they have to travel between quayside (or loading bay) and the relevant storage area, will be considered at a later date, after the first version of the complete port simulation model has been finished.

3.6 Storage Areas

3.6.1 An import stockpile will consist of cargo brought in by ship. An export stockpile will consist of cargo to be taken away by ship. Cargo put on the import stockpile will either be taken away by inland transport, or will be transferred to the export stockpile so that it can be taken away by ship i.e. transhipment. Cargo to be put on the export stockpile will either come from inland transport or from the import stockpile. The proportion of cargo to be transferred from the import stockpile to the export stockpile will be a user defined input.

3.6.2 The size (area), height, and amounts of lost space of the storage area(s) can all be taken account of when defining the capacity of the storage area(s). The storage area of imported and exported cargo for each cargo group will be known as *stockpiles* and will be segregated. The capacity of each stockpile will be a user defined input.

3.6.3 When a stockpile for a particular cargo type is full, unloading on all ships/itus using that stockpile will stop, and all the port equipment which has been acquired will be released. When space becomes available on the relevant stockpile, the ship/itu will rejoin the 'queue' of ships/itus waiting for port equipment. The same priority rules as in the Ship Unloading/Loading Module (and the Inland Transportation Module) will be applied. These priority rules are, in decreasing order of priority, the cargo group priority weighting, the amount of equipment already acquired (the ship/itu with the least has priority), and the time at which the ship berthed/itu arrived at the loading bay (the one which has been there the longest has priority).

The status of the stockpiles will be updated every hour, so as soon as there is enough room to store one hours worth of cargo from all the ships/itus working at the stockpile, unloading will be allowed to continue. Similarly for loading ships/itus affected by the relevant stockpile being empty.

4. Output

4.1 The utilization of port transport and port equipment was covered in the Ship Unloading/Loading Module and the Inland Transportation Module.

4.2 The utilization of each stockpile in terms of cargo units and percentage full with time will be done. The average dwell times of cargo in each stockpile will also be done.

Matthew Winn

PORT SIMULATION MODEL

STORAGE AREA MODULE

DETAILED DESIGN

Revised 10th August 1994

3.1 General

3.1.1 - 3.1.4 There is nothing to be modelled in this module within these sections.

3.1.5 The weather will consist of six states. State one will be the 'good weather' state when all port operations will continue unaffected. States two to six will be 'bad weather' states, which will affect one or more of the cargo types. The idea of having five 'bad weather' states is so that it is possible, if necessary, to have state two affecting cargo type one say, state three affecting cargo types one and two say, and so on.

There will be an input table (six by six in size) to allow the user to input the transition probabilities of going from one state to another, and there will be one input table for each of the six weather states to let the user input a distribution type (choice of six) and relevant parameters in order to calculate lengths of periods of weather when in the said state. There will also be one input table for each cargo type to let the user say which of the six states affect the movement of the relevant cargo type e.g. states 1 - 4 may be good weather states for cargo type one but only states 1 - 2 may be good weather states for cargo type two.

If the user doesn't require six weather states then just set the transition probabilities of going into the unneeded states to be zero.

So a weather state will be chosen based on the transition probabilities, which in turn may depend on the weather's present state. Having selected a weather state, the length of the period of weather will be calculated based on the state's distribution and parameters. When the end of the period of weather is reached the whole process is repeated.

If for a particular cargo type the weather goes from being in a state where cargo movement was allowed to a state where cargo movement isn't allowed, then the relevant stockpiles are updated and their inflow and outflow rates set to zero. Also, the affected ships and inland transport units will release all their acquired resources. The affected ships and inland transport units will then wait for the weather to enter a state which will allow work re-start. When the weather enters such a state, the ships and inland transport units will be allowed to try and re-acquire resources, in order to continue unloading/loading and hence cargo will start to flow through the relevant stockpiles again.

3.1.6 See section 3.6.

3.2 Transportation

3.2.1 There is nothing to be modelled in this module within this section.

3.3 Rate of working

3.3.1 For each cargo group there will be an input table to allow the user to give ships (or inland transport units) which are importing, priority in acquisition of resources over exporting ships, and vice versa.

3.4 Cargo Handling Equipment

3.4.1 The stockpile equipment described in this section in the functional specification are to be modelled in the Inland Transportation Module, and in the Ship Unloading/Loading Module.

3.5 Distance

3.5.1 There is nothing to be modelled in this module within this section.

3.6 Storage Areas

Please note that due to the large number of points to be explained on storage areas, the section headings for this part of the detailed design do not correspond to the section headings of the same part of the functional specification.

3.6.1 For each cargo group there will be an input table which allows the user to give the proportions of imported cargo that will be put on the relevant import stockpile and the proportions of imported cargo that will be put on the relevant export stockpile i.e. transhipment. Each ship that is importing cargo will then spend the relevant proportion of time unloading onto the import stockpile, and the relevant proportion of time unloading onto the export stockpile. This overrides anything previously stated.

3.6.2 There will be a stockpile TYPE with the following attributes

- inflow rate - sum of the work rates of equipment unloading on to it at any particular time.
- outflow rate - sum of the work rates of equipment loading from it at any particular time.
- total capacity.

- present size.
- total dwell time.
- total complete throughput - doesn't include cargo still on the stockpile.
- queue of batches of cargo.
- a number of Boolean variables to trigger off changes in state, such as a change in the stockpiles inflow or outflow rate.

Each batch of cargo will be an ENTITY with the following attributes

- initial size.
- present size.
- creation time.
- total dwell time.
- amount removed in the last hour.

It may become appropriate to create more attributes at the time of coding, particularly internal variables. However all the main attributes are listed above.

3.6.3 An input table will be created to allow the user to define the initial size and total capacity, in units of cargo, of each stockpile.

3.6.4 There will be a b_activity which will be called at the start of every simulation hour. The b_activity will have three main purposes. For each of the stockpiles it will

(1) calculate the size of the batch created in the last hour, and give it its creation time (see section 3.6.6). The batch will then be put at the back of the 'queue' of batches for that stockpile.

(2) calculate the amount of cargo that has been removed from the stockpile in the last hour. This 'amount of cargo' will be taken off the front of the 'queue' of batches for the stockpile. If one or more batches are completely used up in making up the 'amount of cargo', the relevant stockpile statistics can be updated.

(3) ensure that it is okay to continue (un)loading at the stockpile. For unloading to continue at a particular stockpile there needs to be enough room on the stockpile to put an amount of cargo equivalent to the difference between the inflow rate and the outflow rate over one hour (the flow rates are already in cargo units per hour). Conversely for loading.

If it is not okay to continue (un)loading at a particular stockpile, all the ships (or inland transport units) using the stockpile must cease (un)loading, and release all their resources i.e. the (un)loaders, the port transport, and the stockpile equipment. The affected ships (or inland transport units) will be removed from the calendar, and the affected flow rate of the relevant stockpile will be re-set to zero. Boolean variables will be triggered to declare that the affected stockpile has had (un)loading at it suspended. These booleans will be used to prevent the ships and/or inland transport units from re-acquiring resources until it is declared that it is okay to re-start (un)loading at the stockpile. To clarify, there will be for each stockpile a check to see if it is okay to continue unloading, and a check to see if it is okay to continue loading. Therefore it is possible, as a result of the checks, that neither, both or either of the above activities may be suspended.

When it is found that (un)loading at a stockpile, which has had its (un)loading suspended, can re-start, the stockpile 'work suspended' boolean will be de-activated and the affected ships and inland transport units will be able to attempt to re-acquire resources, in order to continue unloading/loading and hence cargo will start to flow through the relevant stockpile(s) again.

3.6.5 There will be a c_activity which will be called whenever the inflow rate or the outflow rate of any of the stockpiles changes. A change in the flow rates may occur due to

- a ship (or inland transport unit) may start or re-start (un)loading.
- a ship (or inland transport unit) may stop (due to, the weather, the relevant port schedule, or the constraints of the stockpile coming into affect) or finish (un)loading.
- a ship (or inland transport unit) may acquire more resources and hence increase its work rate.

The purpose of the c_activity will be to

- calculate the amount of inflow so far in the present hour - the provisional batch size (also see section 3.6.6).
- calculate the amount of outflow so far in the present hour - the outward provisional batch size (also see section 3.6.6).
- take the time that the c_activity was called.
- calculate the new inflow and outflow rates.
- check that it is okay to continue (un)loading for the rest of the hour with the new flow rates.

3.6.6 Calculation of batch size (for the inward batch and the outward batch):

[(present time - time flow rate last updated) * present flow rate]
+ any provisional batch size.

If the calculation is taking place in the b_activity:

- the 'present time' will be the end of the hour.
- if no changes to the flow rate occurred during the last hour i.e. the c_activity wasn't called, the 'time flow rate last updated' will be the start of the hour, and the 'provisional batch size' will be zero.

- if one or more changes to the flow rate did occur during the last hour the 'time flow rate last updated' will be the time that the c_activity was last called, and the 'provisional batch size' will be the amount of cargo moved up to the time of the last change in the flow rate.

If the calculation is taking place in the c_activity:

- the 'present time' will be the present simulation time, and can be any time within the hour.
- if this is the first time the c_activity has been called since the start of the hour, the 'time flow rate last updated' will be the time that the b_activity was called, and the 'provisional batch size' will be zero.
- if this is not the first time the c_activity has been called since the start of the hour, the 'time flow rate last updated' will be the time that the c_activity was last called, and the 'provisional batch size' will be the provisional batch size created the last time the c_activity was called.

4. Output

4.1 There is nothing to be modelled within this section.

4.2 There will be a text screen to show, for each of the ten stockpiles,

- the average dwell times up to the present simulation time.
- the percentage full at the present simulation time.
- the amount of cargo on the stockpile at the present simulation time.

Matthew Winn.

PORT SIMULATION MODEL

LAND TRANSPORTATION MODULE

FUNCTIONAL SPECIFICATION

Revised 10th August 1994

3.1 General

3.1.1 On the dock side of a port the ships that arrive can be in one of five ship cargo groups. These five ship cargo groups each carry one of the five cargo types. On the land side of the port it will be possible to have upto four *inland transport cargo groups* for each cargo type i.e. upto twenty inland transport cargo groups.

The four inland transport cargo groups for a particular cargo type are to take into account the four cases that can occur. These are

(A) inland transport is serviced at a loading bay.

(B) inland transport is serviced at a stockpile.

(C) inland transport is serviced at a quayside.

(D) inland transport is a pipeline.

It will be upto the user to decide how many of the inland transport cargo groups are needed for each cargo type. For example if the cargo type is containers cases A, B, and C may be applicable, however case D obviously isn't.

3.1.2 Each inland transport group will be given attributes. The attributes for groups belonging to cases A, B and C will be

- cargo type.
- an arrival distribution with the relevant parameters.
- a cargo size distribution with the relevant parameters, plus an upper and lower limit.
- trading status proportions.
- service distributions for the entry gates, on arrival and departure.
- delay distributions for the pre - unloading delay, the pre - loading delay, and the pre - departure delay.
- maximum number of (un)loaders allowed per unit (not case B).
- multiple unloader factors and multiple loader factors.

I do not believe that the generation of a size distribution is necessary for inland transport. The only reason a size distribution is created for the ship cargo groups is so that a draught can be calculated which can be compared with the tide level.

The attributes for case D will be

- number of units in the group.
- where located.
- effective rate of each unit.
- efficiency level of each unit.
- trading status of the unit.

3.2 Cargo Allocation

3.2.1 All the points raised in this section have been covered in section 3.1.

3.3 Arrival Scheduling

3.3.1 The cargo type to be carried by a particular inland transport unit will be defined by which inland transport cargo group it is in. Package size and variation will be defined by the inland transport cargo group's cargo size distribution, and frequency of arrivals will be defined by the inland transport cargo group's arrival distribution, both of which are discussed in section 3.1.2. Seasonal variation in demand can be done by allowing the user to vary the arrival rate over the year.

3.3.2 Pipelines are case D from section 3.1.1. Pipelines don't really interact much with the rest of the port, and the only information one can obtain from this module is the throughput of the cargo type.

3.4 Loading/Unloading

3.4.1 Cargo will be put on and taken off stockpiles by *stackers*, *reclaimers*, and *stacker/reclaimers* i.e. can do both, but only one thing at a time. This group of equipment will be known collectively as stockpile equipment. The user will specify the total number of stockpile equipment for the land side of the port. Attributes for the stockpile equipment will be similar to those of the port unloaders and port loaders in the Ship Unloading/Loading Module.

3.4.2 If a land transport unit is being serviced at a loading bay, the transfer of cargo on and off the unit will be done by *land side unloaders* and *land side loaders*. These land side unloaders and loaders will be modelled as the port unloaders and port loaders were modelled in the Ship Unloading/Loading Module.

3.4.3 If a land transport unit is being serviced at a loading bay, the transfer of cargo from the loading bay to the relevant stockpile will by done by *land side port* *transport*. Each inland transport group will have its own group of land side port transport. The land side port transport groups will be modelled as the port transport groups were modelled in the Ship Unloading/Loading Module.

3.4.4 If the inland transport unit is to be serviced at a loading bay (section 3.1.1 case A), the following resources will be needed:

- a suitable loading bay.
- land side unloaders/loaders.
- land side port transport.
- stockpile equipment.

All of the equipment resources will need to be set up by the user to reflect how they work in real life within the relevant port.

In this case, the rate at which the unit of inland transport is serviced will be

MIN (sum of unit's (un)loaders work rates, sum of unit's port transport work rates, sum of unit's stockpile equipment work rates).

For example,

sum of unit's (un)loaders work rates = 2000 tonnes/hr.
sum of unit's port transport work rates = 1800 tonnes/hr.
sum of unit's stockpile equipment work rates = 1000 tonnes/hr.

In this case the unit would be serviced at 1000 tonnes/hr.

3.4.5 If the inland transport unit is to be serviced at a stockpile (section 3.1.1, case B), only stockpile equipment will be needed. The rate at which the unit of inland transport is serviced will depend on the rates of the stockpile equipment working on it. Therefore the user needs to negate the effect of the other land side resources within the model. To do this the user will set up the relevant land side port transport group with very high work rates, and a large number of units. Enough dummy loading bays need to be set up so that a unit is never left waiting for one. Finally, dummy (un)loaders need to be set up with very high work rates. Doing all this will ensure that an inland transport unit never has to wait for one of the dummy resources, and that the constraint on the service rate will be the sum of the rates of the stockpile equipment working on it. All of the above will be explained in the Port Simulation Model User Manual.

3.4.6 If the inland transport is to be serviced at the quayside (section 3.1.1, case C), only port unloaders/loaders will be needed. This case will be done by having specific coding for the inland transport groups whose units go directly to the quayside to be serviced. The rate at which the unit of inland transport is serviced will be the sum of the rates of the port unloaders/loaders working on it.

3.4.7 If the inland transport is a pipeline (section 3.1.1, case D) a 'local' pipeline will be needed to connect the main pipeline to the storage tank. This 'local' pipeline is equivalent in modelling terms to stockpile equipment. This option will also be hard coded so that only stockpile equipment is acquired. This option also needs to be hard coded due to the fact that the attributes of the pipelines are completely different from the other cases (see section 3.1.2).

3.4.8 Schedules will be created for each cargo type, to say when individual cargo types can be worked on. It is assumed that the land side and quay side schedules for a particular cargo type are the same.

3.4.9 The loading bays where many of the inland transport units will be serviced, will be modelled based solely on cargo type. The priority rules, as requested, will be FCFS. Only one inland transport unit will be allowed to occupy a loading bay at any one time.

3.4.10 Delays to inland transport units will occur

- while being serviced at the entry gates on entering and leaving the port.
- before being allowed to unload cargo.
- before being allowed to load cargo.
- before being allowed to leave the service area.

Delays will be based on cargo type, and a choice of distribution will be on offer to the user.

4. Output

4.1 There will be time series graphs to show

- queue length of arriving land transport units at each gate.
- queue length of departing land transport units at each gate.
- queue length for the loading bays.

4.2 There will be histograms to show the utilization ('amounts used') of the land side port transport groups. There will be one histogram for each group. There will also be a histogram to show the utilization ('amounts used') of the loading bays.

4.3 There will be tables to show the utilization and throughput of

- each of the land side port unloaders.
- each of the land side port loaders.
- each unit of land side stockpile equipment.

4.4 There will be an output screen showing average waiting times of land transport units, by cargo type, for arrivals and departures at the entry gates.

4.5 There will be an output screen showing the throughput of cargo, and number of calls, for land transport units, by cargo type and trading status.

4.6 There will be output to show average service times by cargo type.

Matthew Winn.

PORT SIMULATION MODEL

INLAND TRANSPORTATION MODULE

DETAILED DESIGN

Revised 10th August 1994

3.1 General

3.1.1 There will be an input table for each cargo type consisting of four check boxes, one for each of the four inland transport cargo groups representing the four possible cases mentioned in the functional specification. The check boxes will allow the user to turn the inland transport cargo groups on and off. For example if the cargo type in question is coal say, the user may require the inland transport cargo groups representing cases A, B, and C to be turned on, and the inland transport cargo group representing case D to be turned off.

A list of the B and C activities for each of the four cases can be found in Appendix A, and the flow charts for the four cases can be found in Appendix B (see 14th April version for appendices).

3.1.2 The user will be able to select appropriate attributes for the inland transport cargo groups through a series of input boxes. For cases A, B, and C these will be as follows:

- for the arrival distribution there will be an input box offering the user a choice of six mathematical distributions, namely the Negative exponential, the Erlang, the Poisson, the Uniform, the Constant, and the Weibull. Having selected a distribution the user will have to input the appropriate parameters for the chosen distribution. For the Negative exponential and the Poisson this is a mean, for the Erlang these are the mean and 'k' (the Erlang is the sum of 'k' Negative exponential variates e.g. if $k = 1$ one will have the Negative exponential distribution itself), for the Uniform these are an upper and lower limit, for the Constant this is the actual interval at which the inland transport units will arrive apart by, and for the Weibull these are the scale and shape factors.
- for the cargo size distribution there will be an input box offering the user a choice of mathematical distribution. These distributions will be as described above for the arrival distribution, with the extra requirement that if an upper and lower limit haven't been specified (all distributions except the Uniform) they need to be.
- there will be an input table allowing the user to specify the proportion of the inland transport cargo group to be 'import only' and the proportion to be 'export only', and the difference will be the proportion which imports and exports.

- there will be two input tables for each entry gate, to allow the user to input the service distribution for arriving inland transport units and the service distribution for departing inland transport units. The service distributions on offer will be as the arrival distributions described above.
- there will be an input table for each of the delays, again offering the same distributions as for the arrival distributions.
- the tables for the maximum number of land side unloaders and for the maximum number of land side loaders that each inland transport unit is allowed will be similar to the ones created for the ships in the Ship Unloading/Loading Module. The maximum number will again depend on the cargo type and which cargo size band the inland transport unit belongs to. However, there will be a new set of cargo size bands for inland transport units, as we are talking about a completely different size scale than when doing cargo size bands for the ships.
- there will be one input table for the multiple unloader factors and one input table for the multiple loader factors. Each unloader has a work rate in cargo units per hour. When more than one unloaders are working together on a particular inland transport unit it may be that their overall work rate is less than the sum of their individual work rates i.e. the unloaders individual efficiency may go down when the number of unloaders is increased. The multiple unloader factor table lets the user input factors between 0 and 1 which are then multiplied by the sum of the unloader's individual work rates to give an overall work rate. Similarly for the multiple loader factor table.

For case D there will be an input table which will allow the user to specify the total number of pipelines located at the port. There will then be input tables to allow the user to give each pipeline its attributes. The attributes of the pipeline will be:

- the stockpiles that the pipeline can deliver cargo to or receive cargo from.
- the effective flow rate, in cargo units per hour.
- the efficiency level, as a percentage of time that the pipeline will be operational.
- whether the pipeline is delivering cargo to the port (i.e. exporting), or whether the pipeline is receiving cargo from the port (i.e. importing).

3.2 Cargo Allocation

3.2.1 See section 3.1

3.3 Arrival Scheduling

3.3.1 See section 3.1.2.

3.3.2 See section 3.1.2.

3.4 Loading/Unloading

3.4.1 The user will be able to specify the total number of stockpile equipment for the land side of the port. Having stated the desired total number, the user will then be able to set up the attributes for each unit of stockpile equipment individually. These attributes will be:

- whether the unit is a stacker, a reclaimer, or a stacker/reclaimer.
- which of the five cargo types the unit can work on.
- the effective rate: the average work rate of the piece of equipment, in cargo units per hour.
- the efficiency level: the percentage of time that the piece of equipment is operational.
- the final work rate: this will be the effective rate multiplied by the efficiency level.

3.4.2 There will be input tables allowing the user to specify the total number of land side unloaders, and land side loaders. There will then be input tables allowing the user to specify the attributes for each unit of equipment. The attributes for each unit of equipment will be (not all of which are directly input variables):
- which cargo types the unit can work on.
- the effective rate (see section 3.4.1), for each cargo type.
- the efficiency level (see section 3.4.1), for each cargo type.
- the final rate (see section 3.4.1), for each cargo type.
- the present final rate, which will depend on which cargo type is being worked on.

3.4.3 There will be input tables to allow the user to specify for each land side port transport group:
- the total number of units in the group.
- the effective rate (in cargo units per hour) of a unit within the group.
- the efficiency level (as a percentage) of a unit within the group.

There will be one input table for each land side port transport group.

3.4.4 See sections 3.4.1, 3.4.2, 3.4.3, and 3.1.1.

3.4.5 See section 3.1.1.

3.4.6 See section 3.1.1.

3.4.7 See section 3.1.1.

3.4.8 There will be an input table for each cargo type to allow the user to define a schedule for when the relevant cargo type can be worked on. For each day of the week the user will have to say what time of the day work may commence, and what time of day work must cease, the times being based on the twenty four hour clock. So for example if the port works twenty four hours a day, set the work commencement time to 0:00 and the work ceasing time to 24:00. If the port doesn't work at all on a particular day set the work commencement time to be the same as the work ceasing time. The program will be set up to always ignore zero time durations in the schedule. It should be noted that if the user requires a change of state part way through the hour, the minutes part should be inputted as a fraction of the hour e.g. 23:30 should be inputted as 23.50.

For each of the work schedules there are two possible states, namely 'work allowed' and 'work not allowed'. If the work schedule state changes from 'work allowed' to 'work not allowed' then the relevant stockpiles are updated and their inflow and outflow rates are set to zero. Also all the affected ships and inland transport units will release all their acquired resources. The ships and inland transport units will then wait for work to be allowed to re-start. When the state changes from 'work not allowed' to 'work allowed' the ships and inland transport units will be allowed to try and re-acquire resources, in order to continue unloading/loading and hence cargo will start to flow through the relevant stockpiles again.

3.4.9 There will be an input table allowing the user to specify the total number of loading bays for each of the cargo types. An inland transport unit will then try and acquire a loading bay which is suitable and available. An inland transport unit will visit one and only one loading bay.

3.4.10 See section 3.1.2.

4. Output

4.1 There will be time series graphs to show

- queue length of arriving land transport units at each gate.
- queue length of departing land transport units at each gate.
- queue length for the loading bays.

4.2 There will be histograms to show the utilization ('amounts used') of the land side port transport groups. There will be one histogram for each group. There will also be a histogram to show the utilization ('amounts used') of the loading bays.

4.3 There will be tables to show the utilization and throughput of

- each of the land side port unloaders.
- each of the land side port loaders.
- each unit of land side stockpile equipment.

4.4 There will be an output screen showing average waiting times of land transport units, by cargo type, for arrivals and departures at the entry gates.

4.5 There will be an output screen showing the throughput of cargo, and number of calls, for land transport units, by cargo type and trading status.

4.6 There will be output to show average service times by cargo type.

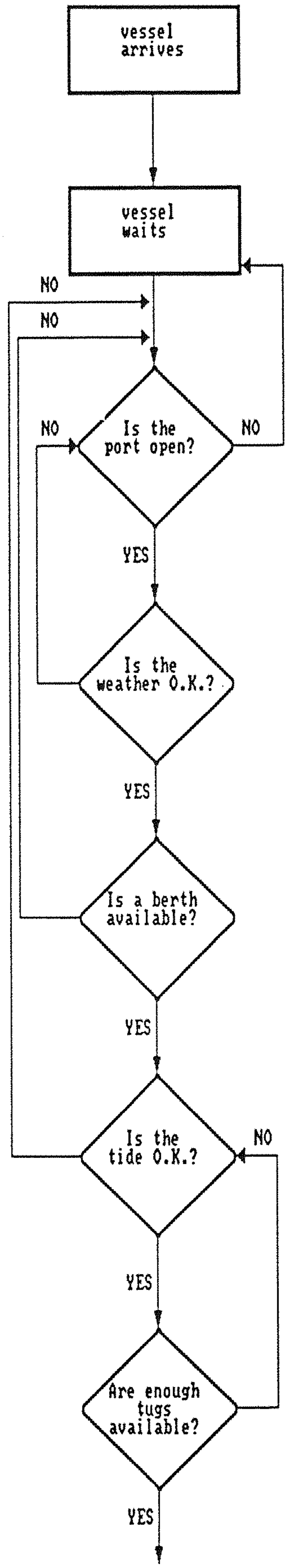
Matthew Winn.

APPENDIX C

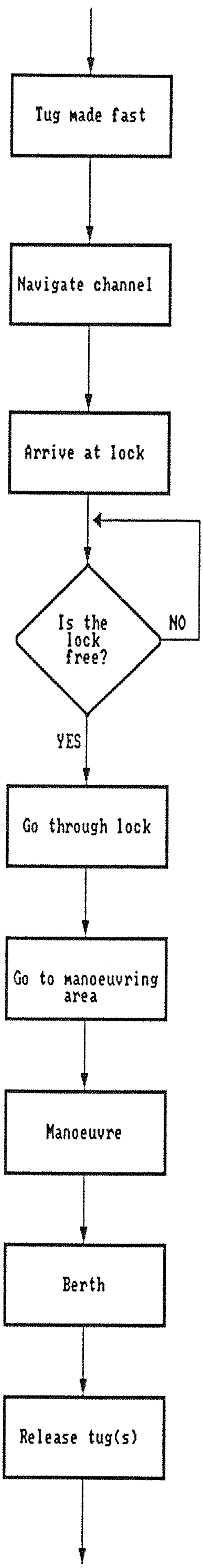
FLOW CHARTS OF THE PORT SYSTEM

FLOW CHARTS OF THE PORT SYSTEM

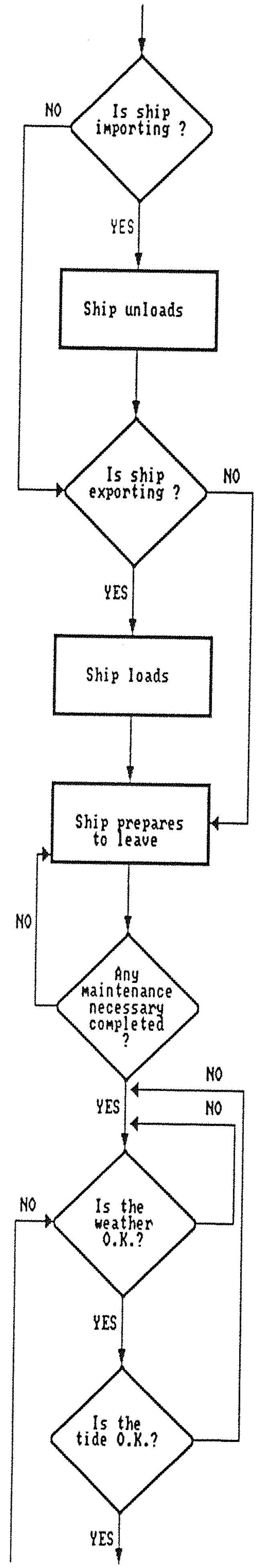
This appendix contains flow charts of the port system modelled. The port system has been split into three parts, namely, ship arrivals and departures, ship unloading and loading, and, inland transport.



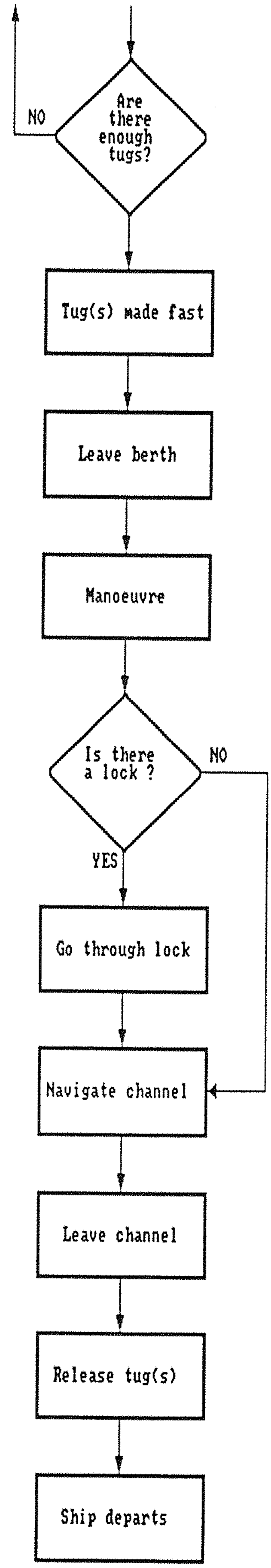
Ship arrivals and departures flow chart page 1



Ship arrivals and departures flow chart page 2

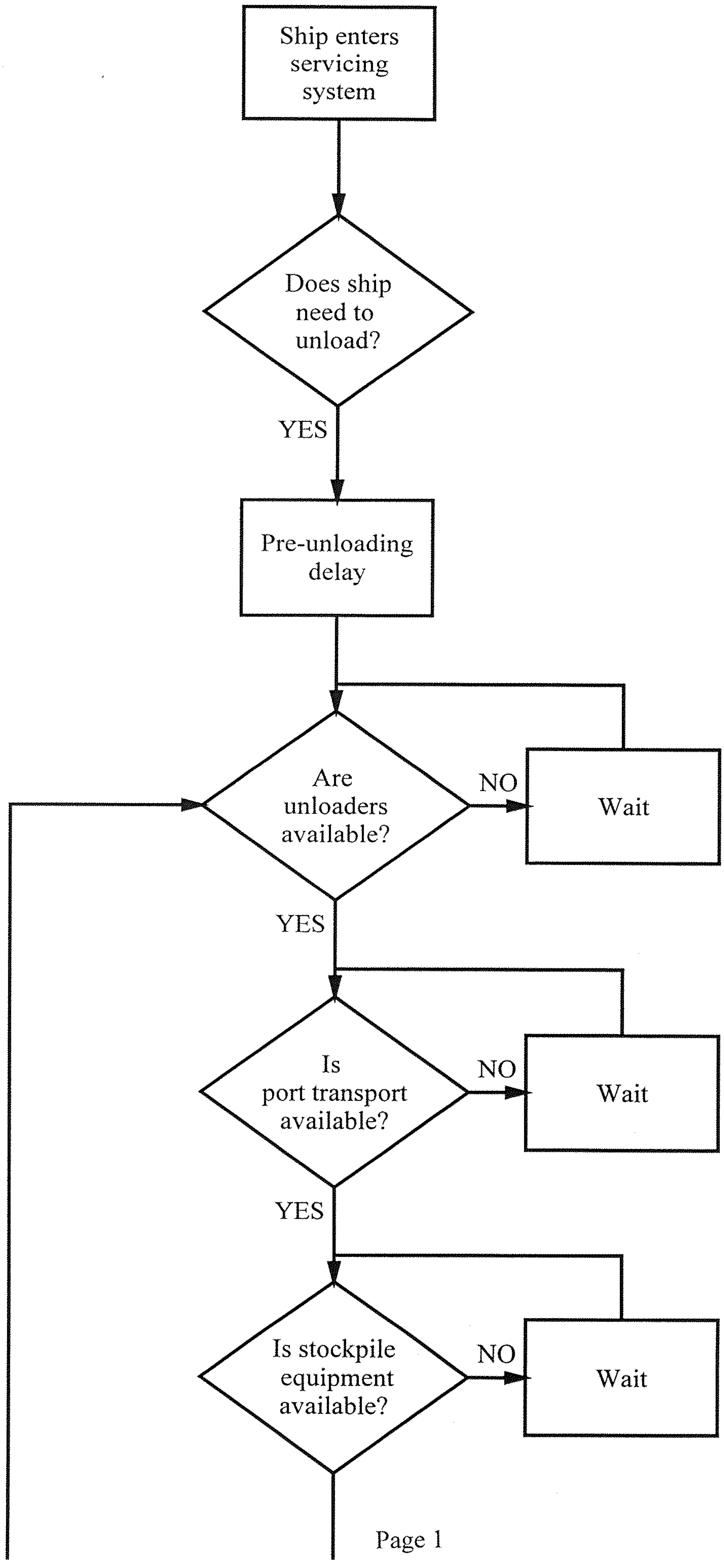


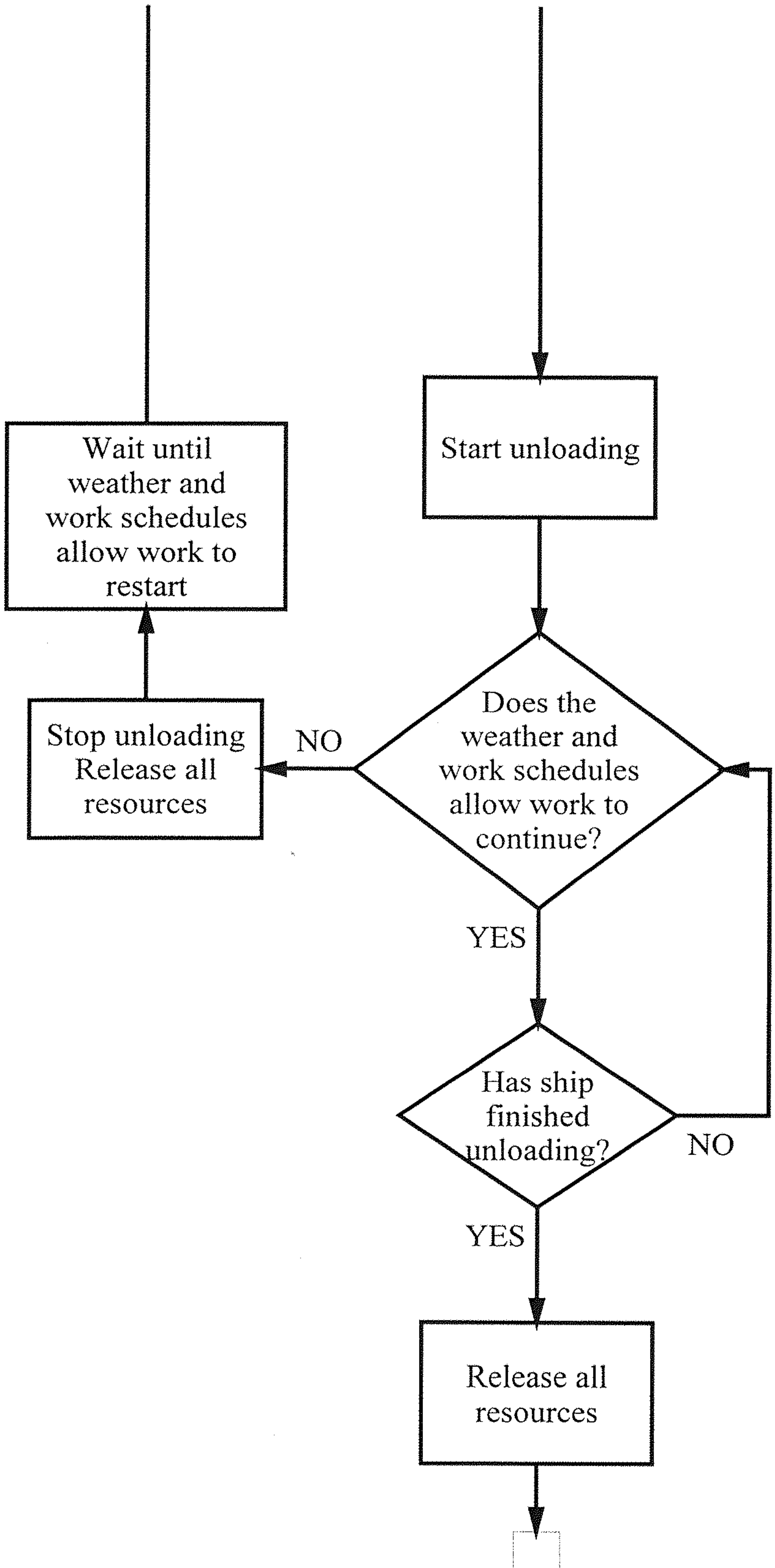
Ship arrivals and departures flow chart page 3

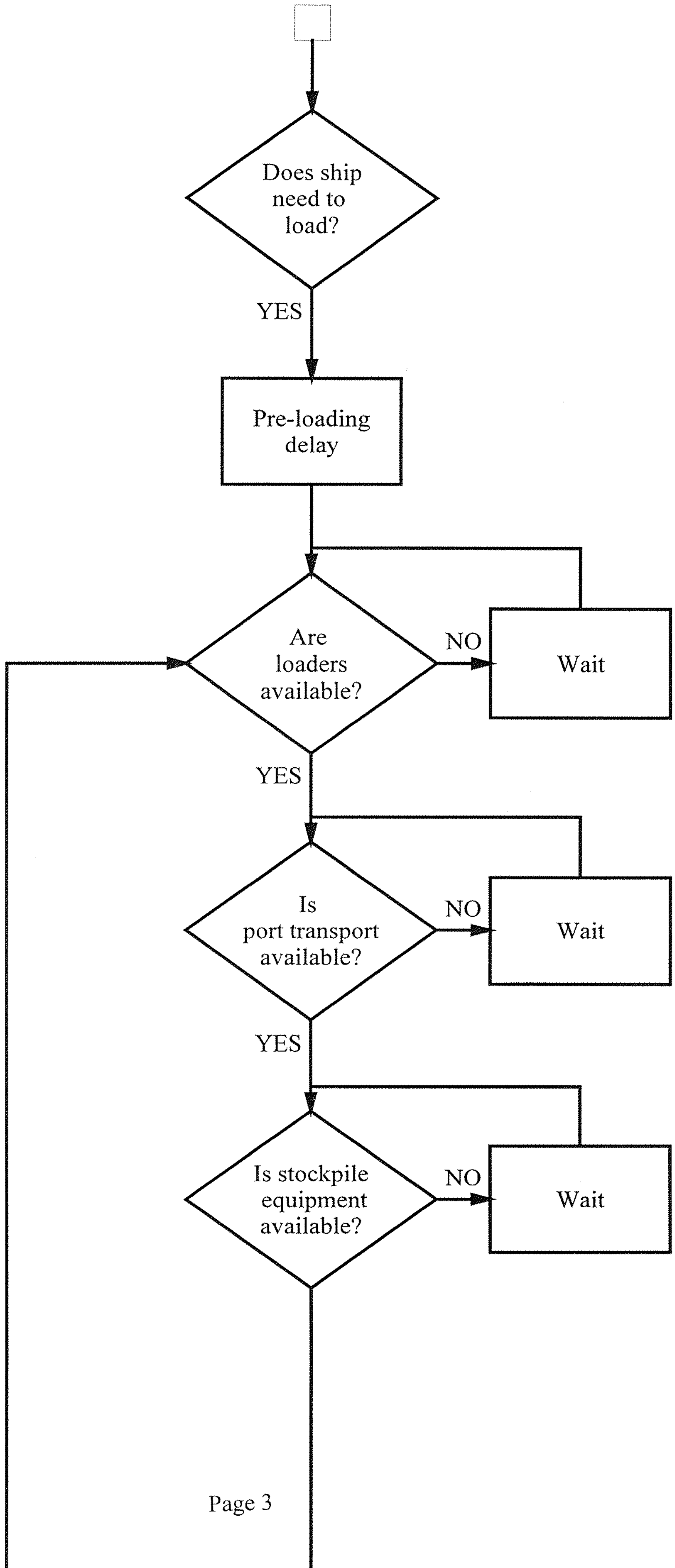


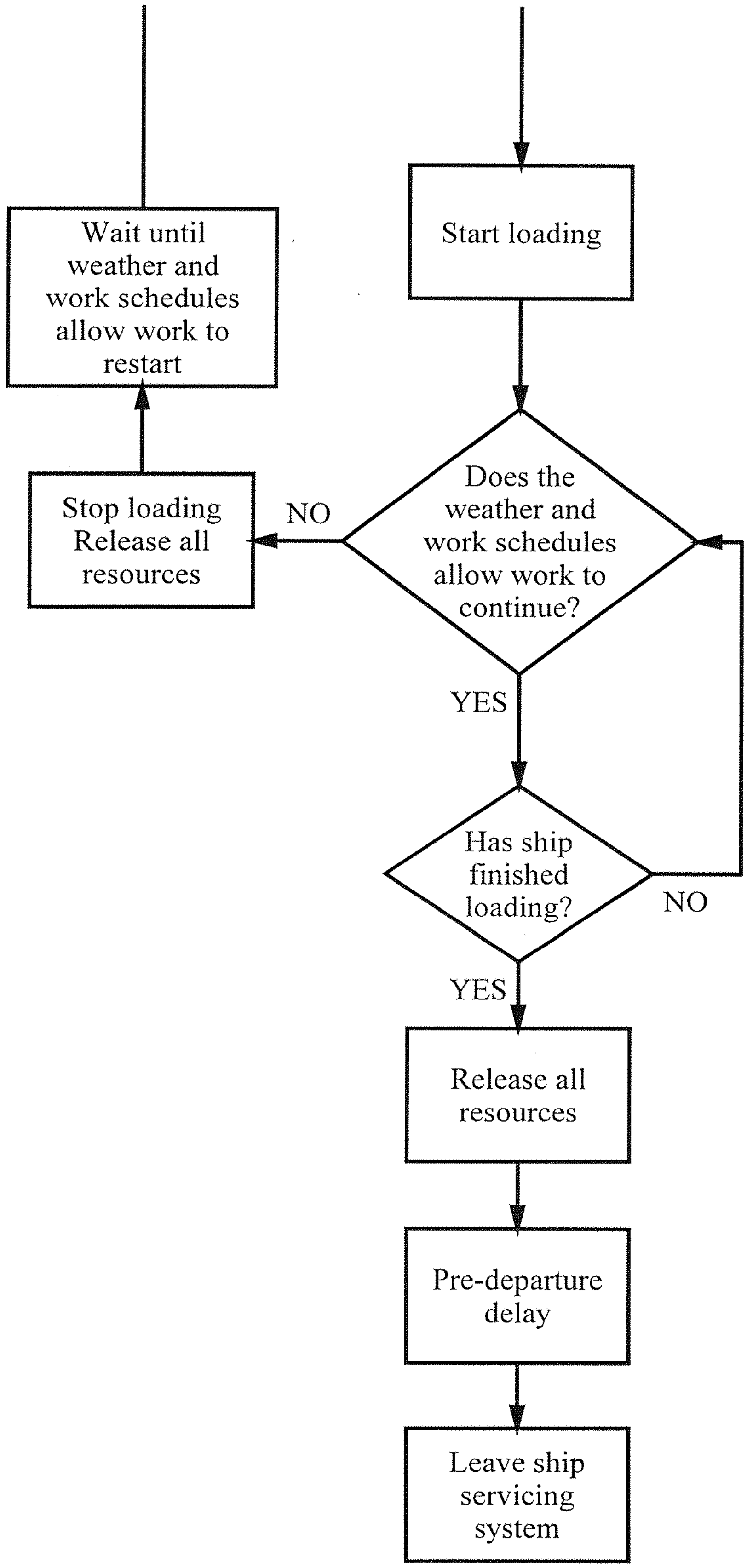
Ship arrivals and departures flow chart page 4

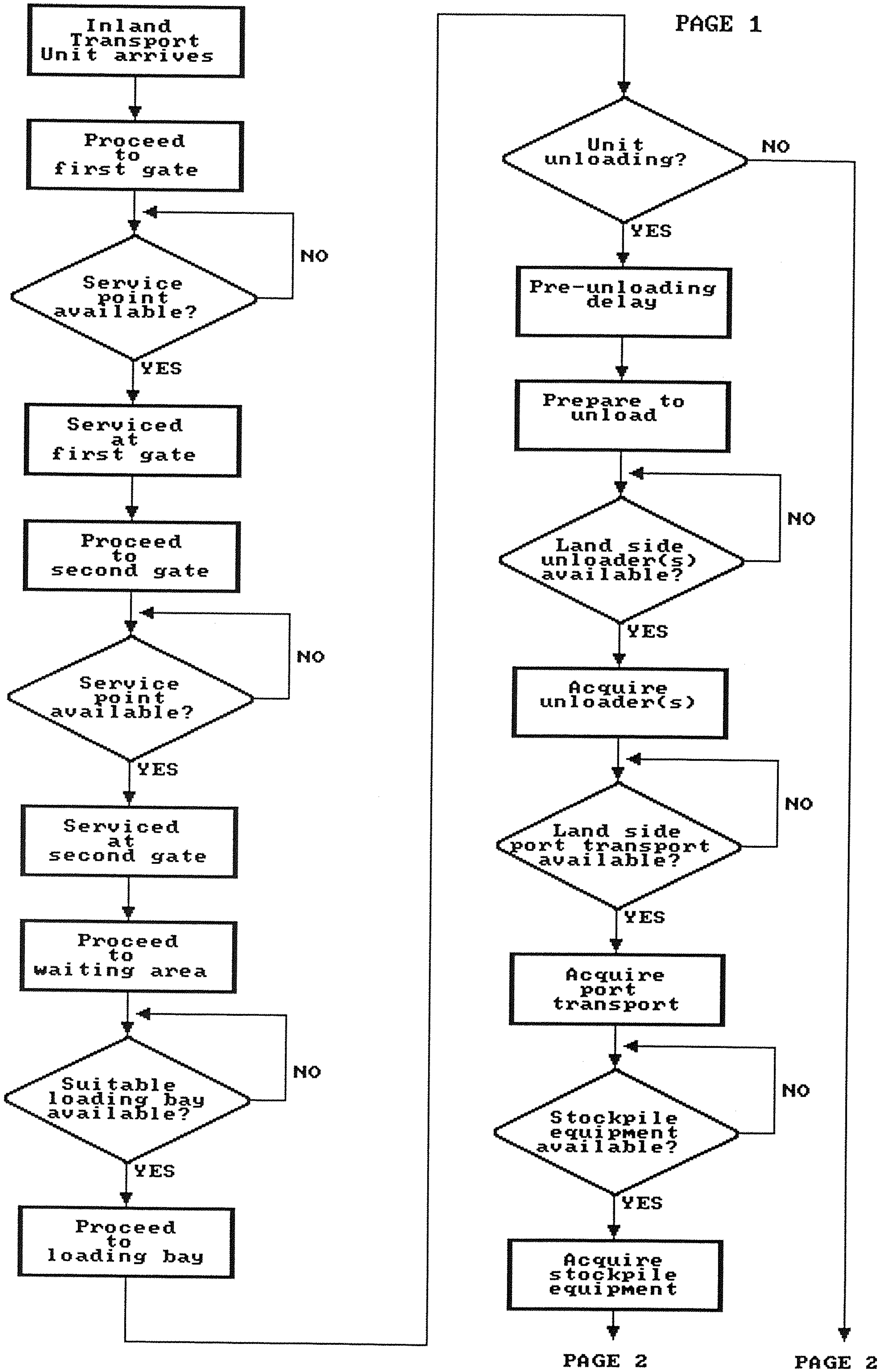
Ship Unloading and Loading System Flow Chart

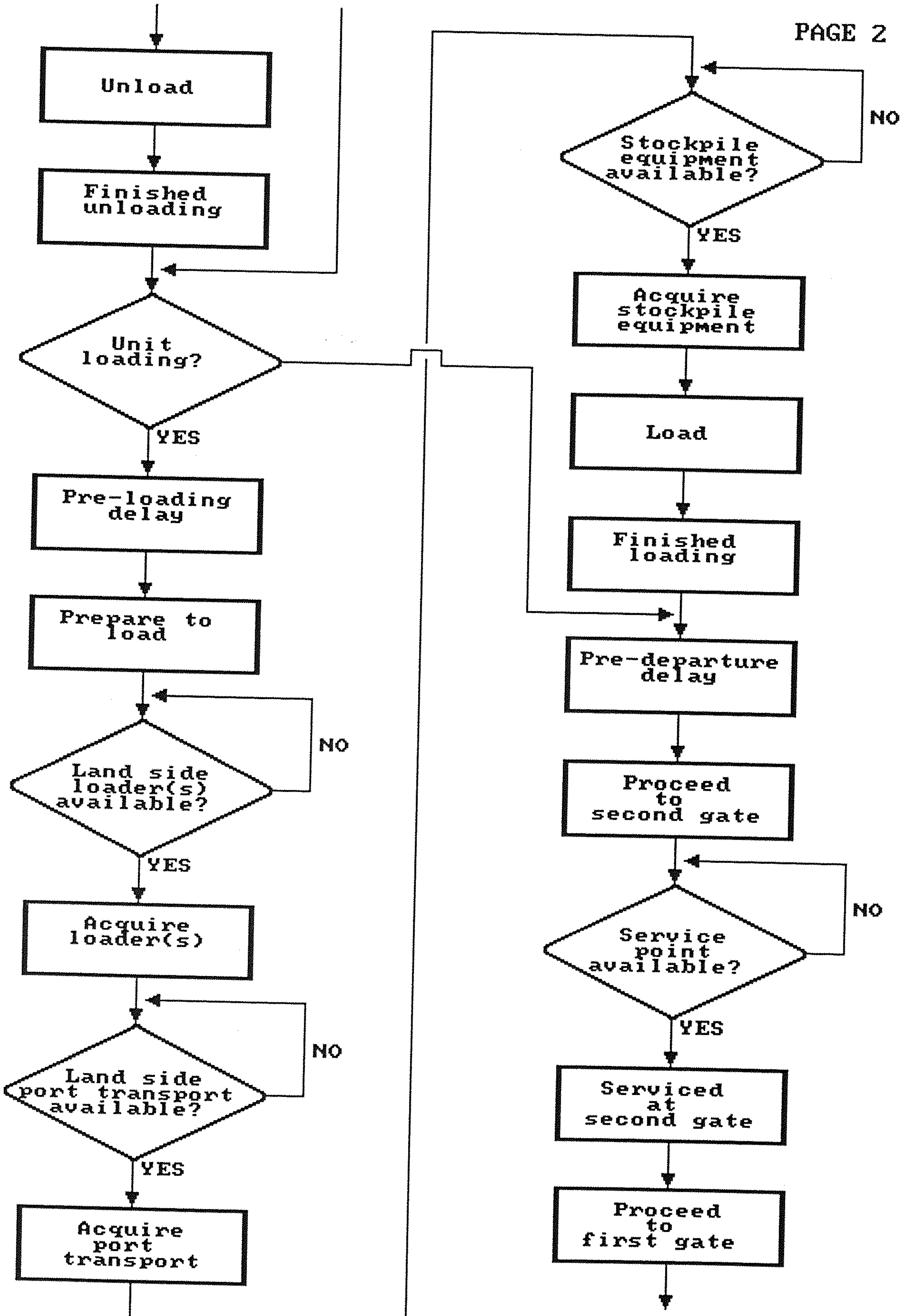



Wait until weather and work schedules allow work to restart
Start unloading
Stop unloading Release all resources
NO
Does the weather and work schedules allow work to continue?
YES
Has ship finished unloading?
NO
YES
Release all resources

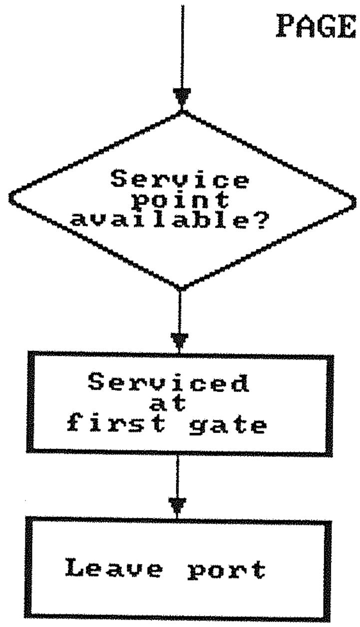

Does ship need to load?
YES
Pre-loading delay
Are loaders available?
NO
Wait
YES
Is port transport available?
NO
Wait
YES
Is stockpile equipment available?
NO
Wait


Wait until weather and work schedules allow work to restart
Start loading
Stop loading Release all resources
NO
Does the weather and work schedules allow work to continue?
YES
Has ship finished loading?
NO
YES
Release all resources
Pre-departure delay
Leave ship servicing system


Inland Transport Unit arrives
Proceed to first gate
Service point available?
NO
YES
Serviced at first gate
Proceed to second gate
Service point available?
NO
YES
Serviced at second gate
Proceed to waiting area
Suitable loading bay available?
NO
YES
Proceed to loading bay
Unit unloading?
NO
YES
Pre-unloading delay
Prepare to unload
Land side unloader(s) available?
NO
YES
Acquire unloader(s)
Land side port transport available?
NO
YES
Acquire port transport
Stockpile equipment available?
NO
YES
Acquire stockpile equipment
PAGE 2
PAGE 2


Unload
Finished unloading
Unit loading?
YES
Pre-loading delay
Prepare to load
Land side loader(s) available?
NO
YES
Acquire loader(s)
Land side port transport available?
NO
YES
Acquire port transport
Stockpile equipment available?
NO
YES
Acquire stockpile equipment
Load
Finished loading
Pre-departure delay
Proceed to second gate
Service point available?
NO
YES
Serviced at second gate
Proceed to first gate

PAGE 3


Service point available?
Serviced at first gate
Leave port

APPENDIX D

ENTITY ATTRIBUTES

ENTITY ATTRIBUTES

This appendix contains a listing of the attributes of the entities within the model, namely the ships, the cargo, and the land transport units. Not all types of entity use all of the attributes listed below. All of the attributes have been set up in one Borland Pascal for Windows Object. The only purpose of this appendix is to give the reader an idea of how complex the entities within the model are. Most of the names of the attributes imply the purpose of the attribute. Where the name doesn't, it is likely that the attribute is an internal parameter and is of no importance to the reader.

has_unloaded
has_loaded
lines_on
animation_pointer
next_b_act
time_b_act1
resource_throughput_last_updated
time_spent_unloading
time_spent_loading
time_started_unloading
time_finished_unloading
time_started_loading
time_finished_loading
old_number_of_stockpile_equipment_acquired
number_of_stockpile_equipment_acquired
overall_unloading_rate
overall_loading_rate
stacking_rate
reclaiming_rate
stockpile_unit_number (array of variables)
initial_size
present_size
total_dwell_time
amount_removed_in_last_hour
t_time
time_spent_at_loading_bay
time_left_loading_bay
arrival_number
type_of_entity
c_number
cargo_size
creation_time
disposal_time
group_weighting
pre_unloading_delay

pre_loading_delay
pre_departure_delay
presently_unloading
presently_loading
found_unloader
time_acquired_unloader_number (array of variables)
time_released_unloader_number (array of variables)
unloader_number (array of variables)
loader_number (array of variables)
number_of_unloaders
number_of_loaders
new_number_of_unloaders
new_number_of_loaders
number_of_unloaders_acquired
number_of_loaders_acquired
number_of_unloaders_still_needed
number_of_loaders_still_needed
old_number_of_loaders_acquired
old_number_of_unloaders_acquired
time_arrived_at_berth
time_left_berth
time_spent_at_berth
finished_servicing_time
approach_time
departure_time
passage_time
amount_still_to_be_unloaded
amount_still_to_be_loaded
amount_already_unloaded
amount_already_loaded
unloading_start_time
at_unloading_stage
at_loading_stage
percentage_unloaded
unloading_procedure_last_visit_time
loading_procedure_last_visit_time
ideal_number_of_port_transport
number_of_port_transport_acquired
old_number_of_port_transport_acquired
number_of_port_transport_still_needed
pt_procedure_last_visit_time
new_unloading_rate,new_loading_rate
unloading_time,loading_time
time_put_on_calendar
time_one
time_two

time_three
time_four
time_five
time_six
time_seven
time_eight
time_to_enter_port
time_to_leave_port
time_to_enter_lock
time_to_depart_through_lock
berth_found
berth_number
c_group
s_class
n_class
size
loaded_draught
unloaded_draught
entering_draught
leaving_draught
fract
fract2
ntugs
cargo_type
capacity_type
av_speed
navigate_channel_time
lock_to_manoeuvring_area_time
manoeuvring_time
tug_fasten_time
tug_release_time
lock_transition_time
b_number
s_number
ship_number
animate_done
service_point_number
gate_number
present_service_time
loading_bay_number

APPENDIX E

DOCK SIDE UNLOADER ATTRIBUTES

DOCK SIDE UNLOADER ATTRIBUTES

This appendix contains a description of the dock side unloader attributes. However, dock side loaders, land side unloaders, and land side loaders also have the same attributes. The attributes are all set up in the same Borland Pascal for Windows Object, and are as follows, with the list referring to the variable names.

effective_rate	array of work rates for the five ship groups.
efficiency	array of efficiency levels for the five ship groups.
final_rate	array of work rates for the five ship groups consisting of the effective_rate multiplied by the efficiency.
mega_final_rate	the work rate at the present ship.
handle_group	which ship groups it can be used by.
handle_berth	which berths it can be used at.
availability	whether it is in use or not.
suitability	used by allocation rules to see if can be used by ship.
throughput	updated whether work on a ship finishes.
occupancy	amount of time has been in use.
utilization	percentage of time has been in use.
time_acquired	time started work at the ship.
time_released	time finished work at the ship.
sub_occupancy	amount of time spent working on present ship.

APPENDIX F

PROGRAM FILE PRINT OUTS

PROGRAM FILE PRINT OUTS

The following six pages show print outs from model data files. The first four pages show the start of a typical input variables file, while the next two pages show sample output from a ship data file. Only samples have been shown as it is not really practical or relevant to put complete listings in the appendices due to the length of the files.

filename:
base94.var

Start of file

total number of berths
6
total number of tugs
4
total number of locks
1
tug average speed
20

for each of the five ship cargo groups:

group 1
status
TRUE
Ship cargo size distn
four parameters - not all may be used
3900.00000
1.00000
600.00000
17367.00000
seven distns - only one should be true
TRUE
FALSE
FALSE
FALSE
FALSE
FALSE
FALSE
Ship arrival distn
first parameter
34.35000
second parameter
0.00000
Ship size distn
four parameters - not all may be used
14448.00000
2.75400
7367.00000
17367.00000
six distns - only one should be true
FALSE
FALSE
FALSE

FALSE
TRUE
FALSE
import only trading status prob
0.00000
export only trading status prob
1.00000
priority weighting
1
stockpile level check for unloading ship
0.00000
stockpile level check for loading ship
0.00000
five arrival distns - only one should be set to true
TRUE
FALSE
FALSE
FALSE
FALSE
for each of the five possible delay distns:

pre-unloading delay
FALSE
pre-loading delay
FALSE
pre-departure delay
FALSE

pre-unloading delay
FALSE
pre-loading delay
FALSE
pre-departure delay
FALSE

pre-unloading delay
FALSE
pre-loading delay
FALSE
pre-departure delay
FALSE

pre-unloading delay
TRUE
pre-loading delay
TRUE
pre-departure delay
TRUE

pre-unloading delay
FALSE
pre-loading delay
FALSE
pre-departure delay
FALSE
end of distns

pre-unloading delay first param
0.00000
pre-unloading delay second param
0.00000
pre-loading delay first param
0.00000
pre-loading delay second param
0.00000
pre-departure delay first param
3.80000
pre-departure delay second param
0.00000

for the ten possible factor levels
multiple unloader factor 1
1.00000
multiple loader factor 1
1.00000
multiple unloader factor 2
0.95000
multiple loader factor 2
0.95000
multiple unloader factor 3
0.85000
multiple loader factor 3
0.85000
multiple unloader factor 4
0.75000
multiple loader factor 4
0.75000
multiple unloader factor 5
0.60000
multiple loader factor 5
0.60000
multiple unloader factor 6
0.60000
multiple loader factor 6
0.60000
multiple unloader factor 7

0.60000
multiple loader factor 7
0.60000
multiple unloader factor 8
0.60000
multiple loader factor 8
0.60000
multiple unloader factor 9
0.60000
multiple loader factor 9
0.60000
multiple unloader factor 10
0.60000
multiple loader factor 10
0.60000

for each of the five cargo bands
max number of unloaders per ship, band 1
1
max number of loaders per ship, band 1
1
max number of unloaders per ship, band 2
1
max number of loaders per ship, band 2
1
max number of unloaders per ship, band 3
1
max number of loaders per ship, band 3
1
max number of unloaders per ship, band 4
1
max number of loaders per ship, band 4
1
max number of unloaders per ship, band 5
1
max number of loaders per ship, band 5
1

port transport group effective rate
4000.00000
port transport group efficiency level
100.00000
port transport group total number
10

group 2
status
TRUE

record number	Run time record created	Ship number	Cargo type	Trading status	Cargo size	Size (DWT)	Creation time	Time arrived at berth	Time left berth	Disposal time	Approach time	Departure time	Passage time	Berth number
1	17.09	1	3	1	1332.29	12190.8	0.00	1.00	16.09	17.09	1.00	1.00	17.09	4
2	31.92	3	1	2	2267.50	10122.5	0.00	2.00	30.92	31.92	2.00	1.00	31.92	2
3	48.30	6	1	2	1631.10	14845.8	25.51	26.51	47.30	48.30	1.00	1.00	22.79	4
4	64.20	4	1	2	4407.88	11158.4	9.49	10.49	63.20	64.20	1.00	1.00	54.72	6
5	88.25	2	2	2	7795.39	11403.6	0.00	1.00	87.25	88.25	1.00	1.00	88.25	3
6	91.78	7	1	2	1732.61	12238.8	66.43	67.43	90.78	91.78	1.00	1.00	25.35	2
7	92.33	5	1	2	5758.11	13431.8	23.55	24.55	91.33	92.33	1.00	1.00	68.78	1
8	128.78	10	1	2	2056.05	9651.5	100.06	101.06	127.78	128.78	1.00	1.00	28.72	2
9	141.63	12	3	1	3500.00	15030.0	104.67	105.67	140.63	141.63	1.00	1.00	36.96	3
10	151.13	11	1	2	3727.56	13705.3	103.50	104.50	150.13	151.13	1.00	1.00	47.63	1
11	164.34	8	1	2	6495.99	14006.5	86.37	87.37	163.34	164.34	1.00	1.00	77.97	4
12	169.60	9	3	1	7588.96	17166.5	96.48	97.48	168.60	169.60	1.00	1.00	73.11	6
13	188.55	14	3	1	4383.61	10259.0	144.10	145.10	187.55	188.55	1.00	1.00	44.45	5
14	213.35	15	3	2	6859.85	9890.6	146.41	147.41	212.35	213.35	1.00	1.00	66.93	2
15	225.68	13	3	1	5697.41	16200.7	126.28	169.60	224.68	225.68	43.32	1.00	99.40	6
16	250.92	17	1	2	816.76	11702.7	235.11	236.11	249.92	250.92	1.00	1.00	15.81	3
17	288.42	16	3	1	6483.34	17270.2	178.14	225.68	287.42	288.42	47.54	1.00	110.28	6
18	296.72	22	3	2	1444.03	11688.0	277.18	278.18	295.72	296.72	1.00	1.00	19.54	1
19	301.99	21	1	2	3042.05	11212.1	261.72	262.72	300.99	301.99	1.00	1.00	40.27	3
20	311.54	19	1	2	4343.21	13780.0	257.50	258.50	310.54	311.54	1.00	1.00	54.04	4
21	330.14	20	1	2	3341.69	17019.5	258.72	289.03	329.14	330.14	30.32	1.00	71.42	6
22	335.22	24	1	2	1767.85	14560.6	309.81	310.81	334.22	335.22	1.00	1.00	25.40	1
23	342.33	18	1	2	7581.61	9561.9	251.55	252.55	341.33	342.33	1.00	1.00	90.78	2
24	356.86	23	3	2	7200.65	14025.1	287.03	288.03	355.86	356.86	1.00	1.00	69.82	5
25	373.42	26	1	2	1076.98	13722.3	354.90	355.90	372.42	373.42	1.00	1.00	18.52	6
26	397.18	25	1	2	5051.04	8214.9	335.76	336.76	396.18	397.18	1.00	1.00	61.41	3
27	414.42	27	3	1	3764.69	13437.5	373.72	374.72	413.42	414.42	1.00	1.00	40.70	1
28	416.60	30	1	2	1553.90	10536.3	393.11	394.11	415.60	416.60	1.00	1.00	23.49	2
29	478.47	28	1	2	7756.59	16793.5	387.37	388.37	477.47	478.47	1.00	1.00	91.10	6
30	479.74	31	1	2	1133.00	11252.8	462.14	463.14	478.74	479.74	1.00	1.00	17.60	2
31	554.56	34	3	2	5482.16	9936.3	499.30	500.30	553.56	554.56	1.00	1.00	55.26	5
32	558.52	33	1	2	4931.69	13148.5	496.85	497.85	557.52	558.52	1.00	1.00	61.67	3
33	570.52	38	1	2	1950.33	10105.6	542.91	543.91	569.52	570.52	1.00	1.00	27.62	1
34	593.84	39	1	2	660.34	11809.0	581.16	582.16	592.84	593.84	1.00	1.00	12.68	3
35	612.24	37	2	2	7057.68	12089.7	531.36	532.36	611.24	612.24	1.00	1.00	80.88	4
36	622.75	29	1	2	12526.41	16463.9	389.04	478.47	621.75	622.75	89.43	1.00	233.71	6
37	633.59	36	3	2	11707.38	12233.9	521.07	522.07	632.59	633.59	1.00	1.00	112.52	2
38	664.25	32	1	2	3259.24	16124.7	491.50	622.75	663.25	664.25	131.25	1.00	172.75	6
39	670.14	41	3	1	4265.20	12140.4	626.69	627.69	669.14	670.14	1.00	1.00	43.45	4
40	705.05	40	1	2	8146.81	15832.5	608.38	609.38	704.05	705.05	1.00	1.00	96.66	5
41	733.23	44	3	1	2272.82	8290.9	706.67	707.67	732.23	733.23	1.00	1.00	26.56	4
42	752.06	45	3	2	2974.49	12027.0	719.55	720.55	751.06	752.06	1.00	1.00	32.51	2
43	754.58	42	2	2	7852.86	15941.3	663.97	665.25	753.58	754.58	1.28	1.00	90.61	1
44	763.73	35	3	1	10464.60	16001.0	502.99	664.25	762.73	763.73	161.26	1.00	260.74	6
45	764.73	46	1	2	3333.34	10229.3	722.40	723.40	763.73	764.73	1.00	1.31	42.33	5
46	807.42	43	1	2	3445.21	16531.1	697.13	763.73	806.42	807.42	66.61	1.00	110.29	6
47	813.17	47	3	2	7524.43	11435.6	739.10	740.10	812.17	813.17	1.00	1.00	74.07	4
48	822.89	51	1	2	2023.28	9257.7	794.51	795.51	821.89	822.89	1.00	1.00	28.38	5
49	827.59	50	1	2	2811.55	12412.3	790.72	791.72	826.59	827.59	1.00	1.00	36.87	1
50	839.05	52	3	1	2139.67	7767.3	815.11	816.11	838.05	839.05	1.00	1.00	23.93	4
51	842.62	48	2	2	7709.51	11021.6	755.22	756.22	841.62	842.62	1.00	1.00	87.40	3
52	847.80	49	2	2	6815.99	12919.1	769.34	770.34	846.80	847.80	1.00	1.00	78.46	2
53	889.81	53	3	1	6994.18	11363.6	821.73	822.73	888.81	889.81	1.00	1.00	68.07	6
54	900.53	56	3	2	4434.85	10217.6	854.14	855.14	899.53	900.53	1.00	1.00	46.38	2
55	914.05	54	1	2	5735.98	10141.6	845.50	846.50	913.05	914.05	1.00	1.00	68.55	1
56	918.29	55	3	2	2618.08	17422.7	850.44	889.81	917.29	918.29	39.37	1.00	67.85	6
57	941.41	58	1	2	2869.88	14643.3	902.71	903.71	940.41	941.41	1.00	1.00	38.69	2

record number	Run time record created	Ship number	Cargo type	Trading status	Cargo size	Size (DWT)	Creation time	Time arrived at berth	Time left berth	Disposal time	Approach time	Departure time	Passage time	Berth number
58	986.78	61	3	2	4427.06	10198.5	941.96	942.96	985.78	986.78	1.00	1.00	44.82	4
59	999.81	57	3	1	8521.40	16325.2	875.57	918.29	998.81	999.81	42.73	1.00	124.24	6
60	1007.85	60	3	2	7394.49	7659.8	936.39	937.39	1006.85	1007.85	1.00	1.00	71.47	1
61	1038.53	66	3	1	1936.17	12314.8	1014.83	1015.83	1037.53	1038.53	1.00	1.00	23.71	1
62	1046.68	63	3	1	7758.15	8237.2	970.63	971.63	1045.68	1046.68	1.00	1.00	76.05	2
63	1046.77	65	1	2	2863.37	9913.1	1009.64	1010.64	1045.77	1046.77	1.00	1.00	37.13	5
64	1049.66	59	3	2	4961.75	16607.1	929.87	999.81	1048.66	1049.66	69.93	1.00	119.78	6
65	1071.42	67	1	2	2853.07	8456.4	1034.41	1035.41	1070.42	1071.42	1.00	1.00	37.02	4
66	1098.42	62	1	2	3932.46	16249.2	953.43	1049.66	1097.42	1098.42	96.23	1.00	144.99	6
67	1145.48	72	3	1	4151.53	15643.3	1102.07	1103.07	1144.48	1145.48	1.00	1.00	43.42	4
68	1154.95	68	1	2	7977.31	10190.7	1061.55	1062.55	1153.95	1154.95	1.00	1.00	93.40	1
69	1172.93	69	3	1	11492.55	14719.3	1063.74	1064.74	1171.93	1172.93	1.00	1.00	109.19	2
70	1210.03	77	3	1	2038.39	10305.3	1185.45	1186.45	1209.03	1210.03	1.00	1.00	24.57	4
71	1238.55	74	1	2	9623.55	13361.5	1125.01	1126.01	1237.55	1238.55	1.00	1.00	113.55	5
72	1242.91	78	1	2	3082.16	8038.2	1203.51	1204.51	1241.91	1242.91	1.00	1.00	39.41	2
73	1245.54	64	1	2	12799.08	16912.9	999.66	1098.42	1244.54	1245.54	98.76	1.00	245.88	6
74	1279.59	76	1	2	10534.97	12165.9	1156.55	1157.55	1278.59	1279.59	1.00	1.00	123.04	1
75	1284.12	79	3	1	6594.45	13638.8	1217.93	1218.93	1283.12	1284.12	1.00	1.00	66.19	3
76	1285.41	80	1	2	3483.99	11287.6	1240.32	1241.32	1284.41	1285.41	1.00	1.00	45.09	4
77	1296.15	70	3	2	5050.50	16114.0	1064.42	1245.54	1295.15	1296.15	181.12	1.00	231.73	6
78	1297.85	81	1	2	2905.12	9635.7	1260.29	1261.29	1296.85	1297.85	1.00	1.00	37.56	2
79	1315.18	71	1	2	1366.65	16668.4	1090.26	1296.15	1314.18	1315.18	205.89	1.00	224.92	6
80	1384.50	73	2	2	6001.73	16775.5	1104.25	1315.18	1383.50	1384.50	210.94	1.00	280.25	6
81	1386.93	85	1	2	3239.59	11655.9	1345.88	1346.88	1385.93	1386.93	1.00	1.00	41.05	2
82	1392.45	88	3	2	2319.06	9637.9	1366.53	1367.53	1391.45	1392.45	1.00	1.00	25.92	1
83	1395.29	86	3	2	4925.85	11261.1	1346.25	1347.25	1394.29	1395.29	1.00	1.00	49.04	3
84	1422.59	84	2	2	8939.35	14567.6	1321.39	1322.39	1421.59	1422.59	1.00	1.00	101.19	4
85	1432.09	87	1	2	5788.79	14080.7	1361.49	1362.49	1431.09	1432.09	1.00	1.00	70.60	5
86	1453.65	92	1	2	2136.90	7716.5	1424.10	1425.10	1452.65	1453.65	1.00	1.00	29.56	4
87	1463.42	75	3	1	8214.74	16969.0	1151.62	1384.50	1462.42	1463.42	232.88	1.00	311.80	6
88	1464.42	90	1	2	5914.15	10445.5	1393.32	1394.32	1463.42	1464.42	1.00	1.69	71.10	1
89	1483.81	89	2	2	8251.21	15003.3	1390.92	1391.92	1482.81	1483.81	1.00	1.00	92.90	2
90	1484.44	91	1	2	5229.36	7691.3	1421.16	1422.16	1483.44	1484.44	1.00	1.00	63.27	3
91	1511.40	82	1	2	3945.53	16038.0	1262.90	1463.42	1510.40	1511.40	200.52	1.00	248.50	6
92	1519.60	95	3	2	1725.95	11969.8	1497.67	1498.67	1518.60	1519.60	1.00	1.00	21.93	4
93	1522.94	93	1	2	3752.59	10650.6	1475.05	1476.05	1521.94	1522.94	1.00	1.00	47.89	1
94	1528.24	94	1	2	3091.02	9966.4	1488.74	1489.74	1527.24	1528.24	1.00	1.00	39.50	2
95	1551.58	97	3	1	4275.45	9711.7	1506.54	1507.54	1550.58	1551.58	1.00	1.00	45.03	5
96	1562.83	83	1	2	4274.58	16413.4	1297.53	1511.40	1561.83	1562.83	213.86	1.00	265.29	6
97	1567.07	96	3	2	6559.11	14983.8	1501.19	1502.19	1566.07	1567.07	1.00	1.00	65.89	3
98	1569.02	98	1	2	2821.74	9846.3	1530.82	1531.82	1568.02	1569.02	1.00	1.00	38.19	1
99	1581.23	100	3	1	2558.43	14579.5	1552.25	1553.25	1580.23	1581.23	1.00	1.00	28.98	4

APPENDIX G

MODEL RESOURCE UPPER LIMITS

MODEL RESOURCE UPPER LIMITS

This appendix contains a summary list of the upper limit within the present version of the model.

• max number of cargo types	= 5
• max number of ship groups	= 5
• max number of inland transportation groups	= 5
• max number of berths	= 10
• max number of trading status'	= 3
• max number of dock side unloaders	= 10
• max number of dock side loaders	= 10
• max number of dock side unloaders per ship	= 10
• max number of dock side loaders per ship	= 10
• max number of dock side stockpile equipment	= 20
• max number of ship classes	= 5
• max number of port gates	= 4
• max number of service points (per gate on entry)	= 10
• max number of service points (per gate on exit)	= 10
• max number of loading bays (per LTU group)	= 10
• max number of land side unloaders	= 10
• max number of land side loaders	= 10
• max number of land side unloaders per unit	= 10
• max number of land side port loaders per unit	= 10
• max number of land side stockpile equipment	= 20
• max weather states	= 6
• max ship data records	= 800

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