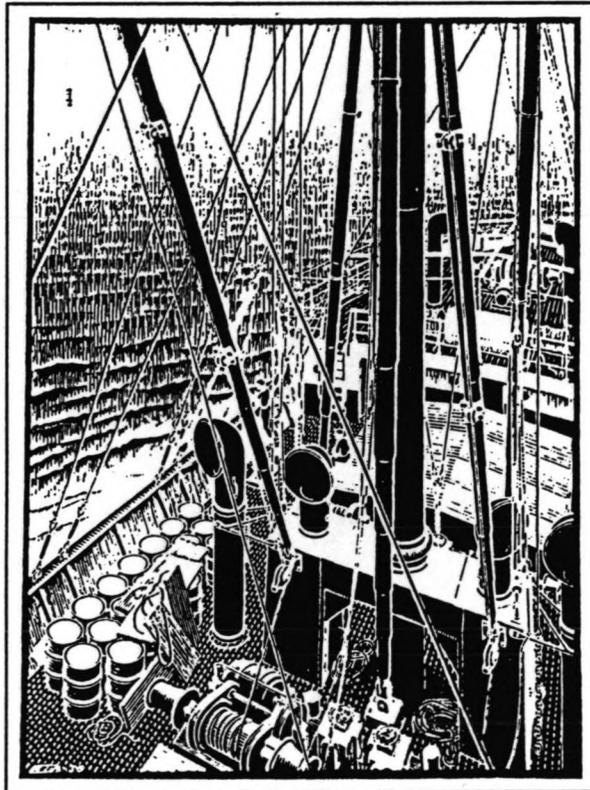


Simulation Model for Port Operations; Application for Pontianak

Volume 1: Main Report



Master Thesis
J.B.P. van Driel
September 1993

Delft University of Technology
Faculty of Civil Engineering, Hydraulic Engineering Division

HASKONING Royal Dutch Consulting Engineers and Architects
International Projects Division

***Simulation Model for Port Operations;
Application for Pontianak***

Master Thesis by J.B.P. van Driel

<i>Volume 1</i>	Main report
<i>Volume 2</i>	Annexes
<i>Volume 3</i>	Lexicon
<i>Volume 4</i>	Users manual

Thesis committee

Prof. ir. H. Velsink
Ir. R. Groenveld
Ir. R. Moor

Front page:

Cargo vessel

Woodcut by M. C. Escher, september 1936

Preface

Studying port operations and simulating these operations in a computer model are the ingredients of an interesting occupation. In this field of civil engineering I have fulfilled my thesis project at the Delft University of Technology. This report presents the output of the project.

An important part of the thesis work has been performed during the period of May-November 1992 at Haskoning Royal Dutch Consulting Engineers and Architects, Nijmegen. I would like to thank all those at the International Projects Division who made the stay such an enjoyable learning experience.

I would like to express my gratitude to the members of my thesis committee, for helping to take difficult decisions, for simple advice along the way and for allowing me much freedom in accomplishing my work.

Finally, a special "thank you" to all others who gave unasked for but always welcome support.

Jurre van Driel
Delft, September 1993

Summary

Port systems are influenced by arrival patterns of ships, quay configurations, cargo handling conditions, storage capacity, connections with inland transport, environmental conditions and various other aspects. The extent to which these aspects effect port operations can be determined by empirical "rules of thumb", queuing theory and simulation models. Simulation models are especially suitable for the analysis of complex port systems.

The objective of this thesis project was to produce a simulation model for a port system. Originally this was a group of terminals at the port of Kaohsiung, Taiwan. Secondly, the model was supposed to be applicable to other ports without extensive adjustments. The model, which has been created, provides a framework to perform a simulation of port operations for port design purposes. The flexibility of the model proved useful when the application of the model was switched to Pontianak in Indonesia.

The model describes a port for which the user can define the number of terminals, berths, cranes, gangs, shifts, cargo-commodities and arriving shipclasses. After a ship has been generated, it follows a route through the port system, starting at the anchorage, sailing to a berth, mooring at a quay, being loaded and discharged and leaving the port. The arrival of a ship creates an incoming and outgoing flow of cargo with inland transport and a requirement for storage area. Port operations can be restricted by several circumstances (tidal window, bad weather, strikes, absence of shifts or inland transport in weekends, breakdowns of cranes).

The Main Public Port at Pontianak is a terminal with five quays (total length 507 m) at which annually 620,000 tons of general and bagged cargo are handled. This throughput is expected to increase to 1,280,000 tons in 2002. In view of the already high berth occupancies at present, it is expected that extensions and adaptations of the port facilities are required. The occurrence of congestion for the current configuration has been examined with the use of the simulation model. Several combinations of quay length increasement and cargo handling rate improvement have been tested, for the 2002 throughput forecast and for four fluctuations of the forecast.

The results of the simulations have been compared to a quay configuration, which is proposed by a previous port development study ('Feasibility Study and Masterplan Review for Pontianak Port Development' by HASKONING Royal Dutch Consulting Engineers and Architects and PT Delta Marga Kreasi, August - December '92) and has been calculated with the queuing theory. Some critical remarks with regard to the proposed configuration are made. One other preferable configuration is pointed out. Comparisons between combinations

of quay length increasement and cargo handling rate improvement are performed with data for vessel performances (waiting and service times) and rates of berth occupation and storage area utilization.

Table of contents

Preface	i
Summary	iii
Table of contents	v
1 Introduction to the report	1
2 Introduction	3
2.1 General problem definition	3
2.2 Tools for port planning	3
2.3 Objective of the thesis project	4
2.4 Modelling process	5
2.5 Requested output	6
3 Simulation-language Prosim	9
3.1 Introduction	9
3.2 Terminology	9
3.3 Structure of a Prosim-program	10
3.4 Facilities of Prosim	11
4 General description of the model	13
4.1 Introduction	13
4.2 Verbal model	13
4.3 Components with an own process-description	17
4.4 Generator	21
4.5 Ship	27
4.6 Harbour-master	33
4.7 Terminal-master	35
4.8 Crane	35
4.9 Storage-master	38
4.10 Typhoon	41
4.11 Strike	44
4.12 Shift	44
4.13 Main	45
4.14 Reporter	51
4.15 Passengership	52
4.16 Model extensions	56

5	Use of the model	59
5.1	Introduction	59
5.2	Required input-information	59
5.2.1	Input-data to create the harbour-environment (H-file)	60
5.2.2	Input-data to create the ship-classes (S-file)	60
5.2.3	Input-data to create the DWT-tables (D-file)	61
5.2.4	Input-data to create the terminals (T-file)	63
5.3	Produced output-information	65
5.3.1	Storestreams	65
5.3.2	Report-file	66
6	Validation and verification	69
6.1	Introduction	69
6.2	Checking of programming procedures	69
6.3	Queuing theory	74
6.4	Simulation of other terminals	78
7	Port of Pontianak	81
7.1	Port of Pontianak: present situation	81
7.1.1	Location	81
7.1.2	Facilities	81
7.1.3	Cargo and vessel traffic	83
7.1.4	Harbour environment	85
7.2	Main Public Port	85
7.2.1	Facilities	85
7.2.2	Cargo and vessel traffic	87
7.2.3	Cargo handling and storage	88
7.3	Port development study	91
7.3.1	Cargo and vessel traffic forecast	91
7.3.2	Cargo handling and storage	93
7.4	Problem analysis	95
7.5	Objective of the application	96
8	Application of the model for Pontianak	99
8.1	Introduction	99
8.2	Model input	99
8.3	Calibration	102
8.4	Short term development	105

8.5	Medium term development	108
	8.5.1 Medium term port planning	109
	8.5.2 Simulation of medium term development	111
8.6	Results of simulation-runs	114
8.7	Discussion of results	123
9	Conclusions and recommendations	125
	9.1 Conclusions	125
	9.2 Recommendations	126
	Documentation	129

1 Introduction to the report

The report of this thesis project consists of four volumes. This volume, *Volume 1*, is the main report. It has 9 chapters of which this chapter is the introductory chapter to the report. Chapter 2 is the introduction to the thesis project; it describes the reasons for making a port simulation model. In the third Chapter, Prosim, the software with which the port simulation has been performed, is briefly discussed.

In Chapter 4 the verbal model is presented and the processes of the model-components are described. In the following chapter, the use of the model is briefly dealt with and the required input and produced output of the model are stated. In Chapter 6 the verification and validation of the model are discussed.

The port simulation model is applied for the port of Pontianak, Indonesia. In Chapter 7 the present situation at port of Pontianak is analyzed and the predicted developments in medium term are presented. In Chapter 8 the application of the model is described. The last chapter of this volume contains the conclusions and recommendations of the thesis project.

Volume 2 contains the annexes of the main report. It includes a line-to-line description and a complete listing of the simulation program. Furthermore this volume contains background details of some of the chapters of Volume 1.

Volume 3 is a lexicon for the simulation model. It contains the vocabulary of all terms which are used in the program. The first part of the lexicon includes components, streams and queues which are used in the model. The second part contains an alphabetical list of all attributes. The line-to-line description, the program-listing and the lexicon are aimed at readers with knowledge of Prosim, who wish to analyze or adapt the model.

The users manual for the port simulation model is *Volume 4*. The purpose of this volume is to allow users, who are non acquainted with Prosim, to use the model.

2 Introduction

The topic of this thesis project is the development of a port simulation model and the application of the model for the Main Public Port at Pontianak, Indonesia. This chapter describes the argumentation for making such a model. It points out a port simulation model as a possible tool for port planning. The boundary conditions for making such a model are discussed and the required output of the model is specified.

The trend in simulation techniques is to produce simulation models which are aimed at specific ports. This principle also applies to this thesis project. Originally, the port system, which was meant to be modelled, was a group of terminals at the port of Kaohsiung in Taiwan. Due to a lack of data, the application of the model was switched from Kaohsiung to Pontianak.

2.1 General problem definition

The Main Public Port in Pontianak is a terminal with 5 quays at which general cargo is handled; it located on the river Kapuas Kecil in West Kalimantan. The throughput of cargo is expected to increase to twice the current amount in medium term (2002). It is expected that the port cannot cope with the growth in cargo and vessel traffic. Research must be therefore be performed into an improved port lay-out and improved port operation procedures. In Chapter 7 the present situation of the Main Public Port and the medium term developments are described in detail. Also a specific problem analysis is presented.

In general sense, it means that a port development study must be performed. A plan must be made how to develop a present port situation into a required future port situation. In the future situation, the cargo handling and storage capacity must be sufficient to accommodate an increased cargoflow and the waiting times of vessels must be at an acceptable level. The question arises how such a study can be performed; in other words, a tool must be found to assist the port planning.

2.2 Tools for port planning

The methods which can be applied for port planning calculations can be divided into three categories. The first is using rules of thumb, based of empirical information. In this method calculations are made by using average values for consignment-sizes and inter-arrivaltimes of ships and using peaking factors to account for irregularities in the port operations. It can be used for simple port systems with a low traffic intensity.

The second possibility is using the queuing theory; a port is regarded as a service system, for which the performance of several aspects of the system are calculated analytically. A service system consists of a queue (anchorage) and of a discrete number of identical service points (berths). This method can also only be applied for simple systems; however high traffic intensities are acceptable.

The third category is using simulation techniques; with the assistance of a computer model, complex port systems can be investigated. A real life port system is modelled and experiments can be conducted with this model, in order to understand the system behaviour and to evaluate certain strategies. In comparison with the queuing theory, simulation techniques can look into port procedures at greater detail (for example the sailing time from the anchorage to the quay), they can deal with more aspects of the port facilities (storage, connection with inland transport), they can take into account possible restrictions on the terminal operations (bad weather conditions, breakdowns) and they can deal with more complicated berth allocations rules (berths which are not identical and do not exist in a discrete number). Disadvantages of simulation models are the large data requirements and the fact that they are quite time and cost consuming. However, they are nowadays an important tool for optimization of port and terminal design.

The general arguments for choosing a suitable method are the level of traffic intensity and the degree of complexity of the port system which is to be investigated. In the case of Pontianak, the empirical calculation techniques are not suitable because of the high traffic intensity. It is possible to regard the Main Public Port as a simple service system. The anchorage is on the river Kapuas Kecil and the 5 quays represent a certain number of service points. Waiting times of vessels and utilization rates of the quays can be calculated. Therefore the queuing theory can be applied.

However, there are also several important reasons to choose for applying a computer simulation model instead. Four general reasons have already been named (greater detail, more facilities, influence of restrictions, variation in berth-types). For Pontianak some extra arguments justify the use of a simulation model. A possible cause for congestion at the MPP is the large number of ships and the manoeuvring they have to perform when mooring at and leaving the quays. Secondly, insight is required in the fluctuation of the required storage area. Thirdly, a variation in the types of vessels can be applied and separate distributions of their waiting times are can be registered.

2.3 Objective of the thesis project

The comparison of alternatives in the previous paragraph points out the method of applying

a computer simulation model as a suitable tool for port planning. The principal objective of the thesis study is to produce such a model.

Besides, there is a second objective: to ensure that the model can be applied to other ports without extensive adaptations to the program. The description of the model in this report is therefore written in a general sense and not directly specified for Kaohsiung or Pontianak. This objective also implies that other users should be able to perform possible new applications of the model. Therefore a thorough documentation of the use and structure of the model is required. This requirement is also an important part of the thesis work.

As stated above, both the queuing theory and the application of a port simulation model are preferable solutions for Pontianak. A port development study for Pontianak, based on the queuing theory, has already been performed by engineers of Haskoning. The port simulation model, which is produced in this thesis study, is therefore applied to analyze the problems for Pontianak. The results of using the model can be compared to the outcome of the study based on the queuing theory.

2.4 Modelling process

The process of making a computer simulation model consists of the following steps:

- * Definition of the system, which is to be modelled
- * Description of the model
- * Programming
- * Verification/validation/calibration
- * Application/experimenting

The first of these stages is dealt with in this paragraph, the latter four are discussed in the other chapters and volumes of this report.

The application of computer simulation models is a strong aid to port planners. A wide range of aspects of port operations can be simulated, on the land side as well as on the marine side. Which aspects are left out of the model and which aspects are included in the model (and at which level of detail) depends strongly on the local circumstances of the port which is to be modelled. Therefore, the primary step for making a computer simulation model is deciding on the boundaries of the model and on the level of detail at which the model should operate; this means it must be determined which aspects are relevant to the port operations and are therefore brought into the model and which level of schematization is applied for those aspects. Also the required output of the model must be specified.

The area of the port to which this model applies consists mainly of the land side; on the marine side the arrivals and departures of ships will be brought into the model together with a consideration of whether or not ships can enter the port (for instance a tidal window) and whether or not ships are obstructed by the manoeuvring of other ships in front of the quays. On the landside the model will focus on the storage facilities and the equipment for handling cargo from ship to quay and vice versa (cranes or crane substituting units, for example gangs) and the connection with inland transport; the equipment for handling cargo on the terminal-premises will not be specified. Special attention will be paid to the effect of events which cause restrictions on the harbour- and terminal-activities (strikes, bad weather conditions, breakdowns of cranes, absence of shifts and/or inland transport in weekends).

For the level of detail, a choice must be made between a model which is generally applicable but may often not be valid because of too excessive assumptions or a model which is very detailed in its output but is very time-consuming to produce. For this thesis study, a sufficient amount of time was available and thus it was possible to reach a substantial level of detail. However, it was considered important to avoid creating too large variations in the level of detail within the model; a second concession to the level of detail is the objective to produce a model which can be used for other ports without too many adaptations. The level of detail at which the model operates is the level of port operations, implying that the model can consist of one or more terminals, each with its own characteristics, inside one port; it also implies that it is not at the level of terminal operations.

The port simulation model, which is called HASPORT-II, has been translated into a computer-simulation-program with the use of Prosim simulation-software. Chapter 3 will give some details about this simulation-language.

2.5 Requested output

The port simulation model should present results which are of assistance to port planning: the results should provide information of the behaviour of the port-system and of details of the way in which parameters in the system influence this behaviour. These demands are translated into specific requirements for the output of the model.

Possible adaptations/extensions to the existing lay out of a port are translated into a new port configuration; this configuration, consisting of characteristics of terminals, berths and equipment, together with other input information (of the ships, the cargotypes, the inland transport, etc.) are then fed into the model. Based on these data, the following output should be produced by the model:

- * Annual throughput per terminal (in tons or TEU)
- * Utilisation of terminal storage (in square meters of open or covered storage, in cubic meters of bulk storage or in groundslots for container storage)
- * Number of trucks, wagons and barges leaving/entering the terminal per year
- * Berth-occupancy (as a percentage of availability)
- * Utilisation of ship-quay/quay-ship cargohandling equipment (hours per year)
- * Ships' waiting time and ships' time at berth per class of ships (hours)
- * Delays to ships and to cargohandling activities due to crane breakdowns, climatic downtime, strikes, tide (in hours per year for berths, in hours for ships)

3 Simulation-language Prosim

3.1 Introduction

Prosim is a simulation-language which has been developed at Delft University of Technology. It originates from computer-language PL1 and can perform both discrete and continuous simulations. The version of Prosim for use on personal computers is Personal Prosim, which has been developed by Sierenberg & de Gans b.v., Waddinxveen. The simulation-model for the port of Pontianak has been performed with version 2.05 of Personal Prosim. This chapter will explain the terminology and modelling principles of Prosim (Paragraph 3.2), the structure of a Prosim-program (Paragraph 3.3), the facilities of Prosim and the build-up of a Prosim-simulation (Paragraph 3.4).

3.2 Terminology

To perform a simulation of a real-life system, the system has to be translated into a model. A model can be regarded as a set of *components* out of the system, which are in some way interrelated. Examples of components in a port-system are the harbour-master, the cranes, the ship-generator. Components can be in a system temporarily (e.g. a ship) or permanently (e.g. a harbour-master). Components can be described by giving values to the so called *attributes* of these components: for instance length, draught and consignment size of a ship. Components which have the same attributes belong to the same class of components; they are called *class components* (e.g. cranes, ships) as opposed to single components (e.g. harbour-master).

Prosim is an abbreviation of Process simulation, indicating that the *method of process-description* is used to describe the behaviour of the components in a system. A process-description consists of a sequence of activities which are performed by a (single or class) component; each step changes one or more of the attributes of that component (and possibly other components) and thus changes the state of that component (and others). For example, the process-description of a ship in a port-system can be described as follows:

- * enter system
- * wait while all berths are occupied
- * go to berth
- * wait during unloading and loading
- * leave system

Components, whose state only changes as a result of the behaviour of other components and therefore have no process-description of their own, are called *data components*. Apart from the data components, all components in a system have their own process-description in a Prosim-program. Components of one class can make use of the same process-description.

The advantage of using the method of process-description is that a process is relatively easy to describe and that a user, who is new to a model, can easily understand the behaviour of a component by reading the process-description. This effect is intensified by the fact that the Prosim-language is short and simple. However, a disadvantage of this method is that often problems arise when processes interact; at those times components have to fulfil many conditions, causing certain complications.

3.3 Structure of a Prosim-program

A Prosim-program consist of two parts: a *definition section* and a *dynamic section*. In order to make a Prosim-program more neatly laid out it can be split up into *modules*. The definition-section, in which the structure of the model is described, consists of the module *Define* and the dynamic section, in which the behaviour of the model is described, consists of (at least) the module *Main*.

In the *Define*-module all single and class components of the system are named, together with their attributes. For all attributes the type (real, integer, character, etc.) must be defined. This module must also be used to state which queues, tables, animation-figures, randomstreams (to create distributions), inputstreams (to extract information from input-files), outputstreams (to produce outputfiles) and time-unit are required in the model.

All processes of components are described in the dynamic section. This section consists of at least one module: *Main*. The *Main*-module controls a simulation-run: it reads information from inputfiles, it initiates and activates components, it shapes distributions from randomstreams, it produces outputfiles and it cancels all components before termination of the run. The *Main*-module also contains the process-descriptions of active components. However, it is obvious that for an extensive model, more modules should be used: for instance one module for the process-description of each component. The dynamic section can also contain so called *macro's*. These are descriptions of a series of component actions, placed outside the components process description. Macro's can be used in case of repetition of the same series of actions in different places in the program or in order to improve the readability of the program.

3.4 Facilities of Prosim

As already stated, the main aim of Prosim is to perform discrete and continuous simulations. To facilitate this, Prosim-software offers several possibilities to influence a simulation-process; either before, during or after a simulation-run.

Input into the model can be performed by drawing up input-files. However, it also possible to let the user enter data at the beginning of a simulation-run or, if required, to change values of attributes during a simulation-run.

The output of a simulation-run can be presented in four ways. During a simulation-run, one can switch on the so called trace-mode, indicating that all events of components and the time that those events occur are shown on the screen. Secondly, output-information can be produced by writing data during the run into output-streams, which Prosim then transfers into output-files. Thirdly, information can be stored in so called storestreams, on the basis of which Prosim can create histograms and other types of graphs and perform a statistical analysis or regression-analysis. In the last place, data-files can be produced, on the basis of which animations of the simulated activities can be performed on the monitor.

The complete set of input-files and output-files, that are defined by the user to accompany one simulation-run is called the environment of that run. Apart from the animation, all output-information can be shown on the screen or on the printer.

4 General description of the model

4.1 Introduction

The purpose of this chapter is to explain the structure of the simulation-model, to indicate which simplifications have been applied, to introduce the components that are defined in the model and to describe the processes these components undergo. The process-descriptions are elucidated by means of flow-charts. Special attention will be paid to the explanation of used procedures and methods of calculation.

Paragraph 4.2 gives a first, summarized description of the model; this is the verbal model, which forms the basis for Paragraph 4.3. This paragraph mentions the components which are used to construct the model. From Paragraph 4.4 onwards the processes and characteristics of these components are specified and translated into requirements for the Prosim-program. Paragraph 4.16 gives three possible model extensions. A complete argumentation of the program, which includes a line-to-line description of all process-descriptions, and further details of some modelling procedures are presented in Annexes 1, 2 and 3.

4.2 Verbal model

The model describes a port-system which has the following general characteristics:

The port which is described by the model consists of a user-defined number of terminals. Each terminal is operated separately and can handle a user defined number of cargo-types. These cargo-types have to be chosen from one or more of the four commodities: containers, breakbulk, liquid bulk or dry bulk. Each terminal has a user-defined number of quays. The number of available berths at a quay depends on the length of the quay, the length of the ships which are moored at the quay and the maximum allowed number of ships at the quay. At each berth ships can be discharged and loaded. Up to five types of cargo can be handled at one berth, depending on the unloading/loading-capacity of the cranes. Each quay has a user-defined number of cranes at its disposal. Cranes are not tied to one specific berth; they can be also shifted to adjacent berths. Cranes can also be replaced by crane substituting units like gangs or terminal tractors unloading RoRo-ships. Also ships' gear can be applied to handle the cargo.

The ships which arrive at the harbour are divided into classes. Each class has its own generator, which generates ships at random inter-arrivaltimes, drawn from user-defined distributions. The generators also allocate several attributes to the ships (for example: DWT, draught, length, consignment-size, the type of cargo it carries, the terminal at which the ship

is served).

The movements of a ship in the model are the following:

- * A ship, which has been generated by the generator of its class, enters the system; it asks the harbour-master of the port for permission to go to a berth; when waiting for permission the ships stay in a waiting-row at the anchorage.
- * The harbour-master performs a check-up of the berths, to find a berth, at which the ship can fit and which is free. When the harbour-master finds a positive answer, the harbour-master allocates the ship to that particular berth and gives permission to the ship to sail to the berth.
- * The ship sails from the anchorage to its berth, unless temporarily obstructed by the manoeuvring of other ships.
- * When the ship joins the berth, the terminal-master is alerted. He allocates cranes to the ship. When the unloading and loading has finished, the amount of cargo which has been unloaded and loaded is registered; next the terminal-master allows the ship to leave the harbour.
- * The ship departs from its berth, unless temporarily obstructed by the manoeuvring of other ships and consequently leaves the port.

Each terminal has storage-facilities for each type of cargo at that terminal. For containers there are import-, export- and empties-stacks, for breakbulk there is covered storage (in sheds/warehouses) and open storage. Each type of cargo has a user defined dwell time distribution, for the cargo which arrives at the terminal with inland transport and has to be exported as well as for the cargo which is unloaded from the ships and has to be imported. The distribution can be defined for inland transport by road, by rail and by inland-waterway. Cargo can also be loaded and unloaded directly to and from trucks, wagons and barges or can be transhipped from one ship to another (for example: cargo brought and collected by feeder-ships)

Once a day the storage-master of the port registers the size of the deliveries of cargo at all stacks on that day. The quantity of daily arrivals of export-cargo and departures of import-cargo of each cargotype depends on the dwell time distribution of that cargo-type. This distribution is made dependant of the moment of arrival of the ship at the port for export-cargo and of the moment of departure of the ship from the port for import-cargo. This implies that during a number of days before the ship arrives it is already artificially present

and causes a flow of incoming cargo and that during a number of days after leaving the port it is still artificially present and causing a flow of outgoing cargo. This procedure will be explained in detail further on in this chapter and in Annex 1.2.

Consequentially, the movements of export-cargo in the system are as follows:

- * Arrival at the terminal by inland transport; the moment of arrival depends on the dwell time distribution of the cargo-type and on the time of arrival of the ship it will be exported with; the quantity also depends on that specific ship.
- * Direct loading onto the ship or a stay in the storage of the terminal; in the latter case it is loaded onto the ship at the end of its dwell time on the terminal.
- * Elimination from the port-system.

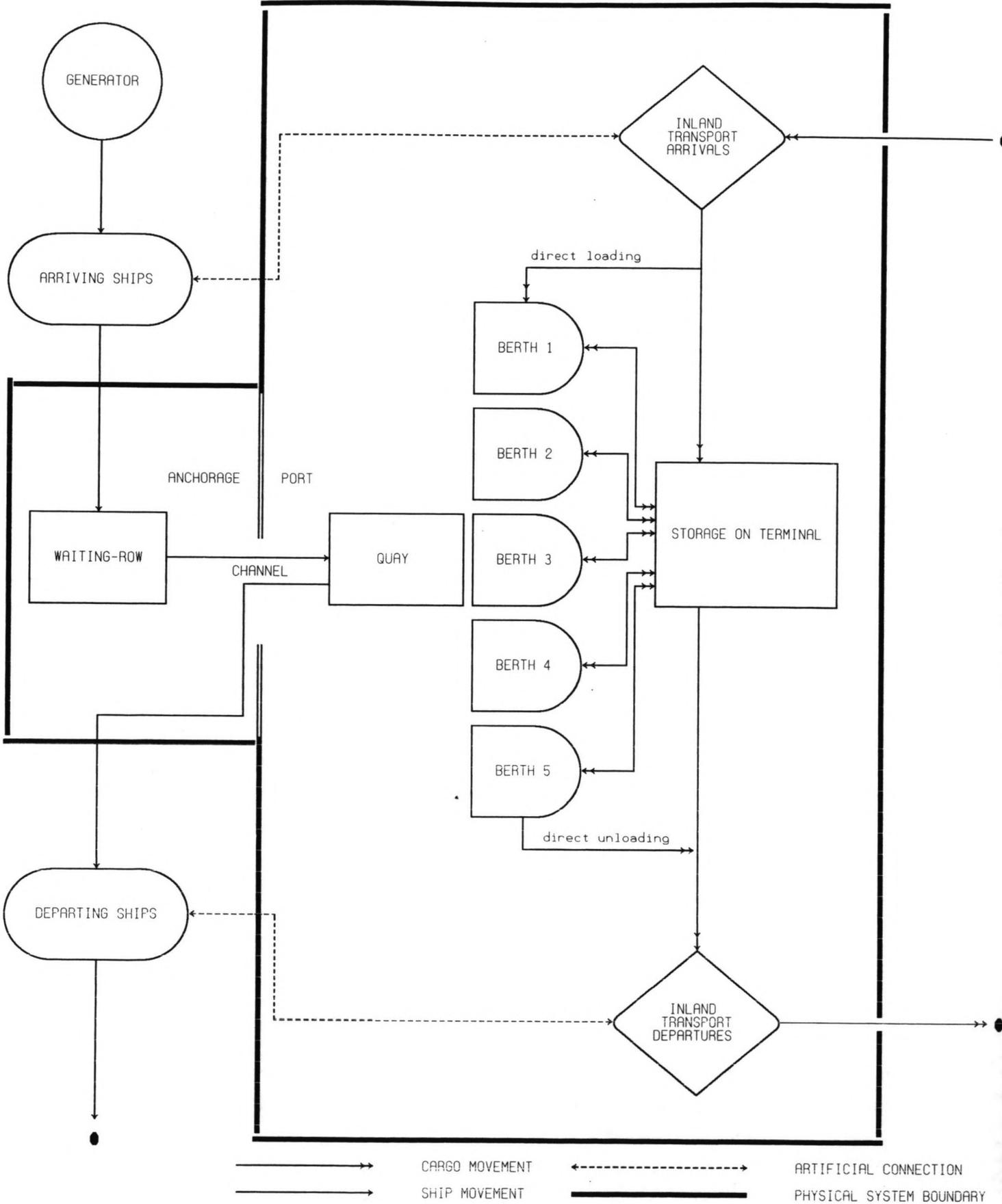
The route of the import-cargo is vice versa: the cargo enters the system when it is unloaded from a ship; it either continues directly by inland transport or is stored on the terminal. In the latter case the departure from the terminal by inland transport takes place at a later date, again depending on the dwell-time-distribution and on the moment of departure of the ship with which the cargo was imported.

The movements of ships and cargo in the port-system are illustrated in Figure 4.1.

Port-activities can be restricted in the model by an extensive range of circumstances:

- * Shifts: the unloading and loading of cargo can only take place when shifts are active on the terminal; the user can define the length and daily number of shifts.
- * Weekends: on Saturdays and/or Sundays inland transport may be absent; also shifts may not take place in weekends, causing an absence of unloading and loading activities.
- * Tide: ships that wish to enter or leave the port through the entrance channel of the harbour may be restricted in doing so due to a tidal window.
- * Bad weather conditions: bad weather can occur, causing windspeeds which are too high for terminal-activities, inland-transport and sailing of ships and causing waveheights which are too high for ship-manoeuvring. For example in Taiwan: typhoons.
- * Strikes: all terminal-activities are cancelled when a strike is called.

Figure 4.1: port-system



- * Breakdowns of cranes: loading and unloading is delayed when one of the active cranes suffers a breakdown.

As stated above, the terminals are operated separately. The interaction between different terminals in one model is the fact that the sailing of ships (during mooring at a berth and departing from a berth) is restricted by the manoeuvring of other ships near the quay. Secondly, strikes and typhoons affect all terminals at the same time, causing a general restriction of terminal activities. For example, during a strike, the row at the anchorage will grow strongly, with vessels destined for all terminals.

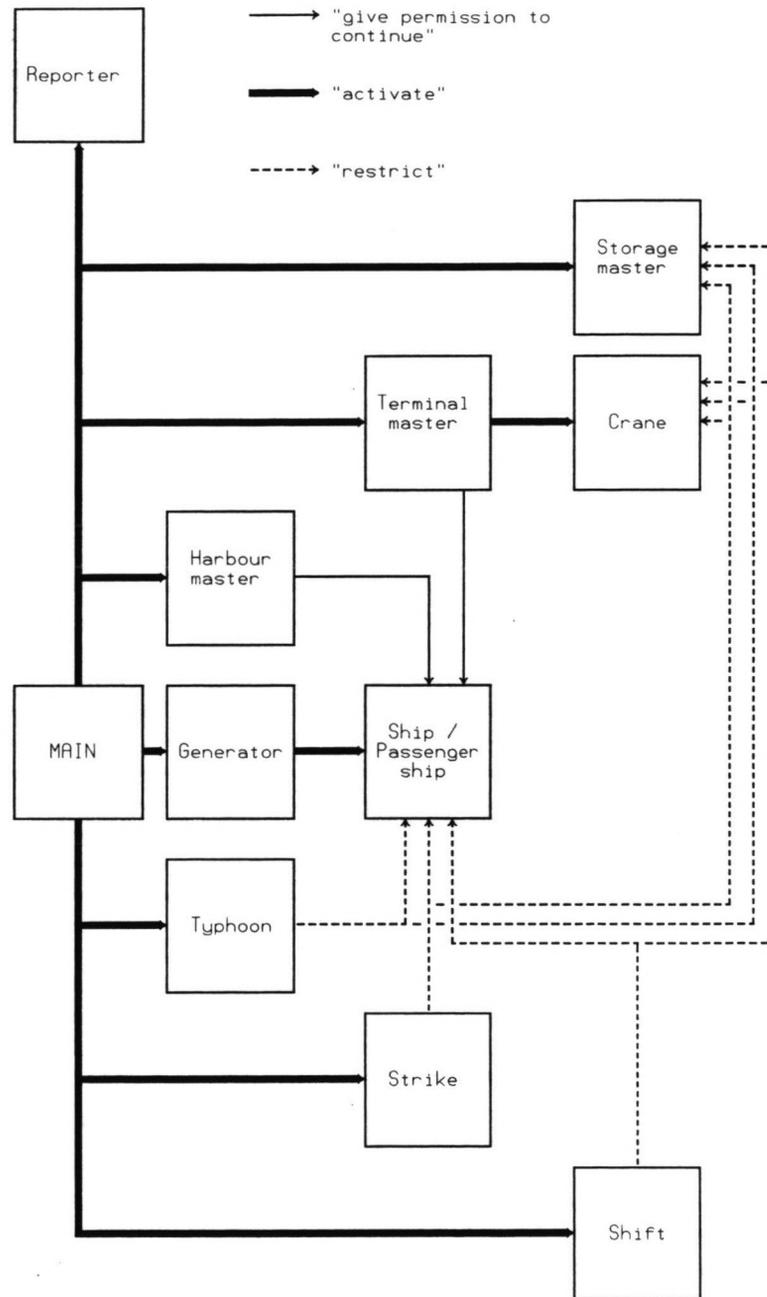
Apart from cargo carrying vessels, also the calling of passengerships at the port can be simulated with the model. This facility has been created especially for Pontianak.

4.3 Components with an own process-description

All activities which take place in the model, as described in the previous paragraph, are divided into different groups. Each group represents the activities which are executed by one specific component of the model. These groups of activities therefore form the process-description of that component. The components can be either single or class components. The components which have an own process-description in this model (and which are dealt with in the remaining paragraphs of this chapter) are:

- * GENERATOR (class component; Par. 4.4)
- * SHIP (class component; Par. 4.5)
- * HARBOUR-MASTER (single component; Par. 4.6)
- * TERMINAL-MASTER (single component; Par. 4.7)
- * CRANE (class component; Par. 4.8)
- * STORAGE-MASTER (single component; Par. 4.9)
- * SHIFT (class component; Par. 4.10)
- * TYPHOON (single component; Par. 4.11)
- * STRIKE (single component; Par. 4.12)

Figure 4.2: relations between components



- * PASSENGERSHIP (class component; Par. 4.15)
- * MAIN (single component; Par. 4.13)
- * REPORTER (single component; Par. 4.14)

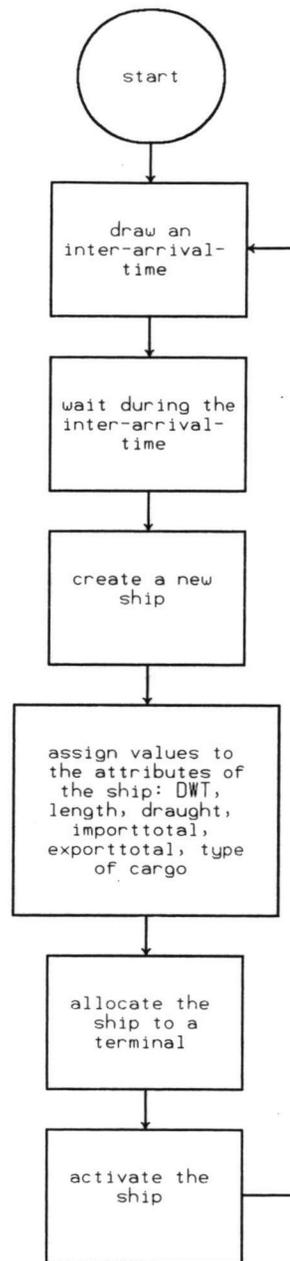
The latter two do not specifically refer to components which are named in the summarized model-description in Paragraph 4.2. However, they are required in the model and therefore they are described separately in the last two paragraphs of this chapter. The system component *Main*, which appears in the obligatory *Main*-module, reads all input information and initiates most processes; the component *Reporter* produces output-information at the end of a simulation-run.

Two important comments must be made at this moment. In first place, it should be remembered that apart from the components with possess an own process-description, there are several other components in the model; however, these components are data components and they solely play a passive role in the model. Therefore they will not be described separately in this chapter, but they will be mentioned in connection with the descriptions of the other components. These data components are:

- * ARRIVALDAY (class component)
- * DEPARTUREDAY (class component)
- * BERTH (class component)
- * TERMINAL (class component)
- * CARGOTYPE (class component)
- * SHIPCLASS (class component)

Secondly, it should be stated that in spite of the fact that the processes of the components are described separately, it is unavoidable that many of them are in some way related. This aspect occurs in three different ways: activation/passivation of other components, restricting the activities of other components, giving permission to other components to continue their activities. The influence of a component on other components' processes is performed by changing the values of the other components' parameters. Figure 4.2 shows a diagram of the relations between the components.

Figure 4.3: process of the generator



4.4 Generator

The generator is a class component; for each class of ships a generator is activated. It is the task of a generator to create ships and to assign values to the main characteristics of each ship. Figure 4.3 shows the flow-chart of this component.

The arrival of ships of a shipclass is modelled to take place based on a negative exponential inter-arrival-distribution. Therefore, the interval-time at which a generator becomes active, which represents the interval-time at which ships arrive at the system, alias the *Inter-Arrival Time (IAT)* of ships, is drawn from a Prosim-randomstream *Exponential* for all generators. The distribution has a user-defined mean value. A negative exponential distribution can be described by the probability density function $f(t)$ of a variate t :

$$f(t) = \frac{1}{\lambda} e^{-\lambda t}$$

in which:

λ = average arrival rate ($1/\lambda$ = average inter arrival time)

A negative exponential distribution with an independent arrival process (this means that the arrivals are not interrelated and λ is time-independent) can be regarded as a Poisson distribution. According to general simulation experience this is the best matching distribution for a service system, as is the case in this model. Also for Pontianak, observations have shown inter-arrivaltimes to occur according to this distribution.

The user also has a second option. It is possible to simulate the circumstance that the operator of a terminal has made an agreement with a shipping company to maintain a regular service, creating a more regular arrival-pattern of ships of the shipclass(es) of that shipping company. The arrival-pattern may even be regular to such a degree, that another distribution of inter-arrivaltimes (for example: Erlang-10 or normal) may be better fitting than the negative exponential distribution. Therefore, another distribution may be requested, depending on the available information of expected inter-arrivaltimes and on empirical arrival rate data.

After creating a ship, the generator assigns values to the length and draught of the ship. The length and draught depend on the dead weight tonnage (DWT) of a ship. Therefore the generator assigns a DWT-value to each ship. Based on the DWT-value, the length and draught are determined. This is performed by using tables of DWT/length-relations and DWT/draught-relations for different types of ships. The value of the draught is raised by 15%, representing the underkeel clearance, and the length is raised by 10%, accounting for

the space between the vessels at the quay.

The generator also assigns a value to the consignment size of a ship; this means that the quantity of import-cargo and the quantity of export-cargo are determined. The characteristics of the distributions of these quantities (mean, deviation, possible lower and upper boundaries) should be made dependent of the dead weight tonnage of the ships. This can be performed by drawing the consignment size from especially created tables of DWT/consignment size-relations (similar to the assignment of values for length and draught) or from distributions, defined by the user for each shipclass. For Pontianak the range in dead weight tonnage in one shipclass is small (mean value ± 7 to 14%) so the method of user defined distributions can be applied.

Each cargo-type in the port-system of the commodity breakbulk has a percentage of the cargo which has to be stored under cover in sheds or warehouses. In order to create a dispersion in the arrivals and departures of cargo, which requires covered storage, the generator defines a percentage of cargo which is in need of covered storage, drawn from a user defined distribution. For ships other than breakbulk-ships, whose cargo does not require covered storage, the default values of the mean value and standard deviation of that normal distribution are both zero. For container-ships the generator also assigns a value to the percentage of forty feet-containers on the ship.

The final ship-characteristic, which is created by the generator, is the destination to which a ship sails, inside the port. An arbitrarily generated ship can only sail to those terminals which have the facilities to handle the specific cargo-type which is transported by the ship. Therefore, the question must be answered which ship-classes (each with their own type of cargo) are accepted by which terminals. In other words: to which terminals can ships of one ship-class sail and how is this distribution of ships between the different terminals executed?

For each shipclass, the user has to define the distribution of destinations e.g. what percentage of arrivals of ships of one shipclass is received by each terminal. The distribution should be based on empirical information. The component *Main* shapes the user defined distribution into a distribution of the cumulative values of the percentages of arriving ships. From this discrete distribution, the generator randomly draws a destination.

The algorithm for allocating ships to terminals is illustrated by the following example. A port has four terminals (named I, II, III and IV) and is called at by ships of two ship-classes (named A and B). The cargo-type which is transported by ships of class A can be transhipped at terminals I, II and IV. Available data and predictions show that 50% of the ships of class A have terminal I as destination, 15% sail to terminal II and 35% are destined for terminal IV. The cargo-type which is transported by ships of class B can only be transhipped at

Table 4.1: distribution of terminal-destinations

SHIP-CLASS A		
Terminal	Destination percentage	Cumulative destination percentage
I	50	50
II	15	65
III	0	65
IV	35	100
SHIP-CLASS B		
Terminal	Destination percentage	Cumulative destination percentage
I	0	0
II	0	0
III	100	100
IV	0	100

terminal III. These data are shown in tabular form in Table 4.1.

When a ship has been generated, the generator draws a random number from a uniform distribution on the interval 0-100. Based on the table of cumulative destination percentages, the terminal for which the ship is destined is determined. For example, a randomly chosen value of 53 would appoint a ship of class A to terminal II and a ship of class B (naturally) to terminal III.

An alternative for having one generator per shipclass and then dividing the ships of one ship-class between one or more of the terminals (as described above) is having several generators per terminal. In that case each generator generates ships of one ship-class for one specific terminal. There is no difference between the chosen procedure and the alternative procedure in case ships of one ship-class attend just one terminal. There is also no difference in the amount of information required to perform either of the procedures. The advantage of the alternative procedure is that a distribution of destinations (as shown in Table 4.1) does not have to be produced by the user. The disadvantage is that, if several ship-classes attend more than one terminal, many more components *Generator* have to be created. Comparing the disadvantage to the advantage, the disadvantage has been considered greater and the alternative procedure has therefore not been applied in the model.

Figure 4.4: process of a ship, part 1

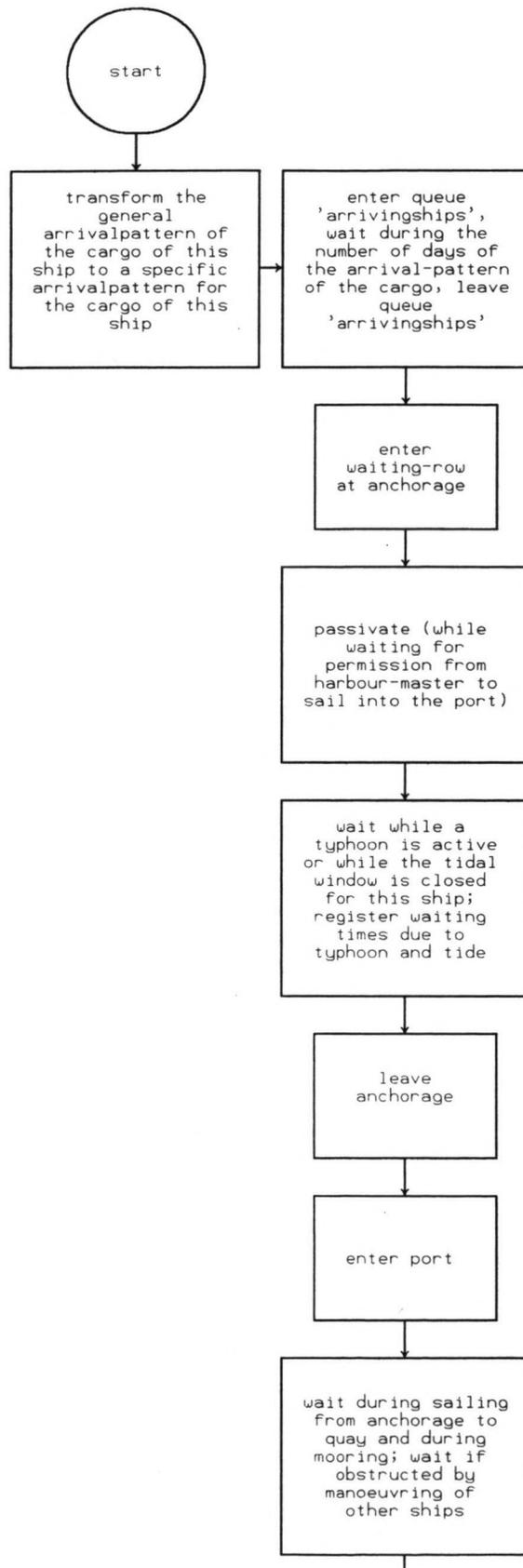


Figure 4.5: process of a ship, part 2

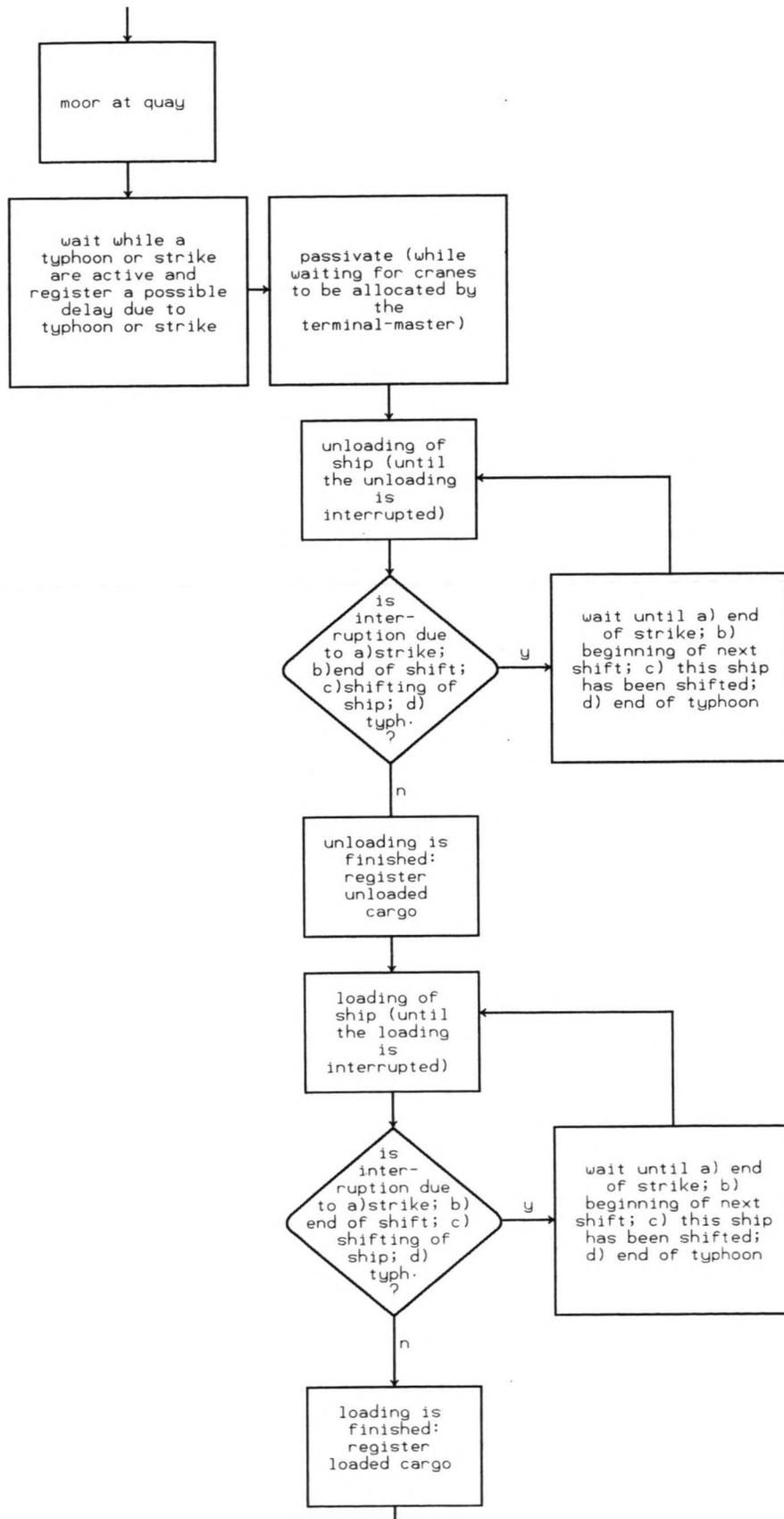
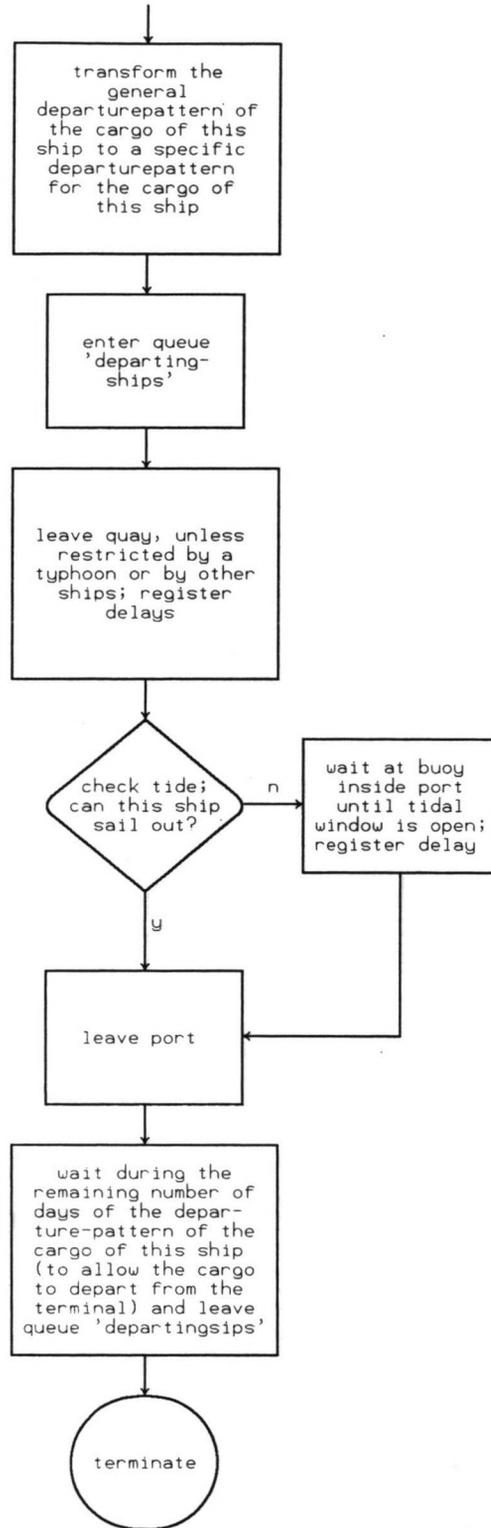


Figure 4.6: process of a ship, part 3



Finally in the module *Generator*, when all characteristics are defined, the generator activates the ship, generates an inter-arrivaltime and waits during this period before creating the next ship.

4.5 Ship

After being activated by the generator of its shipclass, a ship starts her process in the port-system. The flow-chart of this process is shown in Figures 4.4/4.5/4.6. During its process, a ship covers a route through a number of Prosim-queues. The stays in the queues can either be consecutive or simultaneous; Figure 4.7 demonstrates this. The route through the queues is described in this paragraph.

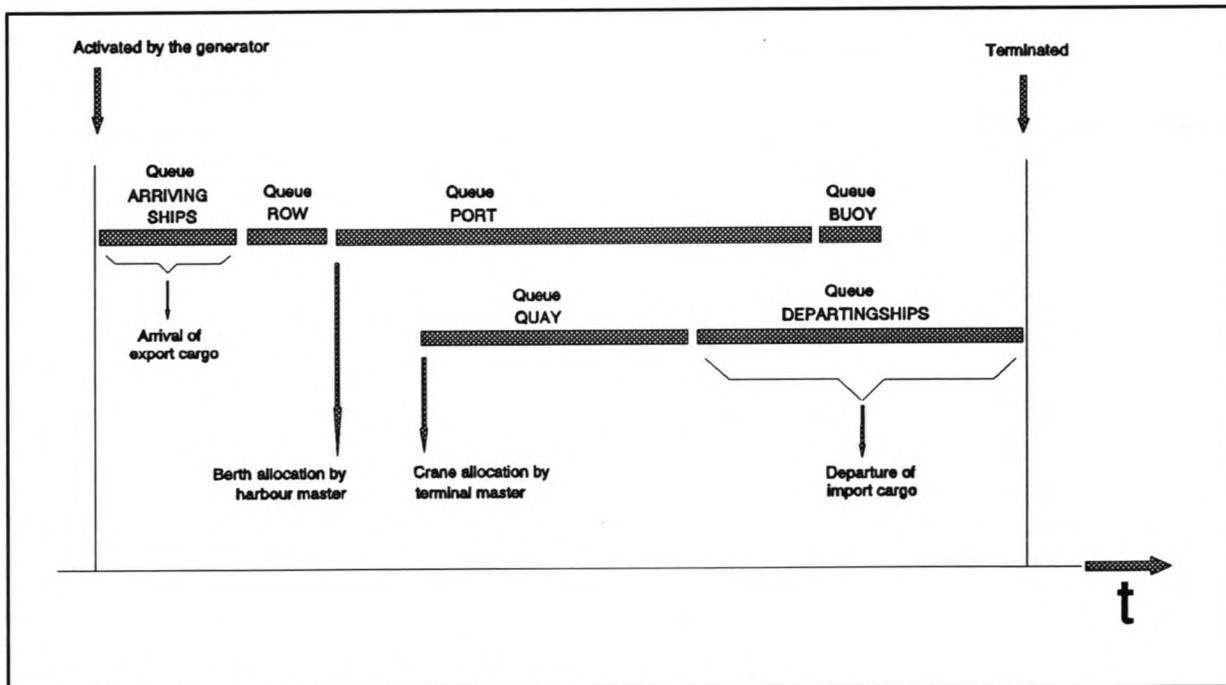


Figure 4.7: route through *queues* in the process of a ship

The moment of activation by the generator is not the same as the actual arrival-time at the port. During the first part of its process a ship is not physically present in the port-system. This is due to the fact that the arrivals of export-cargo of the ship are dependant on the arrivaltime of the ship and on the length of the arrival-pattern of the cargo. This means that the day, on which the ship is activated, is the first day of arrivals of export-cargo of the ship and that the day on which the ship enters the port-system physically, by joining the waiting-row at the anchorage, is the last day of possible arrivals of export-cargo. The arrival-pattern of all cargo-types are constructed at the same length; in this way the pattern of inter-arrivaltimes at the anchorage remains identical to the pattern of shiparrivals which is created

by the generator.

Table 4.2

CARGO ARRIVAL PATTERN										
Day	-9	-8	-7	-6	-5	-4	-3	-2	-1	0
Percentage of cargo arrivals	5	10	20	25	20	10	5	0	0	5
Total = 100%										

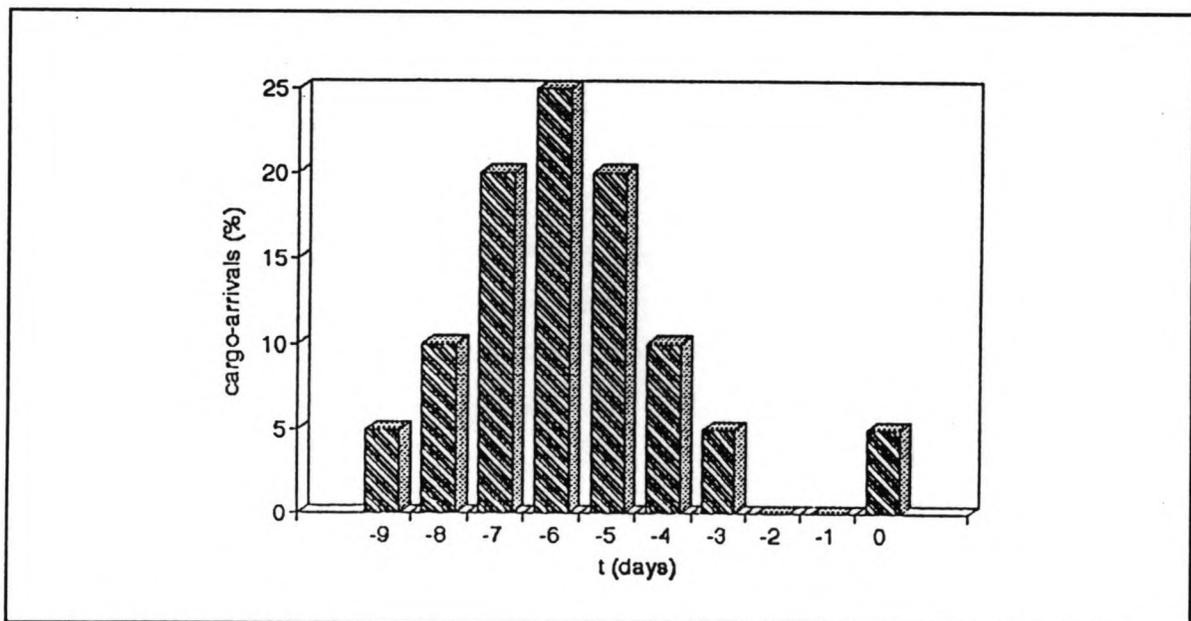


Figure 4.8: cargo arrival pattern

The cargo-arrival-patterns, which consist of user-defined percentages of arrivals of export-cargo on each day in the duration of the pattern, are shaped in general for each cargo-type. An example of a cargo-arrival-pattern is given in Table 4.2 and Figure 4.8, with day 0 representing the day of arrival of the ship. Export-cargo, which arrives on day 0, is cargo which is transferred directly from the inland-transport mode onto the ship. For a day during the arrival-pattern on which no inland transport arrivals occurs a *zero* is entered: such a day can be part of the original pattern (in the example: day -2 and day -1) or can be entered into the pattern depending on the time of arrival of a ship (for instance: absence of inland transport on weekend-days and during typhoons and strikes). If no inland transport takes place on Saturdays and/or Sundays, the specific arrival pattern of the cargo of a ship must be reshuffled. This reshuffle of the arrival-pattern of a ships cargo is the first element in the

process of a ship. The reshuffle takes place in the macro *Arrivalpattern*.

The way in which the arrival-pattern is constructed is explained in detail in Annex 1.2 and the method of reshuffling the pattern in the macro *Arrivalpattern* is described in greater detail in Annex 2.15.

The time during which the ship is artificially present, is spent in the queue *Arrivalpattern*. The ship joins this queue after the macro *Arrivalpattern* has been called. If a strike or typhoon is taking place at that moment, interrupting the arrival of cargo, the cargo-arrival-pattern is reshuffled again; this time in the macro *Patternchange*. This possible second reshuffle is performed in such a way that the pattern of ship-arrivals is not distorted. The ship stays in the queue *Arrivingships* during a period equal to the length of the cargo-arrival-pattern and then leaves the queue. While staying in the queue *Arrivingships*, the storage-master registers the arrival of the ships' export-cargo.

Next the ship joins the queue *Row*; this is the waiting-row at the anchorage. The ship is now physically present at the port. If the ship belongs to a shipclass which has priority, it also joins the queue *Priority_row*. At this moment the ship passivates itself, in order to wait for permission from the harbour-master to enter the port. This permission is received by means of being reactivated by the harbour-master. The ship then leaves the queue *Row*; this can be delayed due to bad weather or a closed tidal window, temporarily detaining the ship at the anchorage. After leaving the queue *Row*, the ship enters the queue *Port*; this queue represents all the ships inside the port (between the moment of leaving the anchorage and leaving the berth).

The time needed for the ship to leave the anchorage, sail through the entrance channel, possibly turn in a turning basin and go to its berth is called *mooring-time* in the model; the mooring-time has been made dependant of the shipclass to which the vessel belongs. For each ship the mooring-time is drawn from a user-defined distribution. The mooring procedure can be prolonged if the ship is obstructed by another ship, also manoeuvring in the area near the berth in question. This area is defined as the area in front of the berth in question and in front of the two adjacent berths on either side. The other ship can be mooring at one of the berths or departing from one of the berths. While the other ship is doing so (during a user-defined period of time), the ship in question has to wait.

When a ship has moored at a berth, a typhoon or strike may be active, hindering the start of unloading and loading of cargo. The possible delay due to this restriction is registered. Then the ship joins the queue *Quay*, which is a queue of all ships in the port system that are moored and which are being unloaded/loaded; next the ship passivates itself in order to let

the terminal-master allocate cranes to the ship.

The ship is reactivated by the terminal-master when the cranes have been allocated. At that time the actual unloading/loading-procedure starts. The length of the unloading/loading-procedure is defined by integrating the function *Ship_load*:

$$\frac{d(\text{Ship-load})}{dt} = \text{Ship-rate}$$

in which:

Ship_load(*t*) = the amount of unloaded and loaded cargo of the ship at moment *t*
Ship_load(0) = 0
Ship_rate = total net effective rate of the cranes that are handling the ship (plus the total net effective rate of the ship's gear, if it is being used)

When the value *Ship_load*(*t*) exceeds the consignment-size (= sum of import- and export-cargo) the integration stops and the unloading/loading procedure thereby finishes. During that procedure the value of *Ship_rate* may change, for example due to the breakdown of a crane. During the procedure the integration-process may be temporarily stopped due to strikes, typhoons, the end of shifts and the shifting of the ship. When the unloading and the loading have finished, the unloaded import-cargo and the loaded export-cargo are registered.

At this point the ship leaves the queue *Quay*. Also at this point the import-cargo can start leaving the terminal with the inland transport. For this reason, the ship now enters the queue *Departingships*, which is the queue containing ships which have finished with the unloading/loading and whose cargo is departing from the terminal with inland transport. The principle of this queue is identical to that of the queue *Arrivingships*. The cargo-departure-patterns consist of user-defined percentages of departures of import-cargo on each day in the duration of the pattern. An example of a cargo-departure-pattern is given in Table 4.3 and Figure 4.9, with day 0 representing the day of departure of the ship. Import-cargo, which departs on day 0, is cargo which is transferred directly from the ship onto the inland-transport mode.

Also in the case of a departing ship, the departure-pattern of the import-cargo may need to be adapted due to weekend-days without inland-transport. Departing ships are not tied to a specific moment for leaving the queue *Departingships* (as is the case with arriving ships in *Arrivingships*); therefore the cargo-departure-pattern of the ship is not reshuffled but is increased with the number of Saturdays and Sundays with no inland transport. The calculation

Table 4.3

CARGO DEPARTURE PATTERN										
Day	0	1	2	3	4	5	6	7	8	9
Percentage of cargo departures	5	0	0	5	10	20	25	20	10	5
Total = 100%										

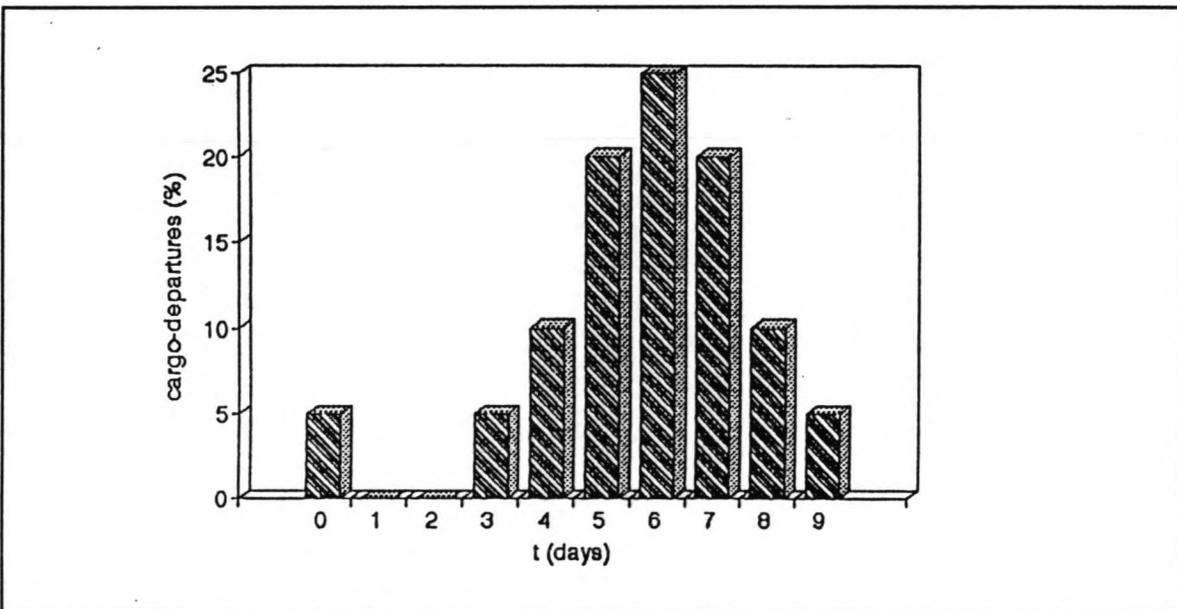
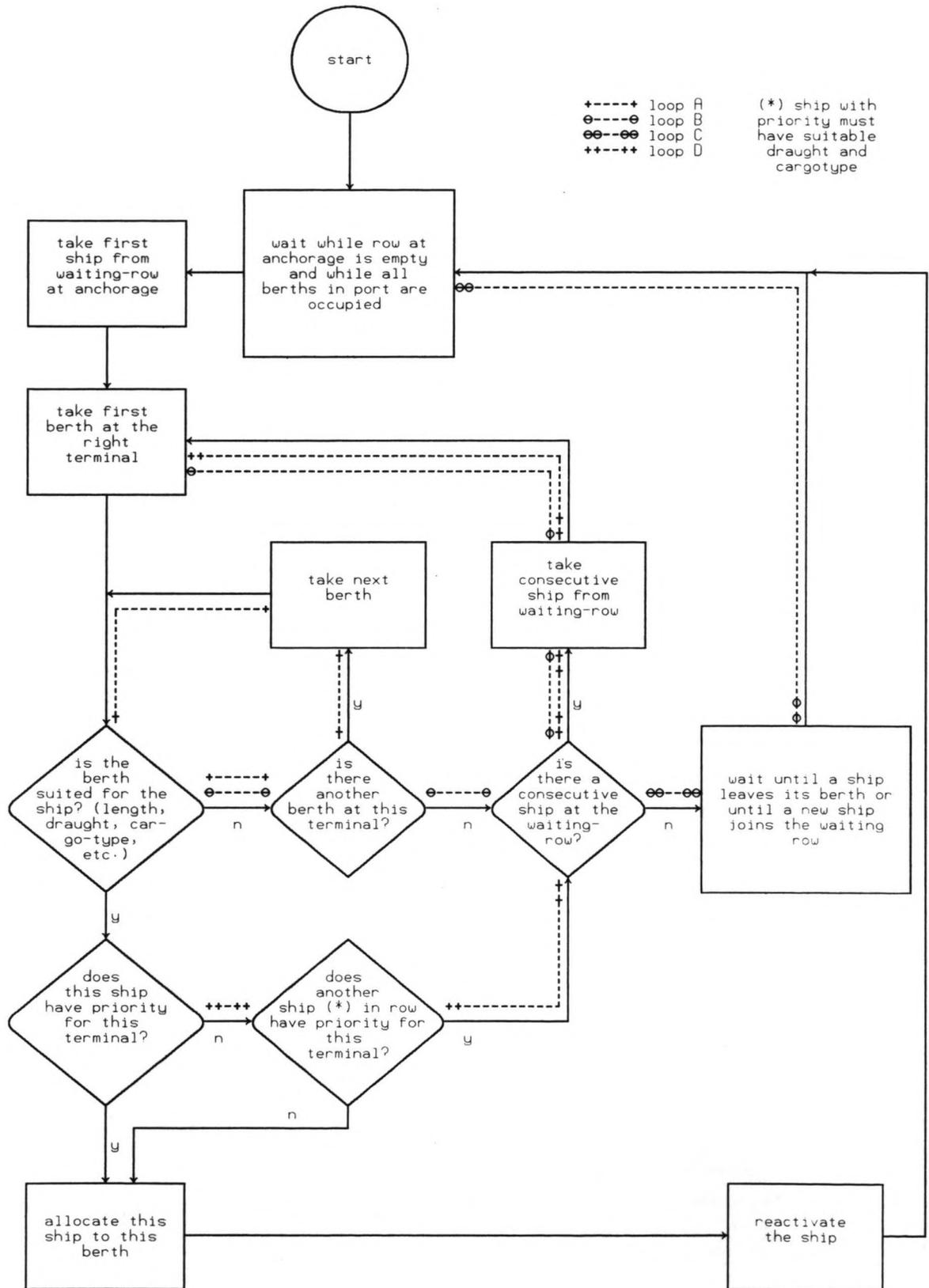


Figure 4.9: cargo departure pattern

of the number of weekenddays is executed before the ship enters queue *Departingships*, by calling macro *Departingships*. The way in which the departure-pattern is constructed is described in detail in Annex 1.2.

Unless restricted by a typhoon or by the manoeuvring of another ship, the ship then leaves the queue *Port*, thereby creating a free space for another ship to moor. Then the ship leaves the port, unless it cannot sail out due to the fact that the tidal window is closed for the ship. During the tidal restriction it stays in the queue *Buoy*, symbolizing a buoy or berth inside the port (as is present in for example Kaohsiung) at which ships can stay when waiting for the tidal window to open.

Figure 4.10: process of the harbour-master



After leaving the port the waiting-time at the anchorage, the mooring-time and the occupation-time at the berth are registered. The ship remains in the queue *Departingships*. The ship is now only artificially present in the system. The ship stays in the queue *Departingships* during a period equal to the length of the cargo-departure-pattern plus the possible extra days, as described above) and then leaves the queue. While staying in the queue *Departingships*, the storage-master registers the departure of the ships' import-cargo. Then the ship terminates itself and the process comes to an end.

4.6 Harbour-master

The task of the harbour-master is to escort ships into the harbour and to allocate them to a berth. This means that every time a ship joins the waiting-row at the anchorage, the harbour-master tries to find a suitable berth for the ship and every time a ship leaves the quay, the harbour-master tries to find a ship which can take the thus created empty space. The harbour-master operates according to the *First In, First Out*-principle. However, per class, ships can be given priority; in this case they are served by the harbour-master before other ships.

Before describing the process of the harbour-master (of which a flow-chart is shown in Figure 4.10) in detail, it first must be explained that the harbour-master has to consider that each berth can either be a so-called *single berth* or a *multiple berth*. A single berth is hereby defined as a berth at which a maximum of one ship can moor and of which the cranes can only be used for that berth; a multiple berth is hereby defined as a quay which can accommodate one or more ships, depending on the length of the ships and the length of the quay. The principle of multiple berths was originally chosen so that the position of a ship at the quay could be taken into account; also cranes could be shifted from one ship to another and ships could be shifted along the quay to make place for an extra ship. Due to switching from Kaohsiung to Pontianak, this principle was no longer necessary. It will be discussed further in Paragraph 4.16 and in Annex 3.2. In the Pontianak-model all berths are multiple berths. The lengths of ships and multiple berths is taken into account, the position of ships at the quay is be specified.

The process of the harbour-master starts by waiting when all berths are occupied or when the waiting-row is empty. When this is not the case, the harbour-master takes the first ship from the waiting-row and tries to allocate this ship to a berth. He does so by checking all berths of the terminal to which the ship is allocated, one by one. Whether or not a suitable berth is found for the ship depends on the following parameters:

- * The cargotypes which are handled at the berth (is the cargo-type which is transported by a ship among the cargotypes which are transhipped at the berth?)

- * The availability of sufficient quay-length to accommodate the ship
- * The maximum number of ships at the berth
- * The waterdepth at the quay

If at least one of the checks is negative, the harbour-master takes the next berth at the same terminal and performs all checks again (loop A in Figure 4.10). If no berth is found for the first ship in the row, the harbour-master goes to the next ship in the row (loop B in Figure 4.10). The harbour-master continues in this manner until he has found a matching ship and berth. If he doesn't find a matching couple, he waits until a ship leaves its berth or until a new ship enters the waiting-row and restarts the routine (loop C in Figure 4.10).

If all checks are positive, the ship can still not be allocated to the berth if it does not have priority for the terminal, while another ship, which (1) is also waiting at the anchorage, (2) is destined for the same terminal and (3) also fulfils the cargotype- and draught-conditions, has priority (it is in the queue *Priority_row*). In that case, the ship with priority has the right to go first and the ship which is being checked by the harbour-master has to wait. The harbour-master therefore continues his procedure with the next ship in the row (loop D in Figure 4.10); he will then automatically reach the ship with priority.

In this context, it should be mentioned that the reason for the procedure as described above (checking the ships in the waiting-row at the anchorage one by one, starting with the first and each time checking whether there is ship with priority for the same terminal in the queue *Priority_row*) is that the ships do not join the waiting-row in order of priority. If that is the case, the first ship to be checked by the harbour-master is always a ship with priority. However, when, in this situation, a ship with priority cannot be allocated to a berth and the harbour-master continues with ships further on in the waiting-row (for example due to insufficient quay-length at a multiple berth), the possibility arises that another ship, which is destined for the same terminal but is without priority (and for example has a smaller ship-length), is allocated first. A long vessel with priority would therefore find it very hard to be allocated to a berth. To avoid this incorrect action, the harbour-master would have to assure himself if a ship with priority is present at the front of the row, each time he checks a ship further on in the row. Thus, a procedure would be required, which is equally extensive as the current one.

Finally, when all checks are positive for a ship, it is allocated to that particular berth. The ship is then reactivated and the harbour-master can restart its process.

4.7 Terminal-master

The task of the terminal-master is to allocate cranes to ships which have moored at a berth. As shown in the flow-chart in Figure 4.11, the terminal-master is activated at the moment the number of ships in the queue *Quay* changes (this is the queue of all ships in the port system moored at a berth and ready to be or being unloaded/loading).

When a ship joins the queue *Quay* it requires cranes to be allocated. First the terminal-master checks the amount of available cranes (in case of Pontianak: gangs) at the berth. This is referred to as the *supply* of cranes. Secondly, the terminal-master checks the number of cranes which are required by the ship (the *demand* for cranes). The demand for cranes can for example be equal to the number of hatches of a vessel.

If the demand for cranes is available, the demanded number can be allocated. If the demand for cranes is not available, only the available supply of cranes can be allocated. In other words: the number of cranes which is allocated to a ship by the terminal-master is equal to the minimum of the supply and demand. The principle of allocating the minimum of supply and demand of cranes was originally chosen in order to simulate the circumstances that there is a shortage of cranes at a quay and that cranes can be shifted from one ship to another. For Pontianak the assumption is made (based on the available information on cargo handling at the Main Public Port) that the supply is always equal to or bigger than the demand and therefore the demanded number of gangs will always be allocated. This implies that the model does not supply information about the optimum number of gangs at a quay. The crane-allocation-principle is still applicable; it does not need to be changed, it just requires some simplifications. The original procedure of the terminal-master (including extensive use of the principle of supply/demand and including the possibility of shifting cranes) is described in Paragraph 4.16 and Annex 3.5.

After having allocated cranes to a ship, the terminal-master reactivates the ship and repeats its process from the start.

4.8 Crane

The status of a crane counts three different situations. The crane is either at rest, at work or having a breakdown. These three situations are also found in the cranes' process description. The flow chart of the cranes' process can be seen in Figure 4.12. A crane is activated by the terminal-master; the crane then goes from the rest-status into the work-status. This status can be interrupted temporarily by a strike, a typhoon or the end of shift and this status can be broken off by a breakdown or by the fact that all the ships' cargo has been unloaded and

Figure 4.11: process of the terminal-master

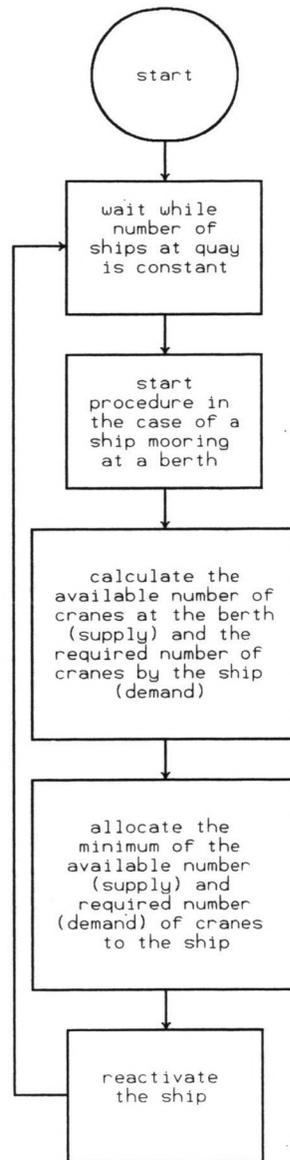
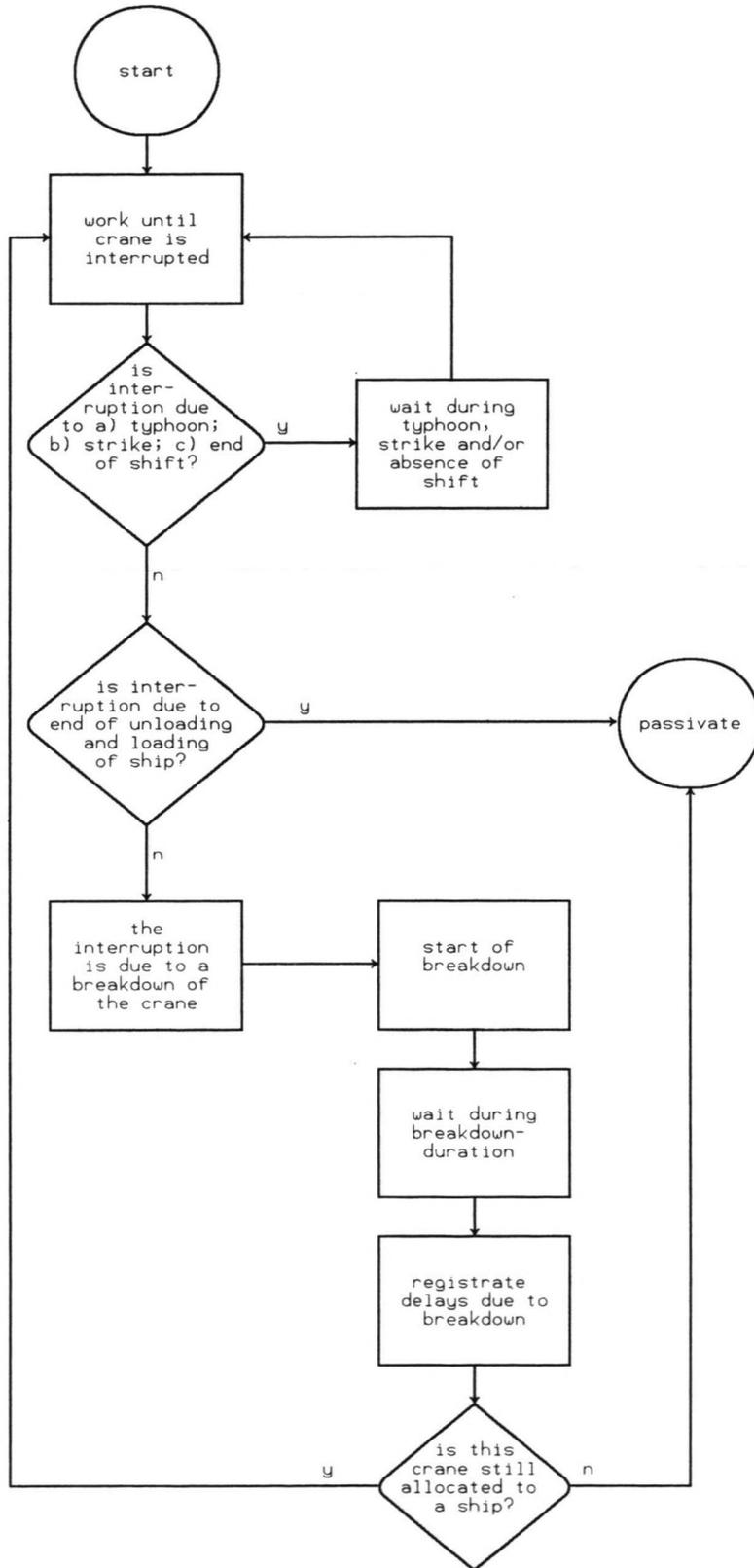


Figure 4.12: process of a crane



loaded. The temporarily interruption is ended when the strike or typhoon are over or when a new shift begins.

If all the required cargo has been handled, the crane goes into the rest-status. This status will be dealt with further on in this paragraph. First, attention will be paid to the breakdown-status. Each crane can suffer a breakdown. Based on empirical information the user must define the mean interval-time between two breakdowns of a crane. Based on this value, a distribution is created and from this distribution breakdown-inter-arrivaltimes are drawn for each crane. A breakdown starts when the period of a crane at work exceeds the generated breakdown-inter-arrivaltime. At that moment, the crane goes into the breakdown-status; the breakdown-duration is drawn from a user-defined distribution. The cargo unloading/loading-rate of the ship it was working for is diminished. No re-allocation of cranes due to breakdowns takes place.

After waiting during the breakdown-duration the breakdown is registered and a new breakdown-inter-arrivaltime is generated. If the ship which the crane was serving before the breakdown is still at the quay, the crane goes back to working for that ship, because during the breakdown, no other crane is allocated to the ship. If another ship has taken its place and the crane has been allocated to that ship during the breakdown-status the crane, starts to work for that ship. In these two cases the crane goes back to the work-status; otherwise the crane goes into the rest-status.

When the crane reaches the rest-status, it passivates itself and waits to be re-activated. Based on the annual period of time in which a crane is at work, the component *Reporter* calculates a first indication of the amount of time which is annually spent on the maintenance of a crane. The maintenance-time is proportional to the total working time: for example 8 hours maintenance per 500 hours working. However, the maintenance is not included in the cranes' process, because it is supposed to take place during the rest-status and not to interfere with the work-status.

The process of a crane can also apply to any crane substituting unit. This can be a terminal tractor which transports containers on terminal chassis on and off a RoRo-vessel or, in case of manual labour, a gang.

4.9 Storage-master

The storage-master is the component in the model which registers the cargo which arrives and departs with inland-transport and which is transhipped *indirectly*, meaning it has to stay on the terminal premises during a certain dwell time and is occupying storage-area c.q.

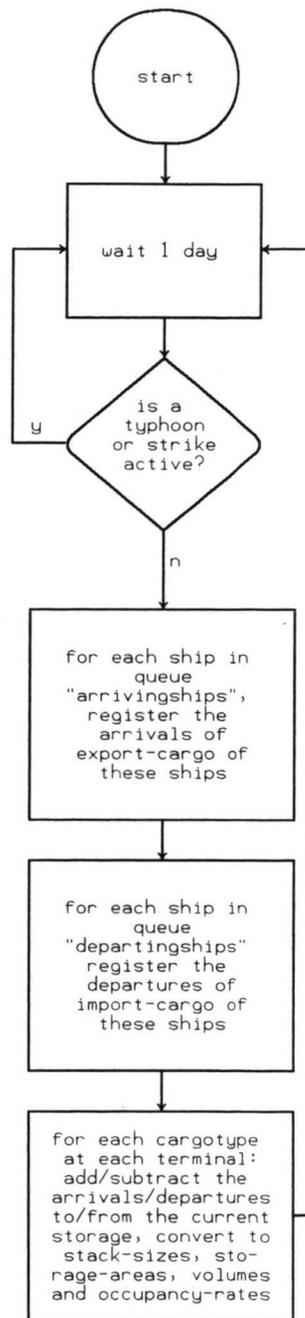
storage-volume during that period of time (as opposed to cargo which is transhipped *directly*: this cargo is loaded directly from the inland transport onto the ships and unloaded directly from the ships onto the inland transport). The storage-master registers this cargo-flow once a day, calculates the consequence of the cargo-flow to the storage-occupancy and converts the storage-occupancy into the required output-information. The flow-chart of the process of the storage-master is displayed in Figure 4.13.

The reason for the storage-master to become active at one day-intervals is that the cargo-arrival- and -departure-patterns consist of daily percentages of cargo-arrivals and -departures. At this point it must be remembered that, as stated in Paragraph 4.5, the cargo-arrival-pattern consists of percentages of arrivals of the ships' total cargo on each day in the period between being created by the generator and arriving at the anchorage. The percentages add up to 100%; the value for day 0 is the percentage of export-cargo that is loaded directly. The same principle is applied to the cargo-departure-pattern; this pattern contains the percentages of departures of the ships' total cargo on each day between leaving the quay and being terminated from the system. The sum of the percentages is 100%; the value for day 0 is the percentage of the ships' cargo that is unloaded directly. Examples of a cargo-arrival-pattern and departure-arrival-pattern are given in respectively Table 4.2/Figure 4.8 and Table 4.3/Figure 4.9. The way in which the patterns are constructed is explained in detail in Annex 1.2.

The process of the storage-manager can be described as follows: for each ship in the queue *Arrivingships* the storage-manager registers the percentage of arriving cargo of that ship on that specific day and multiplies it by the total amount of export-cargo of that ship. If that day is a weekend-day without inland-transport, the percentage is zero. This has been taken care of in the ships' process by reshuffling the cargo-arrival-pattern. Together this offers a quantity of arriving cargo for each cargo-type in the port; for breakbulk a distinction is made for cargo requiring covered storage and cargo requiring open storage. For each ship in the queue *Departingships* the storage-manager registers the percentage of departing cargo of that ship on that specific day and multiplies it by the total amount of import-cargo of that ship. If that day is a weekend-day without inland-transport, no percentages are taken from the cargo-departure-pattern. Together this offers a quantity of departing cargo for each cargo-type in the port; for breakbulk a distinction is made for cargo requiring covered storage and cargo requiring open storage.

Then, for each cargotype on each terminal in the port, the storage-master adds c.q. subtracts the total cargo-arrivals c.q. the total cargo-departures of that day to the existing quantity of that cargo-type in storage. The mutation to the storage-quantities due to the arrival and departure of cargo with the ships is registered in the module *Ship*.

Figure 4.13: process of the storage-master



Finally the storage-master converts the storage-quantities to the required output-information. This means that for containers the size of the import-stack, the export-stack, the empties-stack and the total required storage area are calculated, taking into account average stackheights and a gross-factor for travelling lanes and other gross area utilization. For breakbulk the required covered storage area and the required open storage area are calculated, taking into account the density of the goods, the desired stackheight and a gross-factor. For liquid bulk and dry bulk the desired storage volume is calculated, again taking into account a possible gross-factor and the density. Besides, for each terminal the total occupied storage area (for containers and breakbulk) and/or storage volume (for liquid and dry bulk) are calculated, resulting in an occupancy-rate for the terminal.

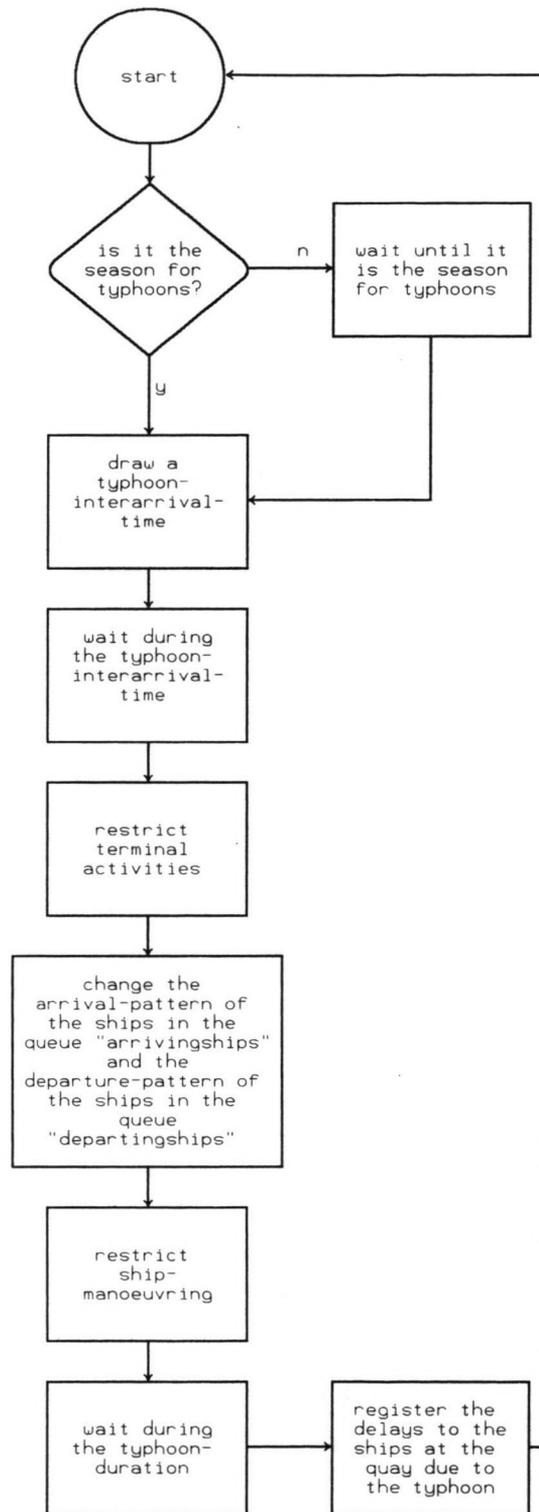
4.10 Typhoon

In this model a typhoon is the name used to simulate bad weather conditions in the port. These bad weather conditions effect the marine activities (manoeuvring of the ships) and/or the landside activities (unloading/loading and inland transport). The process description is illustrated by means of the flow chart in Figure 4.14.

The user can define the season in which bad weather conditions occur and the mean intervaltime at which they take place. Based on the mean intervaltime a distribution is created by the user from which typhoon-inter-arrivaltimes are generated. During the typhoon-season the typhoon waits during a period equal to the length of the typhoon-inter-arrivaltime and then becomes active. First, a typhoon-duration is generated, drawn from a distribution based on user-defined information.

The consequences of restricting the inland-transport is that the arrival-patterns of cargo of the ships in the queue *Arrivingships* and the departure-patterns of the ships in the queue *Departingships* have to be adapted. For departing ships this done by prolonging the stay in the queue *Departingships*. For arriving ships the reshuffling takes place in the macro *Pattern-change* which is called by the component Typhoon. The difficulty in reshuffling the arrival-pattern is that the length of the pattern must preferably remain the same, in order to keep the pattern of actual inter-arrival-times of ships at the anchorage identical to the original pattern of interval-times of activation of ships by the generator. If the end of the typhoon-spell falls within the stay of the ship in the queue *Arrivingships*, all percentages of arriving cargo of each ship of days during the typhoon are added up and transferred to the first day after the typhoon. An example of this procedure is demonstrated by Figures 4.15 and 4.16. The first of these two figures shows an undisturbed cargo-arrival-pattern (identical to the example in Paragraph 4.5) with *indirect* cargo arriving on days -9 to -3, no cargo arriving on days -2 and -1 and *direct* cargo arriving on day 0; the second of these two figures shows the effect

Figure 4.14: process of a typhoon



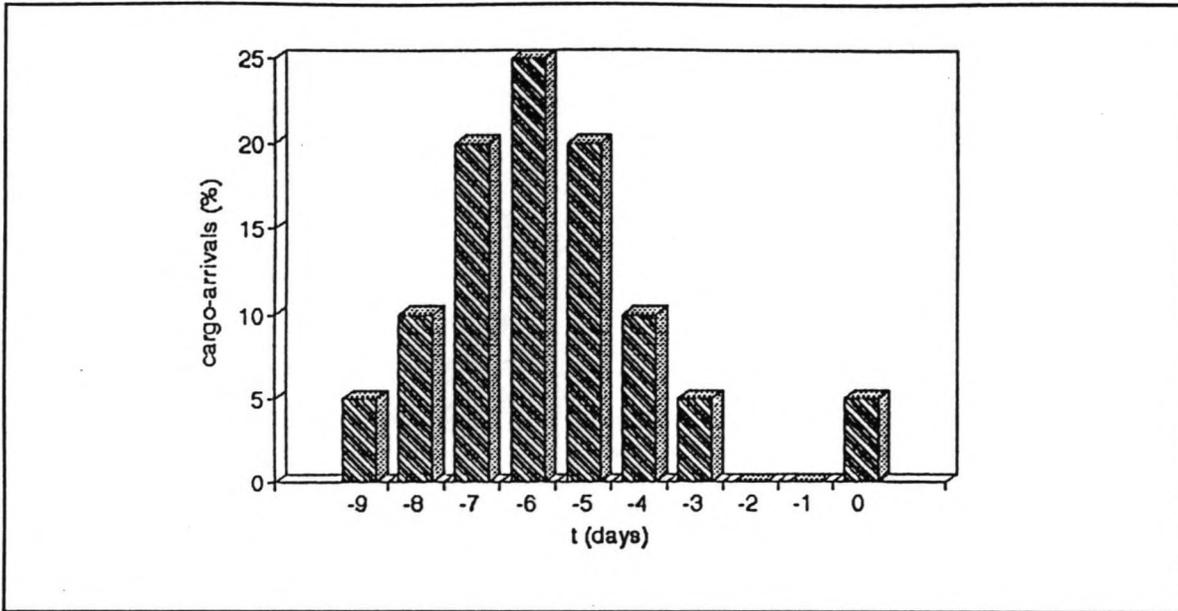


Figure 4.15: cargo arrival pattern

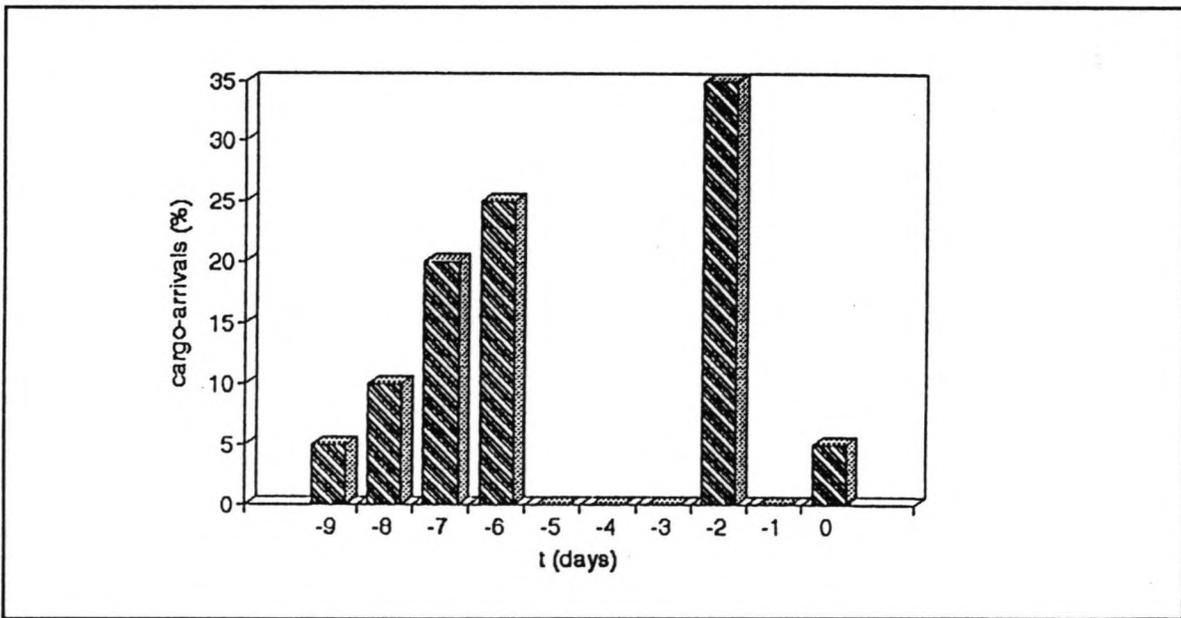


Figure 4.16: typhoon during cargo arrival pattern

to this pattern of bad weather conditions on days -5/-4/-3. The share of the cargo which should have been delivered on these three days (35%), is now delivered on day -2.

If the typhoon-spell ends after the intended stay of the ship in *Arrivingships* the ships' cargo-arrival-pattern is prolonged until the end of the typhoon and all percentages of arriving cargo of each ship of days during the typhoon are added up and transferred to the first day after the typhoon. This means that the arrival-pattern of ships at the anchorage is slightly altered; however, the difference can be considered negligible and, secondly, the arrival of cargo

during a typhoon must be avoided.

After reshuffling the cargo-patterns and after waiting during the length of the bad weather conditions, the component typhoon registers the delay to the ships at the quay due to the bad weather and then repeats its process from the start.

4.11 Strike

The strike is a component which restricts the terminal-operations (unloading/loading, inland-transport, registration of cargo-arrivals and -departures). Strikes are generated at interval-times, which are drawn from a distribution based on a user-defined mean value. The effect of a strike is identical to the effect of a typhoon on the landside-activities. Therefore this paragraph is very similar to the previous paragraph. The flow-chart of the components strike is shown in Figure 4.17.

A strike becomes active after waiting during the inter-arrivaltime of the strike. The component restricts the activities of the storage-master and adapts the cargo-patterns of ships in the queues *Arrivingships* and *Departingships* in an identical manner as described in Paragraph 4.10. Next the component generates a strike-duration, drawn from a user-defined distribution, and waits during a period of time with the length of that strike-duration. Finally, as with the component typhoon, the process ends with the registration of delays caused by the strike to the ships at the quay and then repeats its process from the start. If a typhoon and strike coincide, the cargo-patterns are adapted accordingly. However, in this case one difficulty arises: the method of registration of delays. This method is dealt with in Annex 2.10.

4.12 Shift

This class component, of which one component exists for each terminal, has the task to indicate the periods of time at which shifts are taking place at the terminal for which the component has been created. The user has to define the number of shifts that are active each day at each terminal, the length of each shift and the starting hour of each shift.

The process of the component shift is quite short. It is a constant repetition of the following procedure: wait during the shift, wait until the beginning of the next shift. During a shift loading and unloading of ships may take place, otherwise it may not. If the user defines weekend-days on which no shifts take place, the components waits with starting a shift during those days.

The flow-chart of the component shift is shown in Figure 4.18.

4.13 Main

This component has a threefold task. The first is to read the users' input-information, to check this information for errors and to create the harbour, the terminals and the ship-classes on the basis of that information. The second is to activate all components in the system (apart from the ships, which are activated by the generators, and the cranes, which are activated by the terminal-master). The third is to conclude a simulation-run. Figure 4.19 demonstrates the flow-chart of Main.

The input-information which is read by Main is written down by the user in User Data files. The program uses four files, one for the harbour-information (called *H-file*), one for the information of the terminal-information (called *T-file*) and two for the information of the ship-classes (called *S-file* and *D-file*).

The information about the harbour contains all data concerning the environmental conditions of the port: data concerning typhoons, strikes, the entrance channel and the tide. On the basis of the data for the tide, a tidal window is operated for the ships which are requesting to enter or leave the port. The user has to define the mean depth of the entrance channel, the M2-tide (daily low tide and high tide, moon-contribution to the tide) and the S2-tide (monthly spring-tide and neap-tide, sun-contribution to the tide). Based on this information a function-description for the water-depth in the entrance-channel is specified, allowing checks in the module *Ship* when ships require to pass the entrance channel.

The information about the terminals contains all data concerning the characteristics of the berths, the cranes, the shifts and the cargotypes which are handled at the terminals and further general information on the characteristics of the terminal. The information about the cargotypes contains, among others, the cargo-arrival- and -departure-patterns. As stated in above paragraphs, these patterns contain (for each cargotype) the percentages of daily arrivals and departures of cargo before the arrival of a ship at the port and after the departure of a ship from the port. The way in which such a pattern is constructed is described in Annex 1.2.

The user has to define the general length of arrival-patterns and departure-patterns. Main automatically adds zero-entry-days to the arrival-patterns which represent weekend-days with no inland transport. The number of zero-entry days defined by Main equals two plus another two for each five days in the arrival-pattern. All zero-entry days are placed at the beginning of the arrival-pattern; in case a reshuffle takes place for a separate, these zero-entry-days are used. An example of this procedure, which is performed in macro *Arrivalpattern* (see

Figure 4.17: process of a strike

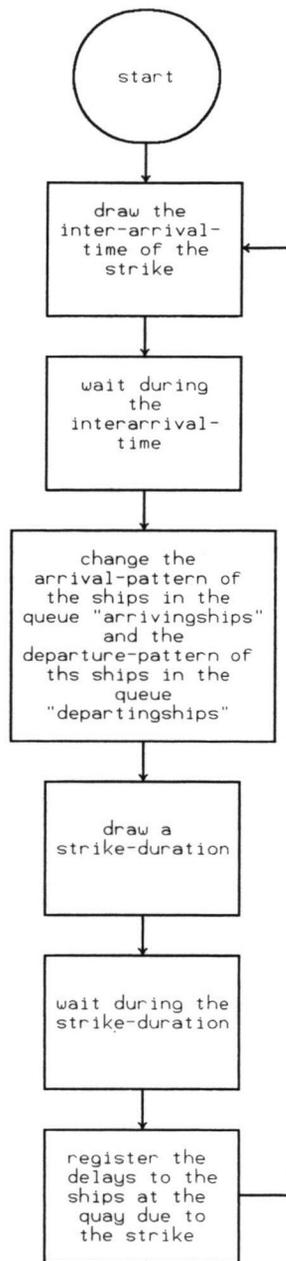


Figure 4.18: process of a shift

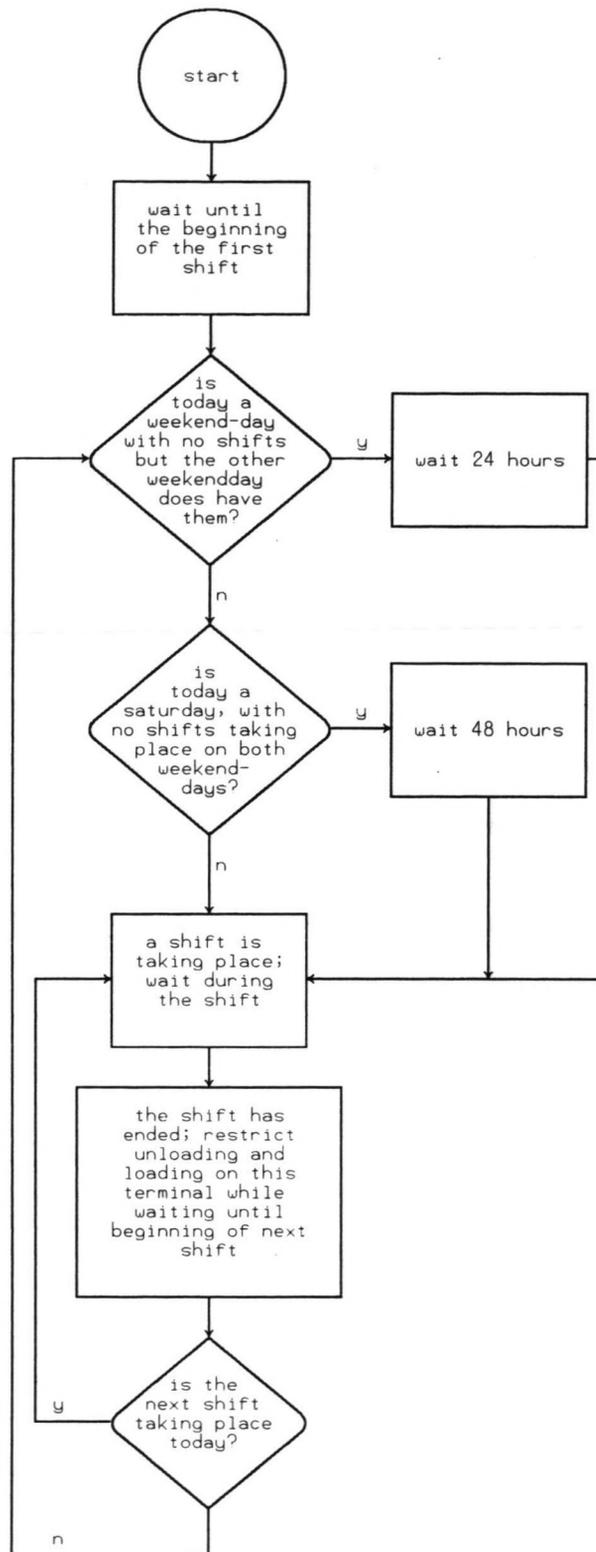
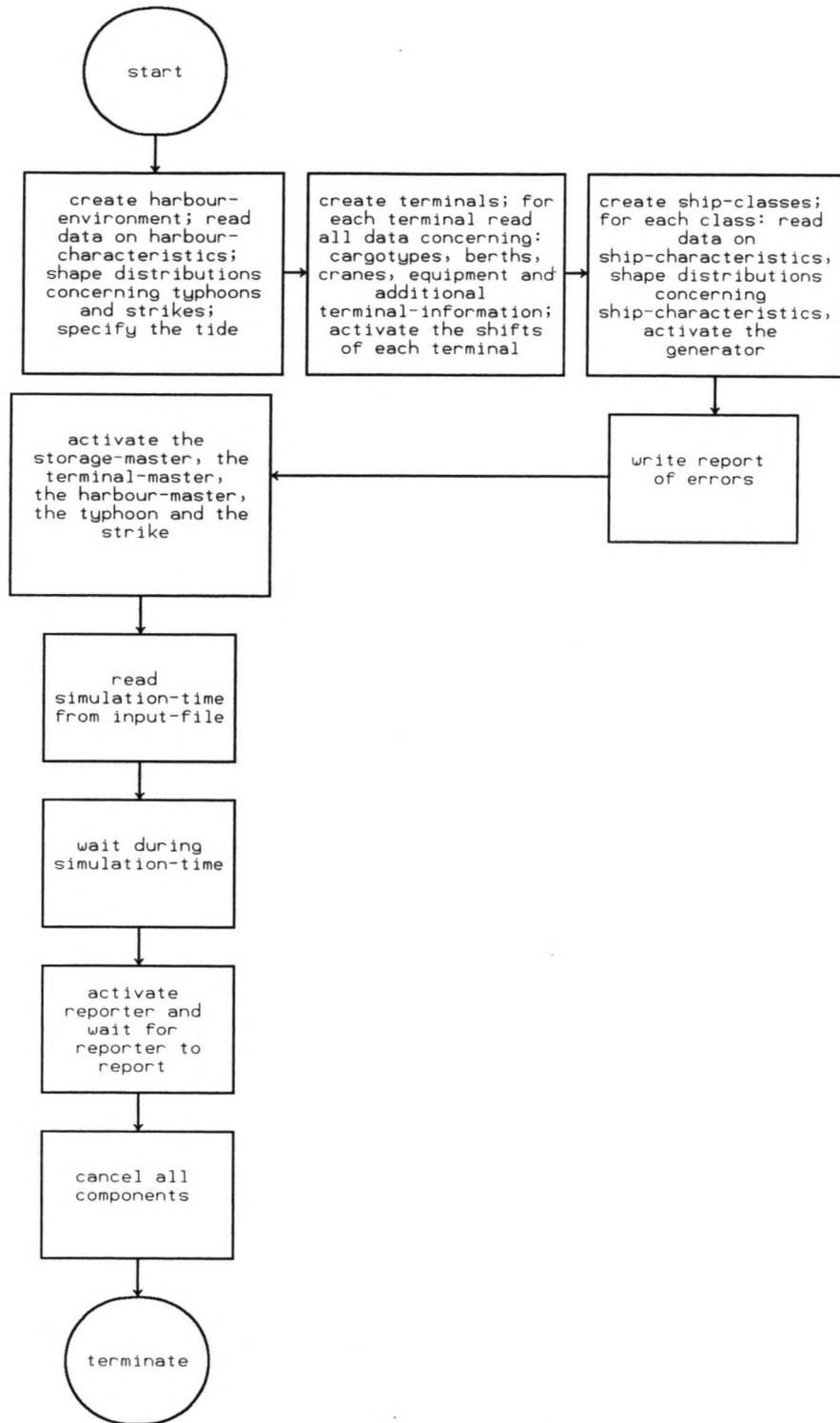


Figure 4.19: process of main



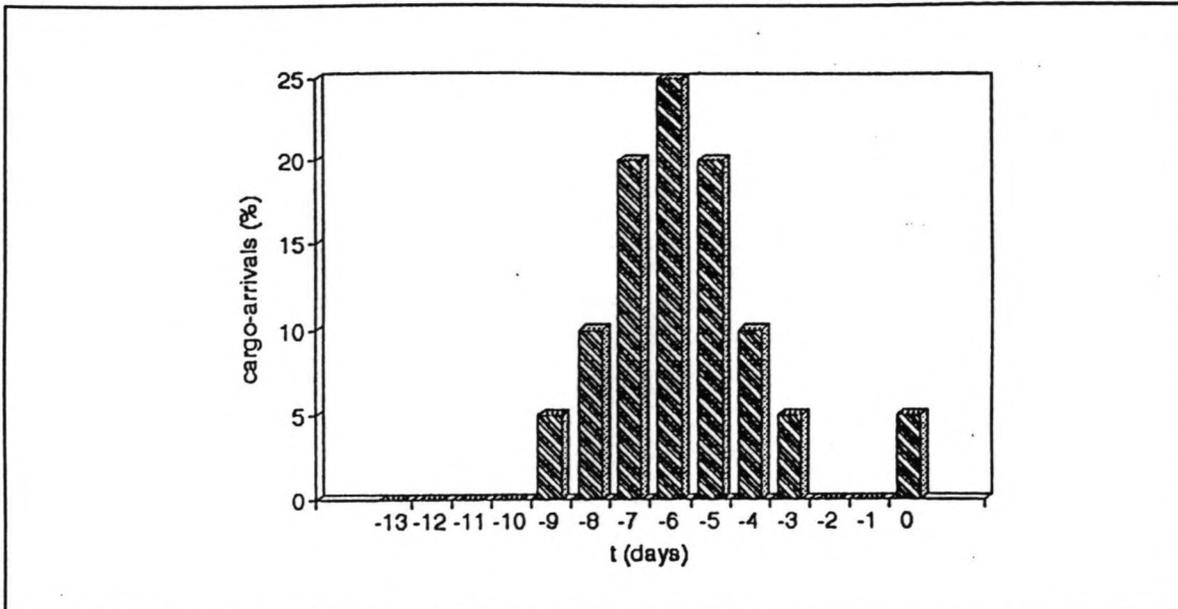


Figure 4.20: cargo arrival pattern

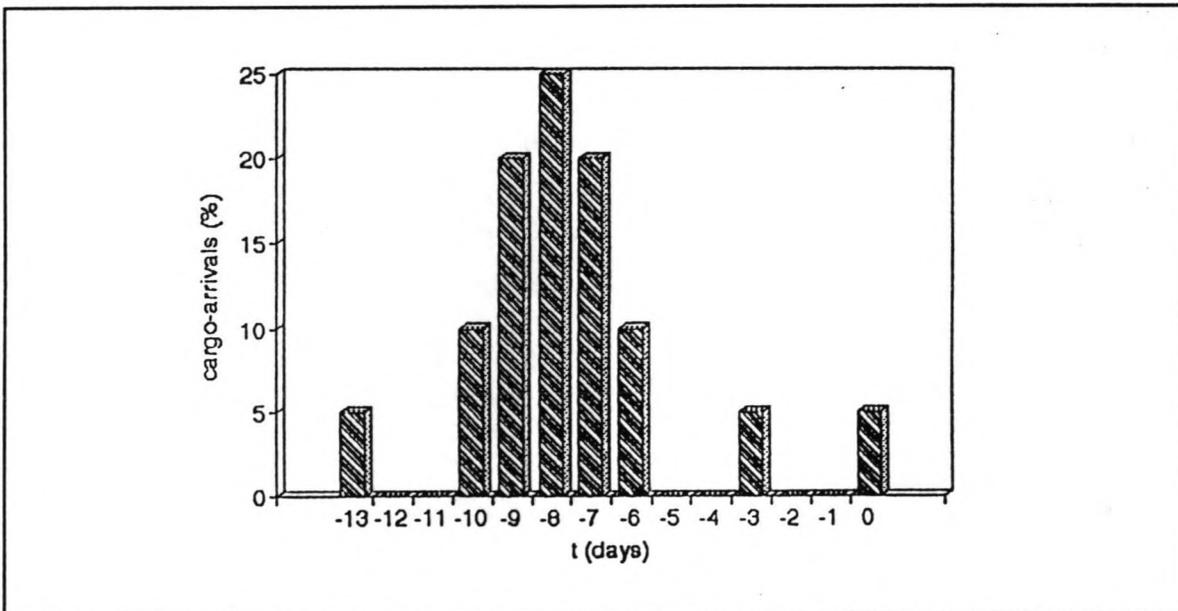


Figure 4.21: no inland transport during weekends in cargo arrival pattern

Annex 2.15) is demonstrated by Figures 4.20 and 4.21. The first of these two figures shows an undisturbed cargo-arrival-pattern (identical to the example in Paragraph 4.5). During the period of cargo-arrivals, four weekend-days can take place, so four zero-entry-days are added at the beginning of the pattern. The second figure shows the effect to this pattern of weekend-days without inland transport on days -4/-5 and -11/-12.

Main calls the macro *Patterns* to construct the general arrival- and departure-patterns. This macro reads the pattern-matrices (containing the arrival- and departure-patterns for all three

Table 4.4: departure pattern matrix

Day number	Truck perc.	Wagon perc.	Barge perc.	Total perc.
0 (direct)	0	0	5	5
1	0	0	0	0
2	0	0	0	0
3	4	1	0	5
4	8	2	0	10
5	16	4	0	20
6	19	6	0	25
7	16	4	0	20
8	8	2	0	10
9	4	1	0	5
Total	75	20	5	100

inland transport modes) and the percentages of directly transhipped cargo (the part of the cargo which is directly loaded from and unloaded to the three different inland transport modes, without intermediate storage). An example of a departure-pattern-matrix is given in Table 4.4.

The information about the ship-classes contains all information concerning the consignment-size and other ship-characteristics. The length, draught and consignment-size of a ship depend on the dead weight tonnage (DWT) of the ship. The complete list of required input-information for harbour, terminals and ship-classes is dealt with in the next chapter.

While reading the input-data, Main checks the information for possible errors. The program distinguishes the following sorts of mistakes:

- * Illegal values for a mean inter-arrivaltime (these values should not be 0)
- * Values which are too big or too small (for example: boundaries compared to mean values)
- * Illegal values for switches (these values should be 0 or 1)
- * Sets of percentages which should add up too 100 but do not do so
- * Incorrect number of values for the storage-characteristics of a cargo-type
- * Input-files which contain too much data

The errors of the above categories are specified in a separate User Data File, the *C-file*. The

checks for these types of errors are performed for two reasons; primarily because it is user-friendly service and secondly because Prosim does not detect these kinds of mistakes by itself. Prosim automatically stops reading data when the types of variables (characters, integers, reals) are mixed up or when a file does not contain enough data. Naturally these errors are not directly specified in the *C-file*.

When the input-data has been read, the program is stopped automatically and the user is given the choice to continue the simulation-run or to look into the *C-file*. Besides, the *C-file* also shows checklists of reference-numbers (one for the cargotypes and one for the cranes), enabling the user to perform extra checks.

During and after reading the input-information, Main activates the cranes, the shifts, the generators, the harbour-master, the terminal-master, the strike and the typhoon. The restriction strike and typhoon can be cancelled by the user. Main then reads the length of the simulation-run from an input-file and waits during that period.

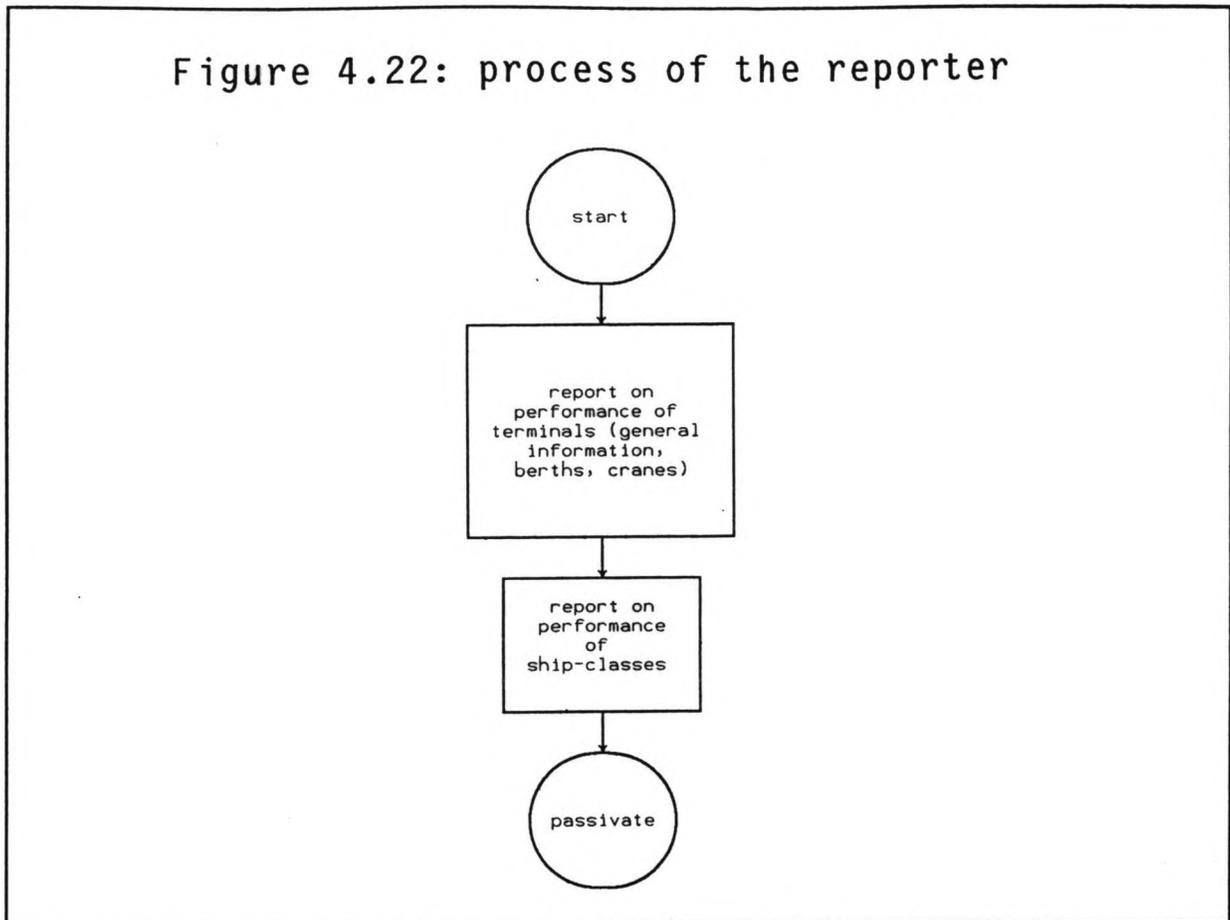
Before ending the program, Main registers the occupancy-periods of the cranes and ships which are active at the moment of ending the simulation-run and Main activates the reporter. When the reporter has ended its process, Main cancels all components and terminates itself.

4.14 Reporter

This component processes the information which has been produced during the simulation-run, concerning the performance of terminals, berths, cranes and ship-classes and writes this information to an output-file (called *Report* or *R-file*), as shown in the flow-chart, Figure 4.22. A exact list of the output-information can be found in the next chapter; in this paragraph the output-data will be discussed in general.

The component reporter first makes a report on the performance of each terminal, including, per terminal, the general performance of the berths, the performance of the cranes and other terminal-output-information. Then the component reports on the general performance of the ship-classes. Finally the performance of the berths and ship-classes are repeated in detail. This detailed information mainly concerns the distribution of delaytimes based on their origin. If two of such origins take place at the same time (for example a closed tidal window and a typhoon, restricting a ship in entering the port) the delay during that period is allocated to the origin that started first. This detailed output-information must be observed with great care by the user; because of possible double origins several runs are needed to decide which origins have the largest influence on the delays of ships and terminal operations. During these runs, the effect of the restrictions on the operations should be analyzed separately, by

Figure 4.22: process of the reporter



simultaneously switching the several restrictions on and off. Only then should the effect of the restrictions be considered jointly.

All output-information of the simulation-run is converted by the reporter into output data on an annual basis. For single berths, the performance is stated in hours per year; for multiple berths the performance is stated in meter-days per year.

4.15 Passengership

The process of a passengership is basically identical to the process of a cargo carrying vessel. The main difference for passengerships is that no cargo is transported; therefore the procedure of unloading and loading can be omitted and the arrival and departure of cargo with inland transport can be left out. This last aspect means that a passengership does not have to enter the queues *Arrivingships* and *Departingships*. The flow-chart of a passengerships process is shown in Figures 4.23/4.24.

After being activated by the generator of its shipclass, a passengership starts her process in

the port-system. The moment of activation by the generator is not the same as the actual arrival-time at the port. During the first part of its process a passengership is not physically present in the port-system. A passengership does not have to enter the queue *Arrivingships* when it is physically not present (like other ships) but it must wait during a period of time equal to the length of the general cargo-arrival-pattern.

Next, the passengership joins the queue *Row*; this is the waiting-row at the anchorage. The passengership is now physically present at the port. A passengership has priority for mooring, so it also joins the queue *Priority_row*. At this moment the passengership passivates itself, in order to wait for permission from the harbour-master to enter the port. This permission is received by means of being reactivated by the harbour-master. The passengership then leaves the queue *Row*; this can be delayed due to bad weather or a closed tidal window, temporarily detaining the passengership at the anchorage. After leaving the queue *Row*, the passengership enters the queue *Port*; this queue represents all the ships inside the port (between the moment of leaving the anchorage and leaving the berth).

The time needed for the passengership to leave the anchorage, sail through the entrance channel and go to its berth is called *mooring-time*; the mooring-time is drawn from a user-defined distribution. The mooring procedure can be prolonged if the passengership is obstructed by another ship, also manoeuvring in the area near the berth in question. This area is defined as the area in front of the berth in question and in front of the two adjacent berths on either side. The other ship can be mooring at one of the berths or departing from one of the berths. While the other ship is doing so (during a user-defined period of time), the passengership has to wait.

Next, the passengership joins the queue *Quay*. A passengership does not require cranes to be allocated. The ship is now moored at its berth so (dis)embarkation can start. The ship waits during a user-defined period of time, in which the passengers (dis)embark. The ship then leaves the queue *Quay*.

Unless restricted by a typhoon or by the manoeuvring of another ship, the passengership then leaves the queue *Port*, thereby creating a free space for another ship to moor. Then the passengership leaves the port, unless it cannot sail out due to the fact that the tidal window is closed for the passengership. During the tidal restriction it stays in the queue *Buoy*, symbolizing a buoy or berth inside the port at which ships can stay when waiting for the tidal window to open. Finally, the passengership terminates itself and its process comes to an end.

Figure 4.23: process of a passenger ship, part 1

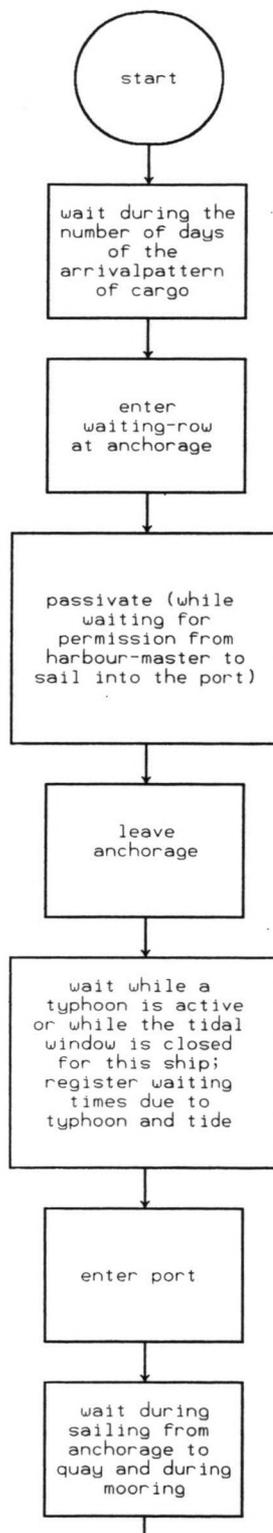
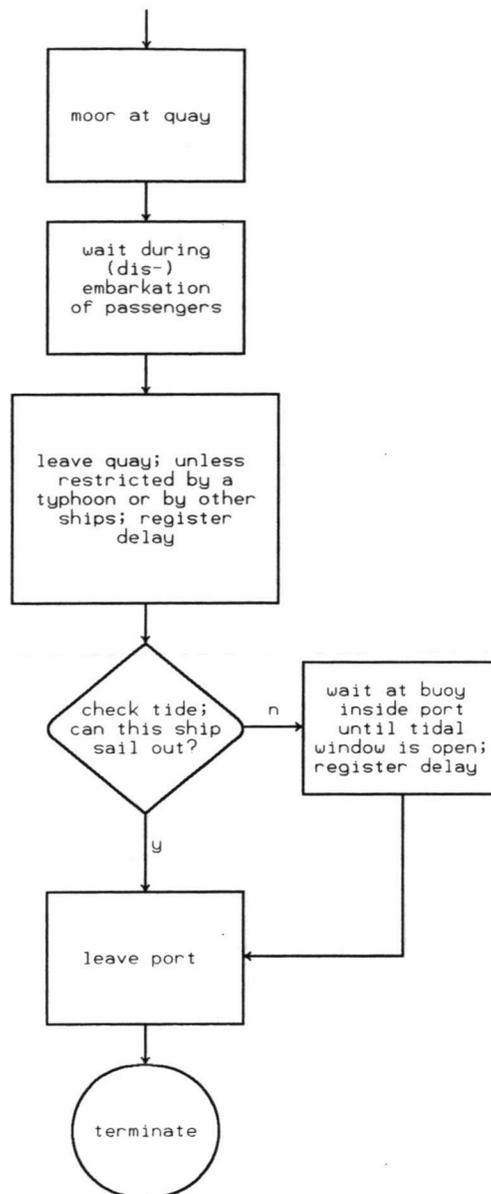


Figure 4.24: process of a passenger ship, part 2



4.16 Model extensions

The port simulation model, as it is presented in the previous paragraphs, has three possible extensions. These extensions were produced for the original port simulation model. Due to switching the application of the model from Kaohsiung to Pontianak, the original model was adapted. Three main aspects were left out; these three are now presented as extensions of the model. They are briefly explained in this paragraph. The first extension is the possibility to shift ships along the quay, the second is the possibility to shift cranes from one ship to another and the third is a more detailed approach to the sailing of ships from the anchorage through an entrance channel to a berth. In Annex 3 the extensions are dealt with in detail.

Berths can either be *single* or *multiple* berths. The extensions for shifting ships applies to multiple berths. In this extension, the harbour-master not only takes the lengths of ships into account when allocating ships to berths but also the position of moored ships at the quay. The positions of ships at the quay are determined by a coordinate system. If the total free quay-length at a quay is sufficient for a ship to moor at but if the free quay-length is composed of several free spaces, either between two ships or between a ship and the end of the quay, the harbour-master can shift ships and reposition them at another place on the quay. The harbour-master can continue to do this until a free space between two ships (or between a ship and the end of the quay) has been created that is long enough to accommodate the ship. If a ship is being shifted, the unloading/loading-procedure must temporarily stop.

The extension of shifting cranes also applies to multiple berths. As described in Paragraph 4.7 (process of the terminal-master), the number of cranes which a terminal-master allocates to a ship is equal to the minimum of the available number of cranes at a berth (*supply*) and the required number of cranes by a ship (*demand*). For a multiple berth, at which the positions of ships are known, the supply is not equal to the total available number of cranes at the berth but it is equal to the number of cranes at rest in between the active cranes which are serving adjacent ships or in between the active cranes on one side and the end of the quay on the other side. The positions of cranes on the quay are also determined by a coordinate system. If the demand for cranes by a new ship at the quay is bigger than the supply (according to the new definition), the terminal-master investigates the possibility to shift a crane from an adjacent ship to the new ship. Also, when a ship leaves the quay, the terminal-master investigates the possibility of shifting a crane which was serving the departing ship to ships in adjacent positions.

The extension of the entrance channel applies to the process of a ship. One of the causes of constraints to port operations can be congestion of the entrance channel and of other areas for ship manoeuvring in the port basin. This is especially true when a large number of ships call at a port. In the port simulation model congestion due to manoeuvring of ships has

already been taken into account for the areas in front of the berths, where ships manoeuvre when mooring and leaving the berth. This extension concerns possible congestion of the entrance channel. When vessels want to enter a port by sailing through the entrance channel, they must do this, for safety reasons at a minimum time (and space) interval. This is performed by introducing an extra queue *Channel* in the process of a ship. Ships stay in this queue for a period of time equal to the safety interval period. Only one ship can take place in *Channel* at the same time, thereby causing a restriction on the manoeuvring of ships. If required, this restriction can be intensified by dividing the entire port basin into sections. For each section the same modelling rules can apply as to the queue *Channel*. Whether a division into sections is required depends on the number of vessel movements and on the port basin lay out.

5 Use of the model

5.1 Introduction

Performing a simulation with the model consists of three steps. The first is to transform the port- and terminal-characteristics into a set of input-data, the second is to perform a simulation-run, based on the input-information, and the third is to read and analyze the results. These three steps must be performed several times to investigate the influence of the different aspects of the port operations. The instructions for performing these steps are written down in the Users Manual, which is Volume 4 of the thesis-report. In this paragraph the method of using the model is shortly discussed; in the next two paragraphs the required input for the model and the produced output of the model are mentioned.

The input-data for the model are stored by the user in four User Data Files: one containing information about the harbour-environment, two concerning the data of the ship-classes which attend the port and one containing information about the terminal- and cargotype-characteristics. The user must then create a simulation-environment and the simulation can be started. The program first reads all input-data, which is performed in the module *Main*. Then the program is interrupted and if any errors have been discovered in the input-data, this is displayed on the screen. The user can then decide to correct the input-data or to continue the program. In the module *Main* a special User Data File is created in which a specification of input-errors is stated. This file also contains a summary of the reference-numbers used in the input-information, for cargotypes, berths and cranes; this gives the user the opportunity to check the correctness of the reference-numbers.

If the option of continuing the simulation is chosen, the simulation is performed. If required, the Prosim-facility *State Analysis* can be used to view the performance of model components during the simulation. After the simulation has been completed all output-data can be viewed and analyzed.

5.2 Required input-information

As stated above, the model requires three input User Data Files; they are:

- * H-file (for the harbour-environment)
- * S-file (for the shipclasses)
- * D-file (DWT-tables)
- * T-file (for the terminal)

These files consist of extensive lists of data; therefore they contain comment-lines to facilitate reading and editing the files. In case a user wishes to make a new set of input files are created by the user, especially created dummy-files can be used, which already contain all comment-lines.

The following four sub-paragraphs contain a list of information, which is required for performing a simulation. The list is divided into four categories, one for each input-User Data File.

5.2.1 Input-data to create the harbour-environment (H-file)

CHARACTERISTICS OF A TYPHOON (BAD WEATHER CONDITION)

- * First and last day of the bad weather-season
- * Mean interval-time of typhoons during the bad weather-season (days)
- * Mean and standard deviation of the duration of a bad weather period (days)

CHARACTERISTICS OF A STRIKE

- * Mean interval-time of a strike (days)
- * Mean and standard deviation of the duration of a strike (days)

CHARACTERISTICS OF THE TIDE

- * Mean water-depth in the entrance channel (m)
- * Amplitude (m), period (days) and phase angle (rad) of the first and second tidal-factor

MISCELLANEOUS

- * Strike-restriction (on/off)
- * Bad weather-restriction (on/off)
- * Simulation-time (days)

5.2.2 Input-data to create the ship-classes (S-file)

GENERAL INFORMATION

- * Number of shipclasses

FOR EACH CLASS OF SHIPS:

- * CHARACTERISTICS OF THE INTERARRIVAL-TIME
 - Type of the distribution of the interarrival-time (Poisson/ normal)

- Mean interarrival-time (days)
 - In case of a normal distribution for the interarrival-time: the standard deviation of the interarrival-time (days)
- * **CHARACTERISTICS OF THE CONSIGNMENT-SIZE**
- Mean, standard deviation, lower boundary and upper boundary of total quantity of export-cargo
 - Mean, standard deviation, lower boundary and upper boundary of total quantity of import-cargo
- NB: the values for these characteristics are expressed in TEU's for containers and in tons for breakbulk, liquid and dry bulk.
- * **SHIPS' CHARACTERISTICS**
- Lower boundary and upper boundary of DWT
 - Reference to the corresponding DWT-table in D-file
 - Mean, standard deviation and lower boundary of mooring time (hours)
 - Required number of cranes to load/unload the ship
 - Net effective loading and unloading capacity of ships' gear (box/hour for container-ships; tons/hours for other ship-types)
- * **CHARACTERISTICS OF THE SHIPS' CARGO**
- Code of the cargo (A for containers, B for breakbulk, C for liquid bulk and D for dry bulk)
 - Reference-number of the cargo-type
 - Percentage of cargo that is transhipped (imported/exported by other ships, not by inland transport)
 - Mean and standard deviation of the percentage of ships' cargo that is stored under cover (only for breakbulkships)
- * **MISCELLANEOUS**
- Name of the class
 - Percentage of the class destined for each terminal

5.2.3 Input-data to create the DWT-tables (D-file)

This file consists of eight tables: one pair for each of the four types of ships. Of a pair of tables, one contains the relationship between the DWT-values of a ship and its draught and the other contains the relationship between the DWT-values of a ship and its length. The four types of ships are: containerships, general cargo ships, tankers, bulkcarriers. The

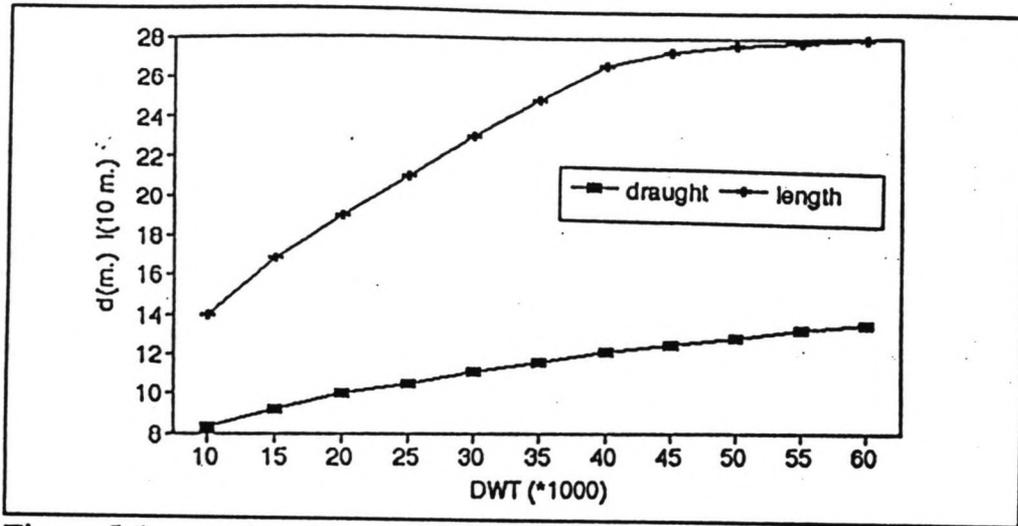


Figure 5.1: containerships

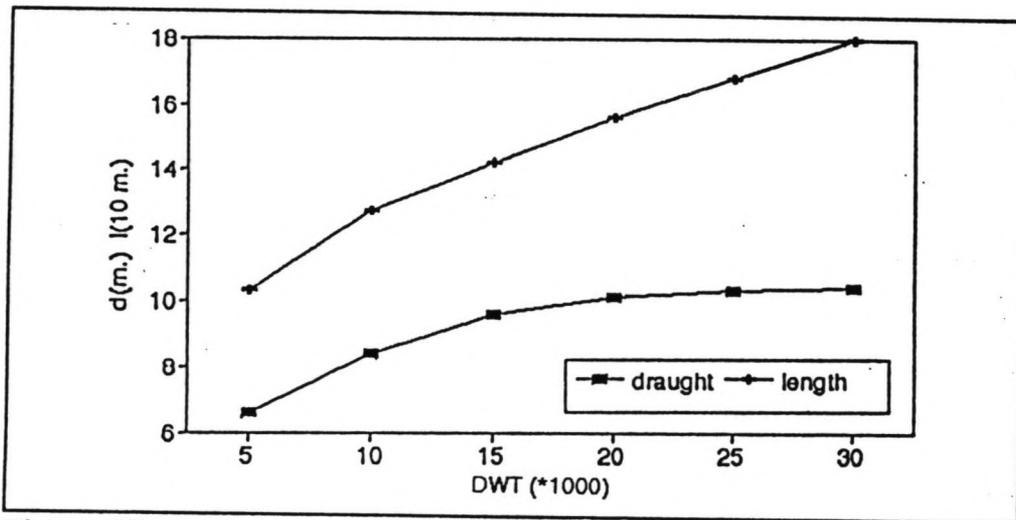


Figure 5.2: general cargo ships

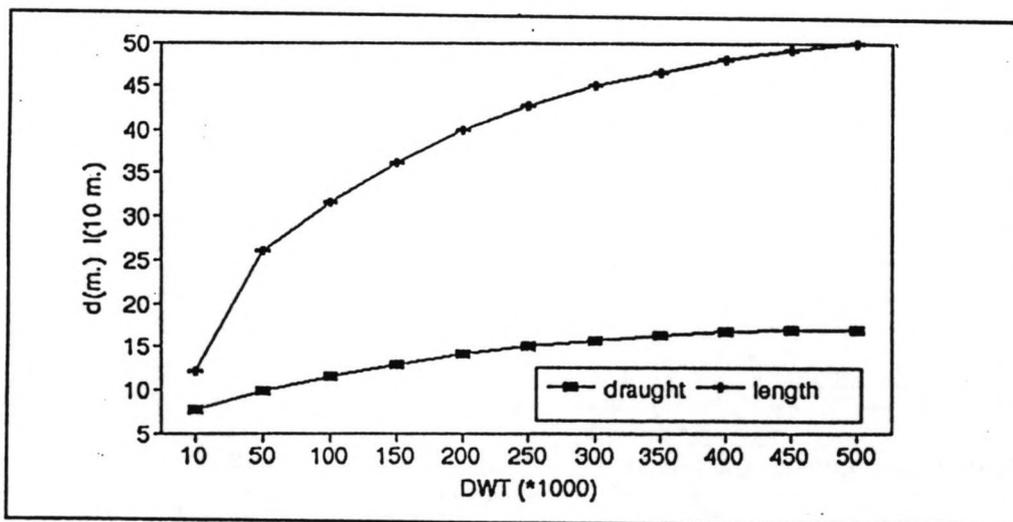


Figure 5.3: tankers

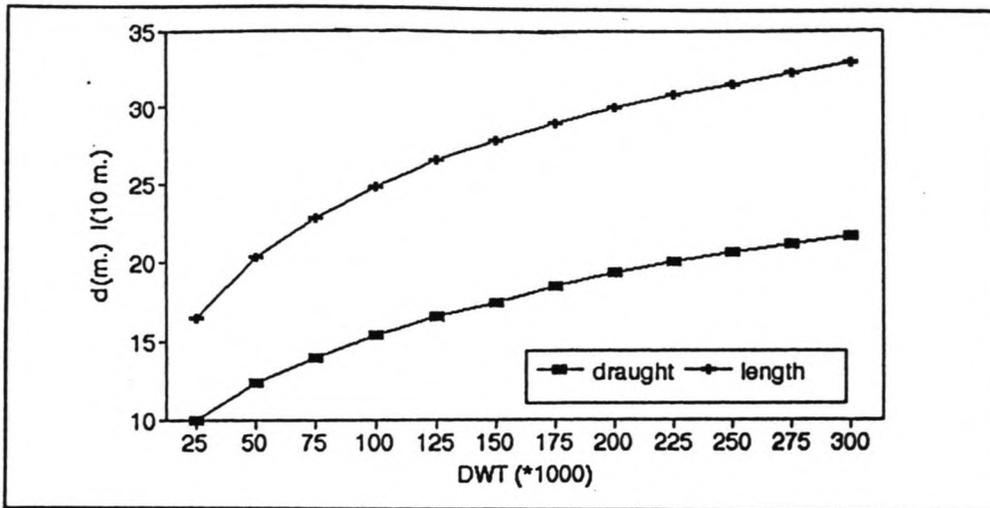


Figure 5.4: bulk carriers

DWT/draught-table consists of a user-defined number of DWT-values and for each DWT value a draught-value. The DWT/length-table consists of a user-defined number of DWT-values and for each DWT-value a length-value. The number of values which are entered into a table depends on the available information which is at the users disposal and on the level of accuracy which the user desires. A favourable option is to use tables which correspond to the standard ship-size data, as represented in Figures 5.1-5.4.

5.2.4 Input-data to create the terminals (T-file)

GENERAL INFORMATION

- * Number of terminals
- * Default value for the arrival-pattern of cargo with inland transport (number of days)
- * Default value for the departure-pattern of cargo with inland transport (number of days)
- * Mean interval-time of a breakdown of a crane (days)
- * Mean duration of a breakdown of a crane (hours)
- * Standard deviation of duration of a breakdown of a crane (hours)
- * Intervaltime of maintenance to a crane (hours)
- * Mean duration of maintenance to a crane (hours)

FOR EACH TERMINAL:

- * GENERAL CHARACTERISTICS OF A TERMINAL
 - Number of cargo-types, berths, cranes
 - Daily number of shifts
 - Availability of inland-transport on saturdays and sundays

- Availability of shifts on Saturdays and Sundays
 - Capacity for storage of containers and breakbulk (m²)
 - Capacity for storage of liquid and dry bulk (m³)
 - Net operation factor; this factor indicates the loss of cargo-handling-capacity during shifts
- * FOR EACH SHIFT:
- Starting time (hours)
 - Duration (hours)
- * FOR EACH BERTH:
- Serial number
 - Type (single/multiple)
 - Capacity (number of ships, one for a single berth; two or more for a multiple berth)
 - Length (m)
 - Water-depth (m)
 - Number of cranes or crane-substituting units
 - Number of cargo-types handled at that berth (maximum: three)
 - For each cargo-type: serial-number
- * FOR EACH CRANE OR CRANE SUBSTITUTING UNIT:
- Name and serial number
 - Reference number to the berth to which the crane or crane-substituting unit belongs
 - Gross capacity for loading and unloading (for containers boxes per hour; for other cargo-types tons/hour)
 - For cranes at a multiple berth: minimum and maximum of range on the quay (m)
- * FOR EACH CARGO-TYPE:
- GENERAL CHARACTERISTICS
 - + Name
 - + Reference number (which corresponds with the cargo-type-numbers of the ship-classes and the numbers of the cargo-types that are handled each berth)
 - + Code of the cargo type (A for containers, B for breakbulk, C for liquid bulk, D for dry bulk; the code corresponds with the code of the shipclass' cargo)
 - STORAGE CHARACTERISTICS
 - + Gross factor (factor for travelling lanes etc.)
 - + Only for breakbulk, liquid and dry bulk: mean density (ton/m³)
 - + Only for breakbulk: mean stackheight (m) for open and covered storage

- + Only for containers: mean stackheight of the export-stack, the import-stack and the empties-stack (expressed in the number of containers)
- + Only for containers: the mean percentage of empties in the export-containers and in the import-containers
- + Only for containers: the mean percentage of forty feet-containers in the export-containers and in the import-containers
- CHARACTERISTICS OF INLAND TRANSPORT MODES
 - + Mean capacity of trucks, wagons and barges (unit is TEU for containers, unit is ton for the other commodities)
- CHARACTERISTICS OF ARRIVAL-PATTERN WITH INLAND TRANSPORT
 - + For each day in the pattern: the sum of the percentages of cargo arriving on that day with the three modes of transport
 - + For each of the three modes: the percentage of arrivals that are loaded directly
N.B. The sum of all these percentages is 100
- CHARACTERISTICS OF DEPARTURE-PATTERN WITH INLAND TRANSPORT
 - + For each day in the pattern: the sum of the percentages of cargo departing on that day with the three modes of transport
 - + For each of the three modes: the percentage of departures that are unloaded directly
N.B. The sum of all these percentages is 100

5.3 Produced output-information

The model offers two modes for showing output-information to the user. The first is a written report, which is shaped as a User Data File (*R-file*). The second is a set of storestreams on the basis of which graphs, histograms and barcharts can be produced.

5.3.1 Storestreams

Storestreams are arrays of data, representing the time-dependant behaviour of variables. Prosim can automatically shape these data into graphs, barcharts and histograms. These facilities, especially the histograms, which present extra information, as mean values, deviations, minimum and maximum values, are of importance to the user for viewing and analyzing the results of a simulation. The output-data which can be viewed with storestreams consist of:

- * Utilisation of terminal storage for each cargo-type
 - Containers: distribution of the number of occupied groundslots for export-containers, import-containers and empty containers, distribution of the number of feeder containers in storage on the terminal (TEU), distribution of total occupied storage area (m²)
 - Breakbulk: distribution of the occupied open storage area, distribution of the occupied covered storage area (sheds, warehouses, etc.) (m²), distribution of the quantity of feeder cargo (tons)
 - Liquid bulk: distribution of the occupied storage volume (m³)
 - Dry bulk: distribution of the occupied storage volume (m³)
- * Occupancy-rate of the total storage-facility of a terminal: distribution of the occupancy-rate of the total storage-area and distribution of the occupancy-rate of the total storage-volume
- * Distribution of the daily quantities of arrival and departing cargo at a terminal
- * Distribution of occupied number of waiting spots at the anchorage for entering the port
- * Distribution of number of ships at a berth

5.3.2 Report-file

The output-information which is supplied by the *R-file* can be split up into three categories: the performance of the terminals (including all terminal-parts like berths and cranes), the performance of the ships and the delays due to the restrictions on the operations.

The output-data for each terminal consist of:

- * Average annual number of ships at the terminal
- * Annual throughput of each cargotype
- * Annual number of trucks, wagons and barges leaving and entering the terminal
- * Annual occupancy-rate of each berth
- * Performance of each berth; annual time c.q. quaylength-time not occupied, annual time

c.q. quaylength-time occupied; the latter is specified in:

- Full operation
- Partial operation, due to the breakdown of a crane
- Not in operation due to delays: no shifts at work, bad weather, strikes, shifting of ships

* Performance of each crane; specified in:

- Annual time in operation
- Annual time not in operation due to a breakdown
- Annual time not in operation due to delays: no shifts at work, bad weather, strikes, shifting of ships
- Annual time in maintenance (maintenance is considered to take place during times the quay is not occupied)
- Annual time at rest

* Average annual number of shifting of ships

* Average annual number of shiftings of cranes

* Indication of the annual average annual time in operation of the terminal equipment

The output-data for each shipclass consist of:

* Average annual number of ships of that shipclass visiting the port

* Average ratio of the annual time spent at the anchorage divided by the time spent at the quay

* Average time spent at the anchorage

* Average mooring time (sailing from the anchorage to the quay)

* Average time spent at the quay; specified in:

- Time in full operation
- Time in partial operation (due to the breakdown of a crane)
- Time not in operation due to a delay: no shifts at work, bad weather, strike, shifting of the ship

The performances of the berths and of the shipclasses are described in greater detail in the last part of the R-file which specifies the consequences of the restrictions on the operations:

strikes, bad weather, tidal window, breakdowns of cranes, no shifts at work (= gross - net operation time). For each berth the causes of the delays to the operations at that berth are specified (breakdowns of cranes, strikes, bad weather, shifting of ships, gross - net operation time) and the causes of the periods of time that the berth is not occupied are specified (tidal window, bad weather, no ships at the anchorage which can moor at the berth). For each shipclass the causes of the waiting time at the anchorage are specified (all suitable berths are occupied, tide, bad weather) and the causes of delays while moored at the quay are specified (breakdowns of cranes, strikes, bad weather, shifting of ships, gross - net operation time). For delays which take place at the same time, the delayed time is attributed to the restriction on the operations which started first.

6 Validation and verification

6.1 Introduction

The results which are produced by the simulation model must meet a certain level of accuracy and reliability. This can be tested by performing a validation, a verification and a calibration of the model. This chapter is a report of these tests.

A *validation* is meant to assure that the model can perform faultless simulation-runs and that the produced output-data are of the right order of magnitude. The objective of calibration is to tune the model, in order to work towards an acceptable level of accuracy. The purpose of *verification* is to prove that the model really predicts the required level of accuracy. *Calibration* should be performed on the basis of historical data for the *Main Public Port* at Pontianak. For this procedure a large number of data is required. The calibration for Pontianak is dealt with in Chapter 7. The emphasis in this chapter is on validation and verification.

Firstly, the checking of basic programming procedures is discussed (Paragraph 6.2). Secondly, results of simulation-runs are compared to calculations which are performed using the queuing theory (Paragraph 6.3). Finally, the results of simulation-runs, which have been made for two terminals in Argentina and the Netherlands are compared to existing data for those terminals (Paragraph 6.4).

6.2 Checking of programming procedures

This paragraph describes the validation of general programming procedures. The objective of doing this can be divided into three aspects.

The first purpose is to make sure that no events occur during the simulation which are impossible. For example: ships being served (unloaded/loaded) during a general strike, ships sailing into the port when the tidal window is closed, cargo disappearing or mysteriously entering the system, etc. The main method of checking these irregularities is using the *Trace-mode* (in the *Run time*-system of Prosim). The *Trace-mode* made it possible to view all events, activities and processes of components in the system carefully and to remove all impossibilities and mistakes. This will not be discussed in greater detail, because it concerns a very long list of possible irregularities and a long time span of switching back- and forwards between programming and the *Trace-mode*.

The second objective of checking the programming procedures is to ensure that the program

possesses the correct sensitivity behaviour. This means that the simulation should correspond correctly with real life port- and terminal-procedures. For example: more cranes at a terminal should cause shorter waiting times for ships which attend that terminal, bad weather conditions should cause constipation of the waiting row, larger values for mean dwell times of cargo should cause larger storage requirements.

The third objective is to eliminate faults from the output of the model. Contradictions within different parts of the output and contradictions between the output and general port operation-principles must be spotted and avoided.

For these last two objectives the *Trace-mode* has also be used, together with two other options of the Prosim *Run time*-menu (*Data handling* and *State analysis*). More important for these two aspects, several simulation-runs have been performed, using a imaginary port and testing it under different circumstances. First the TEST-model will be generally described; then the tests which have been performed with this model will be discussed.

Let the TEST-port be an imaginary port with four terminals, each with one cargo-type and each attended by one class of ships. The terminals have the following general characteristics:

- * Terminal 1: containers; three identical single berths, each with two cranes; attended by container ships
- * Terminal 2: breakbulk; two single berths, with different berthlengths; attended by general cargo ships
- * Terminal 3: vegetable oil; one single berth with two pumps; attended by liquid bulk carriers
- * Terminal 4; wheat; two single berths with different water-depths; attended by dry bulk carriers

The TEST-port is a simple model in order to facilitate comparisons with hand-made calculations. Nine test-runs have been performed for this port, each with one specific restriction. The nine runs have been chosen as follows:

- * TEST 0: no restrictions
- * TEST 1: 20 hour-breakdowns of cranes at an average interval time of 500 working hours per crane

- * TEST 2: no inland transport on weekend days
- * TEST 3: no shifts at the terminal during weekend days
- * TEST 4: two day-strikes at average interval times of 75 days
- * TEST 5: two day-typhoons at average interval times of 75 days obstructing both landside- and marine-activities
- * TEST 6: a tidal window, restricting the classes which attend terminal 3 and 4
- * TEST 7: 3 six hour-shifts per day instead of 3 eight hour-shifts per day
- * TEST 8: at terminal 1 a multiple berth with a capacity of three ships, replacing the three single berths

Several verification-checks have been performed, using the TEST-model; four important checks are described in this paragraph. The first is a check of the continuity of cargo flows. Within a period of time, the quantities of cargo-arrivals and cargo-departures and the change in the storage level must be in balance. This is described by:

$$C_i = \Delta S + C_o$$

in which:

- C = quantity of a cargo-flow
- i = entering the terminal-storage (in)
- o = leaving of the terminal storage (out)
- S = storage-level

The cargo flows can be split up into import- and export-cargo:

$$C_{import,i} + C_{export,i} = \Delta S + C_{import,o} + C_{export,o}$$

In-coming export-cargo and out-going import-cargo also consist of a directly transhipped part (leaving and entering the terminal without intermediate storage). Figure 6.1 describes the cargo-flows visually. For each of the four cargo-types at the four terminals calculations have been performed for TEST 0 for a certain period of time. The results of the check are given in Table 6.1; the results, indicated by the value of the discrepancy [A-B], can be considered satisfactory. Annex 4.1.1 gives more details of the calculation.

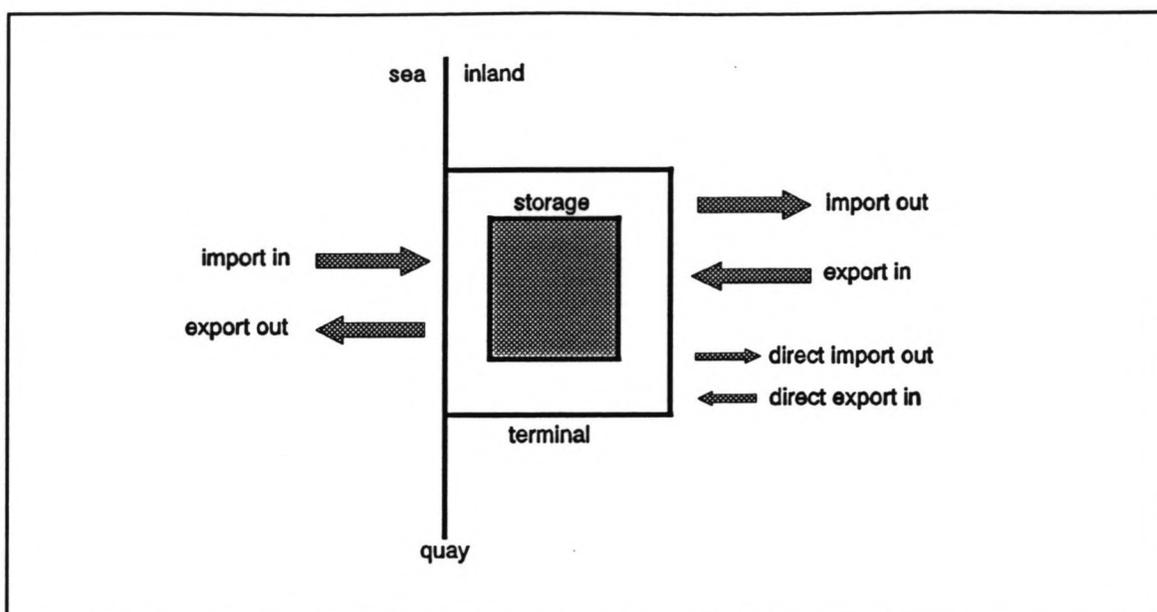


Figure 6.1: continuity of cargo-flows at a terminal

Table 6.1

RESULTS OF CHECK OF CARGO CONTINUITY				
CARGO FLOW	CONTAINER	BREAKBULK	VEGET_OIL	WHEAT
	[TEU]	[tons]	[tons]	[tons]
import in	159178	984313	868191	1752357
export in	149744	786258	931055	1803489
dir. export in	0	243219	0	0
total in [A]	308922	2013790	1799246	3555846
export out	158760	972922	893804	1782230
import out	152110	791687	892973	1750322
dir. import out	0	246092	0	0
total out	310870	2010701	1786777	3532552
d(storage)	-1948	3084	12470	23299
tot.out + d(sto) [B]	308922	2013785	1799247	3555851
A - B	0	5	-1	-5

The second verification-check with the TEST-model is a check of the output which is given by the Report-file. Important items of the R-file are the performances of berths and shipclasses. For berths, the periods of time in full operation, in partial operation (due to the breakdown of a crane) and not in operation (due to delays: bad weather conditions, a strike or a closed tidal window) are given. For shipclasses, this distribution is also specified. Every terminal is matched to exactly one shipclass so the two distributions can easily be checked. Naturally, the outcome of both must correspond. This has been checked, using TEST 0, TEST 1, TEST 4, TEST 5 and TEST 6. The result of the check is all right; Annex 4.1.2 shows the calculations of this check.

The third verification-check with the TEST-model is a check of the output which is given by the storestreams concerning the storage requirements. Hand-made calculations of the average occupied storage area (for containers and breakbulk) c.q. storage volume (for liquid bulk and dry bulk) have been compared with the results which are produced by the simulation for TEST 0. Table 6.2 shows the comparison; Annex 4.1.3 demonstrates the calculations. As can be seen in the table, the calculations for terminal 1 (containers) and terminal 2 (breakbulk) match very well with the simulation results, the calculations for terminal 3 (vegetable oil) and terminal 4 (wheat) match less well. However, extra research of the storage-registration of liquid and dry bulk cargo, for instance with the TRACE-mode, give no reason to assume a programming error.

Table 6.2

STORAGE REQUIREMENTS			
Average occupied:		Calculation	Simulation
storage area (m ²)	Containers	81207	80954
	Breakbulk	35358	35977
storage volume (m ³)	Vegetable oil	165196	185790
	Wheat	159530	185770

The fourth verification-check with the TEST-model, which is described in this paragraph, is an analysis of the distribution of service-times, which is created by simulation with the program. These distributions have been examined, in order to find to which type of distribution they fit best. This has been performed in the *Statistics*-menu of Prosim, with the *Goodness of fit test*. This Prosim-facility defines the best fitting distribution with 95% probability.

In the particular situation that there are no restrictions on terminal- and berth-activities (TEST 0), the service-time of a ship depends solely on the quantity of cargo which must be

unloaded and loaded. This quantity is indicated in the program by the sum of *Ship_importtotal* and *Ship_exporttotal*. These two attributes of a ship are drawn from normal distributions. According to the fit-test, this has resulted, not unsurprisingly, in service-times which are normally distributed (see table 6.3).

Because this does not necessarily match general port operation principles, a second check has been performed with TEST 0, this time using exponential distributions to draw the attributes *Ship_importtotal* and *Ship_exporttotal* from (with the same mean values). This test has been called TEST-A. The service-time distributions are now gamma-shaped distributions, according to the *Goodness of fit test* (see Table 6.3); in fact they are Erlang-k distributions with the value for k being approximately 2 for each of the four terminals. The probability density function $f(t)$ of an Erlang-k distribution for a variate t is described by:

$$f(t) = \frac{(k\mu)^k t^{k-1}}{(k-1)!} e^{-k\mu t}$$

in which:

μ = average service rate ($1/\mu$ = average service time)

The Erlang-k distributions satisfy general port operation principles. The value $k=2$ can be explained due to the fact that the service-time is built up out of two main components, one part based on the import-cargo, which is unloaded from the vessel, and one part based on the export-cargo, which is loaded onto the vessel.

Naturally, the different service-time distributions in TEST-A result in longer waiting-times at the anchorage in TEST-A, compared to TEST 0. The values of the waiting-times of ships, destined for each of the four terminals in TEST 0 and TEST-A, are given in Table 6.4.

6.3 Queuing theory

One of the tools for port planning, which is mentioned in Paragraph 2.4, is the queuing theory. For a service system, in which customers require a single service, wait in a single queue and are served at one or more equal service points, the waiting time and other waiting-data can be calculated. The inter-arrivaltime of customers and the service-time for customers are drawn from statistical distributions.

In the TEST-port, terminal 1 and terminals 3 can be regarded as service-systems on which the queuing theory can be applied and for which the waiting times of ships, which are

Table 6.3

SERVICE TIME DISTRIBUTION			
TEST 0	Service time (days)		Kolmogorov-Smirnov Goodness of fit test
Terminal	Mean (M)	Deviation (D)	
1	0.824	0.100	Normal
2	0.757	0.071	Normal
3	2.181	0.262	Normal
4	1.524	0.167	Normal
TEST-A	Service time (days)		Kolmogorov-Smirnov Goodness of fit test
Terminal	Mean (M)	Deviation (D)	
1	0.657	0.463	Gammashape LB=0.009 k=1.999
2	0.463	0.418	Gammashape LB=0.003 k=2.000
3	1.970	1.308	Gammashape LB=0.089 k=2.068
4	1.269	0.920	Gammashape LB=0.026 k=1.825
		LB = Lower Boundary	$k = (M-LB)^2/D^2$

destined for that terminal, can be calculated. The results of that calculation do not necessarily have to correspond exactly with the outcome of the simulation of the TEST-model; however, the average waiting time, according to the queuing theory, must be smaller than the average waiting time, in case restrictions are applied during the simulation (crane-breakdowns, bad weather conditions, strikes, tidal window, etc.: TEST 1 to TEST 7).

Terminal 2 and terminal 4 cannot be regarded as queuing theory-service systems, because the service points are not equal. Terminal 2 has two berths with different berth-lengths (150 m. and 200 m.); smaller ships can therefore moor at both berths and longer ships can moor at only one. Terminal 4 has two berths with different water-depths at the berth (15.5 m. and 17 m.); ships with a smaller draught can moor at both berths, others at only one. These lengths and depths have been chosen in order to verify the process of the harbour-master,

Table 6.4

RESULTS OF CHECK WITH QUEUING THEORY					
	A: Average waiting time (hours) B: Average mooring time (hours) C: Average service time (hours)				
	SHIP CLASS:	1	2	3	4
TEST 0	A	2.80	6.75	37.52	7.72
	B	4.00	3.99	6.07	5.98
	C	15.78	14.16	46.27	30.51
Queuing theory	A	2.71	x	38.59	x
	B+C	19.78	x	52.34	x
TEST 1	A	3.22	6.77	42.15	8.75
TEST 2	A	2.80	6.75	37.52	7.72
TEST 3	A	22.18	21.28	131.35	35.65
TEST 4	A	3.62	7.99	43.13	9.36
TEST 5	A	4.40	7.05	38.94	7.92
TEST 6	A	2.80	6.75	40.47	16.57
TEST 7	A	34.08	30.50	291.68	52.19
TEST 8	A	2.83	6.75	37.52	7.72
TEST-A	A	4.00	7.73	48.15	16.79
	B	4.00	4.00	6.07	6.00
	C	15.92	14.28	46.27	30.46
Queuing theory	A	3.54	x	52.06	x
	B+C	19.92	x	52.34	x
TEST-A1	A	4.53	7.87	53.89	17.22
TEST-A4	A	8.09	8.26	52.28	19.13
TEST-A5	A	5.06	8.87	52.46	18.07

who allocates the ships to their berths. It has resulted, for example, in the deeper berth at terminal 4 being used more often than the berth with the smaller water-depth.

Terminal 1 is a service system with a single queue and three equal service points. The inter-arrivaltime of ships is drawn from a negative exponential distribution, the service time is drawn for a normal distribution (see Paragraph 6.2). For the queuing theory-calculation, a normal distribution is best reproduced by a Erlang-k distribution with $k=10$ (see Groenveld, lecture notes f12 "Service systems in ports and inland waterways", page 36). Therefore terminal 1 is regarded as a $M/E_{10}/N$ -system with $N=3$.

Terminal 3 is a service system with a single queue and one service point. The inter-arrivaltime of ships is drawn from a negative exponential distribution, the service time is drawn for a normal distribution (see Paragraph 6.2). Again the normal distribution is reproduced by a Erlang-k distribution with $k=10$. Therefore terminal 3 is regarded as a $M/E_{10}/1$ -system.

In Annex 4.2 the queuing theory calculations are demonstrated. Table 6.4 shows the results of the calculations. For TEST 0 to TEST 8 this table also shows the average waiting times, as were produced by the simulation-runs. For the ships attending terminals 1 and 3 in TEST 1, TEST 3, TEST 4, TEST 5 and TEST 7, the waiting times are longer than the queuing theory-calculation. For TEST 6 (tide restriction), the waiting times for terminal 1 and 2 do not differ from TEST 0 because the container- and breakbulk-ships are not hampered by a tidal window. The restriction in TEST 2 (no inland transport on weekend days) does not increase the waiting times; it just influences the required storage space. When reading Table 6.4, it should be taken into account that the results of TEST 1 to TEST 8 should only be compared to the results of TEST 0 and the queuing theory and that no conclusions can be drawn from mutual comparison.

For the sake of completeness, the queuing theory is also compared with TEST-A. As described in Paragraph 6.2, this is a simulation of the TEST-model with an Erlang-2 distribution for the service times. TEST-A has been performed for the restrictions of crane-breakdowns (TEST-A1), strikes (TEST-A4) and bad weather conditions (TEST-A5), similar to TEST1, TEST4 and TEST5. The results of these tests are also given in Table 6.4. Executing TEST-A for TEST2, TEST6 and TEST8 would not provide extra information, so this has not been performed.

For the comparison of the queuing theory with TEST-A, terminal 3 is regarded as a $M/E_k/1$ -system (with $k=2$) and terminal 1 is regarded as a $M/E_k/N$ -system (with $k=2$ and $N=3$). The queuing theory calculations are shown in Annex 4.2 and the results of the calculations are shown in Table 6.4. As with the TEST-model, the waiting times of ships attending

terminals 1 and 3 in TEST-A1, TEST-A4 and TEST-A5 are longer than the queuing theory-calculations. This underlines the positive result of the verification-check with the queuing theory.

Table 6.5

ROTTERDAM WAALHAVEN PIER 2				
STORAGE AREA	Historic data		Simulation	
A (m ²)	open	covered	open	covered
Gen. cargo	3990	5740	4167	5931
Wood	43080	7600	43149	7632
Iron etc.	1220	960	1170	970
Containers/ro-ro	4760	-	5293	-
THROUGHPUT	Historic data		Simulation	
(ton/year)	(*1000)		(*1000)	
Gen. cargo	315		317	
Wood	240		246	
Iron etc.	235		211	
Containers/ro-ro	270		284	
TOTAL	1060		1058	
INL. TRANSPORT	Historic data		Simulation	
Number of:	Per day:		Per year:	Per day:
Trucks	158		54186	148
Wagons	1		353	1
Barges	no information		1586	4

6.4 Simulation of other terminals

In connection with the validation of the program, two simulation-runs have been performed, using existing terminals. The first is a comparison with a computer simulation model for container terminals called *TTACTE*. This comparison has been performed using data for a

container terminal in Campana, Argentina. The second is a simulation-run of multipurpose-terminal *Pier 2* of Rotterdam-Waalhaven; the output of this run is compared with historic data and hand-made calculations for the terminal in question. Detailed descriptions of the two simulation-runs are shown in Annex 4.3 (Campana) and Annex 4.4 (Waalhaven).

The aspects of port operations which are dealt with in the comparisons of the program with Campana and Waalhaven are matters like throughputs, storage requirements and inland transport performances. Less emphasis is laid on berth- and crane-utilisation and waiting- and service-times of ships.

For the terminal in Campana the frequency distributions of the occupied number of groundslots for import containers, export containers and empty containers are compared for two different throughput-predictions. For each of the three storage-categories and for each of the two throughput-values, the models calculate patterns which are very similar.

For the terminal in Rotterdam, results of the simulation are compared to data, which have been hand-calculated during a previously made study of this terminal. Table 6.5 shows a comparison of the two sets of data, viz. for three aspects: throughput-figures, storage area requirements and inland transport calls. For all three aspects, satisfactory comparisons can be made.

The conclusion for these two comparisons is that both runs prove that the simulation model functions correctly. The results of the runs for Campana and Waalhaven show that the model produces output which is of the right order of magnitude; a reasonable level of accuracy is offered.

7 Port of Pontianak

The port simulation model has now been described, its required input data and possible output data have been discussed and the results which can be produced have been validated. The port simulation model is now applied for the Main Public Port at Pontianak, Indonesia. This chapter describes the present situation of the port of Pontianak and explains the expected developments for the port in medium term. Problems concerning the predicted medium term changes are analyzed and the objective of the application of the model for Pontianak is presented.

7.1 Port of Pontianak: present situation

7.1.1 Location

The city of Pontianak is located on the island of Borneo, which is one of the larger islands of the Indonesian archipelago. Kalimantan is the part of Borneo which belongs to the Republic of Indonesia; other parts of Borneo are the sultanate of Brunei and the Malaysian states of Sarawak and Sabah (see Figure 7.1). Pontianak is the main city of West Kalimantan. It has a population of 1.6 million, half the total population of West Kalimantan. Pontianak is situated on the river Kapuas Kecil, 20 km upstream from the coast (see Figure 7.2).

7.1.2 Facilities

The port of Pontianak comprises of 5 types of facilities:

- * *Main Public Port* (from now on called: *MPP*): this facility is located in the city, on the southern bank of the Kapuas Kecil river, on a strip of land of 680x145 m². At the MPP general cargo (mainly incoming) is transhipped. The characteristics of the MPP are described in detail in Paragraph 7.2.
- * *Sailing Vessel Terminal (SVT)*: this facility consists of 170 m long wooden quay and caters for sailing vessels and small motorized ships. It is located 1500 m upstream from the MPP. General cargo (cement, rice, sugar, animal feeds, fertilizer, all mainly incoming) is transhipped at this facility.
- * *Midstream Anchorage*: at anchorages midstream on the Kapuas Kecil river, direct transshipment takes place, to and from barges. A mixture of import and export cargo (plywood, logs, rubber, palm oil and several other smaller quantities of cargo)



THE REPUBLIC OF INDONESIA



Figure 7.1

SCHEMATIC OVERVIEW PONTIANAK + ENVIRONS

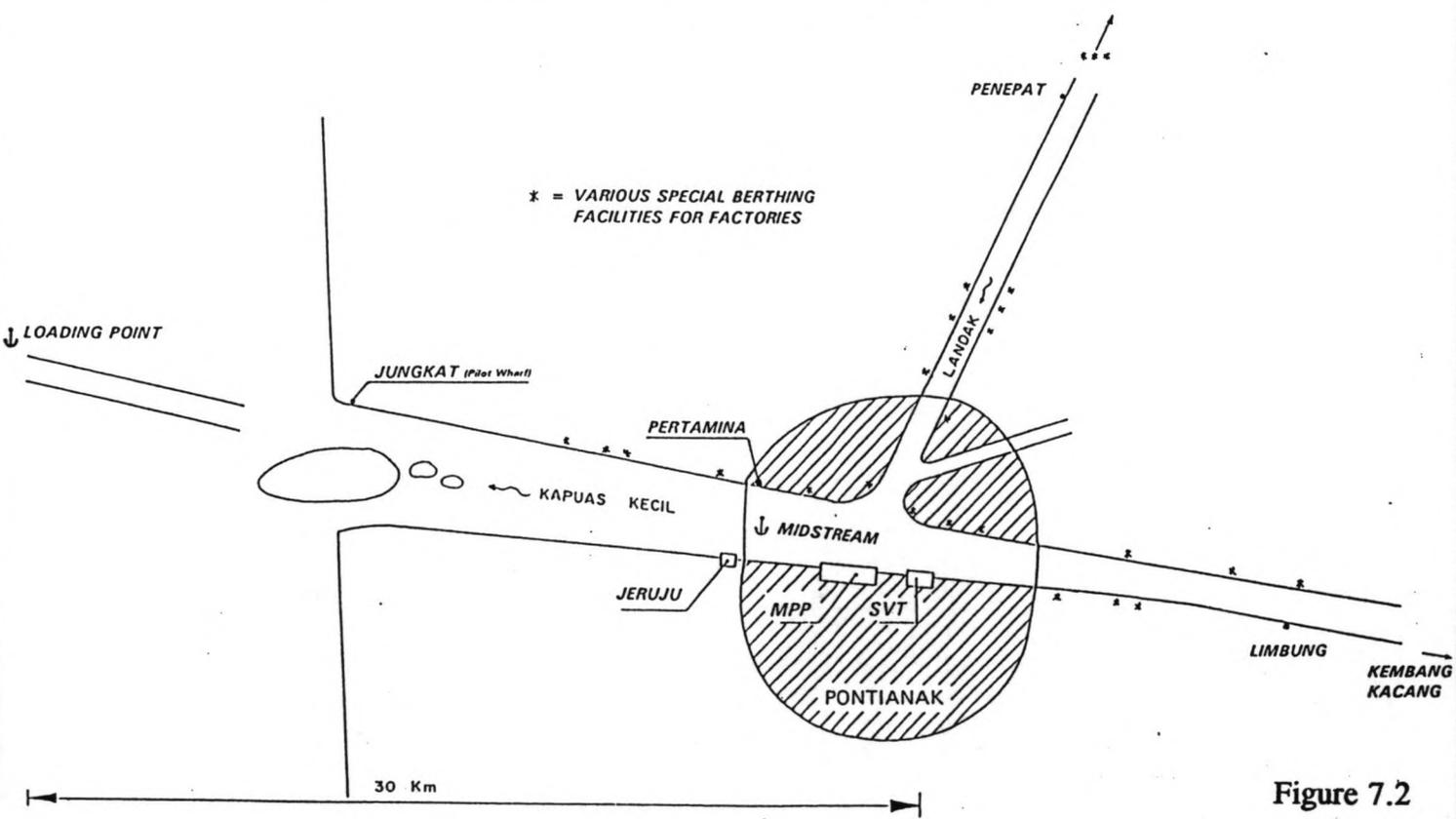


Figure 7.2

are transhipped. The midstream anchorages are also utilized by ships which are waiting for berthing at the quays of the MPP. There are no physical facilities available.

* *Offshore Loading Point*: beyond the estuary of the Kapuas Kecil river, in deep water, transshipment of plywood and other forestry takes place; all cargo is export cargo and is loaded to the ships from barges. The Offshore Loading Point is not a clearly defined area and no physical provisions are available.

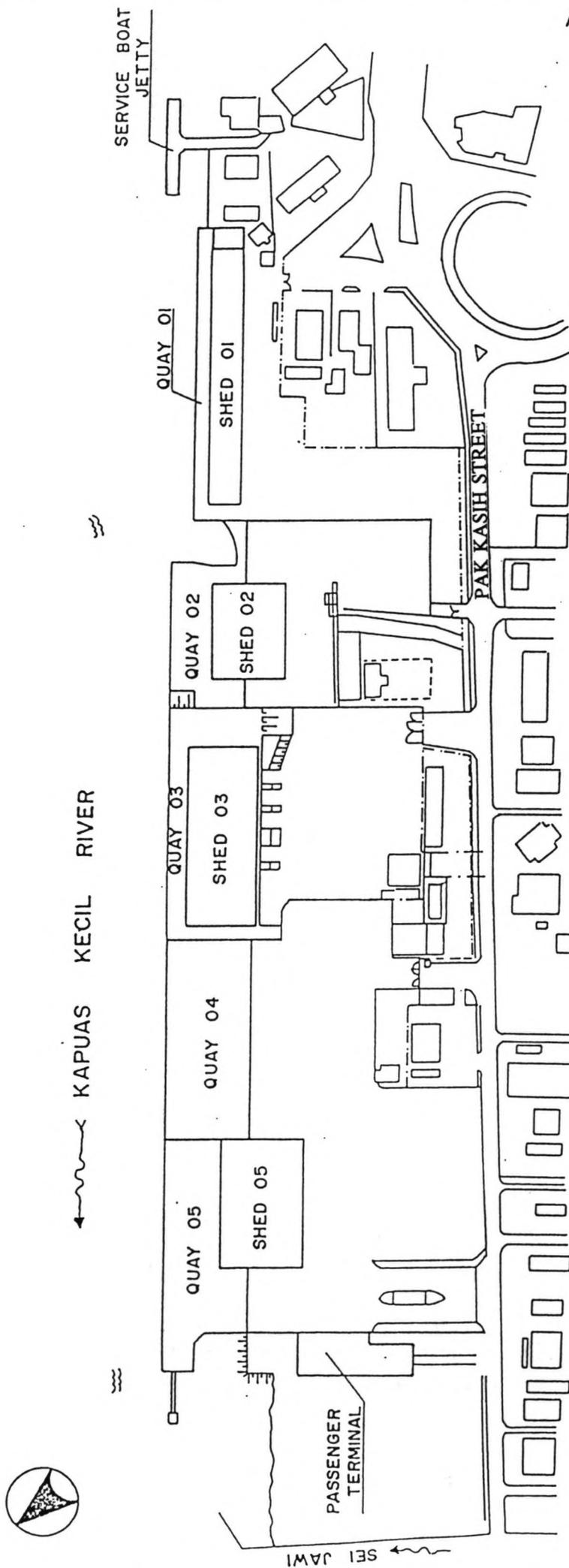
* *Special berths*: along the banks of the Kapuas Kecil and Landak rivers, there are many special facilities for loading/unloading, which are owned by the Government Oil Company and several private companies (plywood, sawmill and rubber industries). The main cargo-types are petroleum and oil products, forestry products, fruit and smaller quantities of other products.

Table 7.1

VESSEL AND CARGO TRAFFIC PONTIANAK	Figures of 1991		Estimates for 2002	
	Cargo handled (1000 tons)	Total number of vessels	Cargo handled (1000 tons)	Total number of vessels
MPP	624	1762	1281	3601
SVT	184	1384	200	1504
Midstream	756	523	1340	772
Offshore	566	316	828	385
Special berths	1042	1085	1622	1340
Total	3172	5070	5271	7602

7.1.3 Cargo and vessel traffic

Table 7.1 shows the cargo and vessel traffic figures for 1991 and the estimates for 2002. The estimates for 2002 are based on forecasts for all different cargotypes in the port of Pontianak. The average annual growth is 4.6 percent. No major diversions of cargo flows within the port are foreseen. The parcel size of vessels is expected to increase with 20% (except for local and sailing vessels and tankers, which are already loaded at full capacity).



100 m

Figure 7.3

7.1.4 Harbour environment

Vessels enter the port of Pontianak via the Kapuas Kecil river and an entrance channel through the outer bar (see Figure 7.2). The river stretch has a length of 20 km (between the river mouth and Pontianak) and a maximum width of 650 m. The navigable width at the MPP is 300 m. The natural depths in the river are nearly everywhere more than 7 m below Low Water Spring (LWS) tidal conditions. The depth of the entrance channel is maintained at a minimum level of LWS - 4.5 m by maintenance dredging, amounting to one to two million m³ annually. The tide at the Kapuas Kecil river mouth is diurnal, with one daily high and one daily low water. The tidal range is approximately 1.5 m, thus implying a maximum allowable draught at the entrance channel between 4 and 5.5 m, depending on the tide and taking into account a keel clearance of ca. 0.5 m.

The climate in Pontianak is strongly influenced by its latitude (0°01' south of the equator) and the two monsoon seasons. The average annual rainfall is relatively high, with maxima in November and May and minima in February and August. In December to March the dominant wind direction is NW, with an average velocity of 5-7 knots and a maximum velocity of 16-20 knots; in May to September this changes to a SE direction, with an average velocity of 5 knots and a maximum value of 14-19 knots. During these two seasons the wave heights at the river mouth are at a maximum: 20% of the waves are higher than 1 m. However, the offshore waves do not have any impact on the operations at the MPP or at neighbouring port facilities, due to their location upstream on the river. The maximum wave height at the MPP, caused local by winds and ship-induced waves, is 0.5 m.

7.2 Main Public Port

7.2.1 Facilities

The main facility of the Pontianak Public Port Corporation is the Main Public Port, located on a 8.6 ha area between the southern bank of the Kapuas Kecil river and the Pak Kasih road, which runs parallel to the river. The location is illustrated in Figure 7.3. The MPP has 5 quays; all quays have an open storage facility and all except quay 4 have a covered storage facility (shed). Table 7.2 shows the main characteristics of each of the quays and their storage facilities.

The structure of all quays consists of a deck supported by piles. Quay 1 is a wooden structure; it is in a bad condition. All other quays have reinforced concrete decks, supported by reinforced concrete piles and are in a satisfactory condition. The fender systems of quays 2, 4 and 5 are "V" type rubber fenders. The fender system at quay 3, vertical timber fender

piles, is in a very bad condition. At quay 1, ship-owned rubber tires are used. A level difference exists between quay 2 and quay 3, so a concrete ramp has been constructed between these two quays.

Shed 2 and 5 have reinforced concrete floors, steel pipe piles, a single beam steel portal superstructure, aluminium roof sheets and concrete blockwork walls. Shed 3 has reinforced concrete floors and piles and a single beam steel portal superstructures with iron clad walls and roof. Sheds 2, 3 and 5 are in good condition. Shed 1 has a wooden superstructure and a wooden floor, supported by wooden piles, and is in a poor condition. Another problem concerning shed 1 is the fact that the shed covers the entire length of the berth, implying that all cargo must be transferred through the shed, even if it does not require intermediate storage.

There are also several other facilities at various locations on the MPP premises: a building for the port administration, a building for the customs, a building for the coast guard, a passenger terminal, a building for the pilot and harbour-master, services for power, water, lighting, an equipment service building and a staff building.

Table 7.2

FEATURES OF MAIN PUBLIC PORT	Length (m)	Apron width (m)	Gross storage area of shed (m ³)	Gross open storage area (m ³)
Quay 1	115	7	110 * 15 = 1650	3700
Quay 2	75	21	50 * 35 = 1750	1600
Quay 3	117	10	90 * 30 = 2700	2100
Quay 4	100	36	0	4800
Quay 5	100	24	66 * 40 = 2640	3600
Total	507	-	8740	15800

7.2.2 Cargo and vessel traffic

In 1991 a total of 1762 cargo vessels called at the MPP. The types and sizes of those vessels can be described by the following distribution and average values of characteristics:

- * 793 local vessels (45 % of total, length 33 m, 150 GRT, 210 DWT)
- * 810 interinsular vessels (46% of total, length 55 m, 550 GRT, 750 DWT)
- * 159 ocean going vessels (9% of total, length 60 m, 750 GRT, 1000 DWT)

The mean load of local vessels is 200 ton; they carry general cargo. The interinsular and ocean going vessels have a combined total of 969 vessels. Their mean load is 480 tons. Of the combined category, 581 vessels (60%) carry general cargo and 388 (40%) carry bagged cargo.

The cargo which is handled at the MPP can be broken down as shown in Table 7.3. A large part of the cargo concerns the category *others*. This includes various commodities and types of packages: big cases, small cartons, drums, bales, crates, poles, etc. The category *others* is mainly transported by local vessels. The categories rice, cement and fertilizer are mainly transported as bagged cargo.

In 1991 a small share of general cargo was transhipped as containerised cargo at the MPP: 6430 tons, equal to 804 TEU. Of the outgoing containers (50% of the total number of containers) 5% is empty, of the incoming containers (also 50% of the total) 90% is empty. The containerised commodities are rubber, moulding, furniture, pepper and frozen shrimps. Containers are handled at quay 5.

In addition to the cargo carrying vessels, also passengerships attend the MPP. These vessels, of which ca. 180 call at the MPP annually, account for 320,000 passengers. The average duration of their stay is 5 hours; they moor at quay 5. Embarking and disembarking passengers and their relatives/friends use the storage areas of quays 4 and 5 as a parking area for cars.

Statistics for August 1992 concerning cargo carrying vessels indicate the following average waiting times:

- * Local vessels, general cargo: 96 hours
- * Local vessels, bagged cargo: 103 hours
- * Local vessels, unitized cargo: 73 hours
- * Interinsular vessels, general cargo: 18 hours
- * Interinsular vessels, unitized cargo: 55 hours

* Ocean going vessels, unitized cargo: 101 hours

* Ocean going vessels, containers: 10 hours

Table 7.3

THROUGHPUT MPP (1991)	Cargoflow (1000 tons)		
	Out	In	Total
Rice	0	126	126
Wheat flour	0	12	12
Animal feeds	0	7	7
Indust. flour	1	9	10
Rubber	2	0	2
Sugar	0	30	30
Sawn wood	0	4	4
Plywood	9	0	9
Asphalt	0	13	13
Fertilizer	0	50	50
Cement	0	57	57
Dang. cargo	0	8	8
Others	65	221	286
TOTAL	77	537	614

Other observations indicate values of 48 hours and 31 hours respectively for the average waiting time of interinsular and ocean going ships. The available data on waiting times are inconsistent and do not provide satisfactory information to draw exact conclusions about the waiting times, apart from the fact that they are relatively long.

7.2.3 Cargo handling and storage

General cargo is handled at all five quays. Local vessels (with general cargo) moor at quays 1 and 2; quay 3 may also be used by local vessels, if it is free. Local vessels work 8 hours per day with 1 gang per vessel. The output per gang hour during working hours is 12 tons. Interinsular and ocean going ships with general cargo moor at quays 3, 4 and 5. They work

10 hours per day with an average of 2.5 gangs per vessel. The output per gang hour during working hours is 13 tons.

Bagged cargo arrives at in full loads with interinsular/ocean going ships at quays 3, 4 and 5. These ships work 8 hours per day with an average of 3.5 gangs per vessel. The output per gang hour during working hours is 12 tons. Table 7.4 shows the figures of the cargo handling rates, as described above. They are transformed into the net output per ship per hour at berth. The figures of the net outputs and the figures of the vessel traffic lead to two indications of the performance of the berths: the average time at berth per vessel and the berth occupancy rate. The berth occupancy rate (B.O.R.) is defined as:

$$B.O.R. = \frac{N * t * l_{vessel}}{365 * 24 * l_{berth}}$$

in which:

- N = annual number of vessels
- t = average berth time per vessel (hours)
- l_{vessel} = average vessel length (m)
- l_{berth} = berth length (m)

For the month of August 1992 the berth occupation rates have been measured. The measured values are:

- * Quay 1: 73.4
- * Quay 2: 90.5
- * Quay 3: 77.8
- * Quay 4: 85.2
- * Quay 5: 57.0

The calculated berth occupancy rate-figures of Table 7.4 are compared to the measured values. It can be concluded that the measures and calculated values are quite similar. The major discrepancy is for quay 5: this is due to the fact that passenger ships have not been included.

The handling of general cargo and bagged cargo is carried out manually, using only basic equipment (slings, nets, handcars). Cargo is handled roughly and carelessly, often causing damage. Bagged goods are mainly transhipped directly onto trucks. However, often the available number of trucks to transport the unloaded bags is insufficient, causing constraints in the discharge of bags. The total share of directly loaded/unloaded cargo is 18%. General

Table 7.4

CARGO HANDLING/ BERTH OCCUPATION MPP (1991)	Local vessels	Interinsular/ocean going vessels: general cargo	Interinsular/ocean going vessels: bagged cargo
Number of gangs per vessel (A)	1	2.5	3.5
Output per gang hour (tons) (B)	12	13	12
Ratio working hours/ hours at berth (C)	8/24 = 0.33	10/24 = 0.42	8/24 = 0.33
Output per ship hour at berth (tons) (D = A*B*C)	4.0	13.7	14.0
Annual number of vessels	793	581	388
Tons per vessel (E)	200	480	480
Average berth time per vessel (hours) (E/D)	50.0	35.0	34.3
Average berth occupancy ratio	78.6 (quay 1 + 2)	77.0 (combined) (quay 3 + 4 + 5) (incl. pass. vessels)	

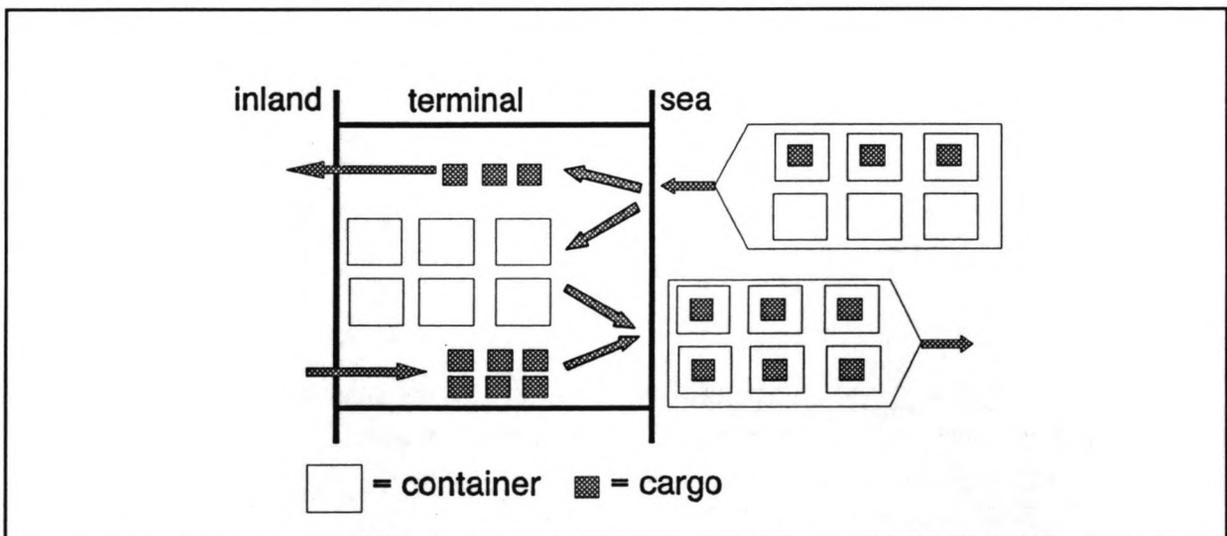


Figure 7.4: example of stuffing and stripping of containers on terminal premises

cargo predominantly requires intermediate storage. Of the total throughput 67% is stored in sheds and 15% is stored open on the terminal premises. The dwell times are 2 days on average for export goods, local traffic and interinsular traffic and 10 days on average for import goods. The large amount of directly delivered cargo and the low dwell time for export goods and local and interinsular traffic result in a net average storage occupancy ratio of ca. 20%.

The following mechanical cargo handling equipment is present at the MPP:

- * 1 mobile crane (nominal capacity 25 ton, actual capacity - due to wear and tear - 16 ton, capacity at a 10 m working radius 5 ton)
- * 4 fork lift trucks (capacity 2 ton)
- * 2 head trucks
- * 3 chassis for container transport

Containers are loaded/unloaded by ships' own gear. The transfer between ship and storage v.v. is performed by the truck-chassis combinations and the crane. Containers are stuffed and stripped on the terminal premises. Containers do not leave the terminal when they have been stripped but they stay on the MPP premises. The average dwell time of containers is 15 days. After that period they are stuffed again and loaded onto other vessels. The dwell time of cargo which is stuffed into/stripped from containers is 5 days. The separate cargoflows of containers and cargo which is containerized is shown in Figure 7.4. In the figure, 50% of the incoming containers are empty; all outgoing containers are loaded.

7.3 Port development study

A study has been performed to predict the cargo throughput growth at Pontianak in medium term and to plan the required development of port facilities to cope with the growing cargo flow. For the situation in ten years from now (the year 2002) cargo forecasts have been made. In Table 7.1 the estimates for the entire port for 2002 are given. This paragraph deals only with the port development aspects of the Main Public Port.

7.3.1 Cargo and vessel traffic forecast

Table 7.5 shows the cargo forecast at the MPP for 2002. In column (A) the outgoing cargo is specified; in column (B) the incoming cargo is specified. In medium term no major diversions of cargoflows are expected, except from:

- * 126,000 tons of incoming general cargo which should be handled by the Sailing Vessel Terminal but is expected to be diverted to the MPP, due to constraints at the SVT. This diversion is specified in column (C).
- * 27,000 tons of rubber (outgoing) which is expected to be diverted from the Midstream Anchorage to the MPP, because it will be containerised. This volume has been added to the forecast for 2002 in Table 7.5 (column (A), commodity rubber).

Table 7.5

THROUGHPUT FORECAST MPP (2002)	Cargoflow (1000 tons)				
	Out (A)	In (B)	In; diversion from SVT (C)	Total (2002) (A+B+C)	Total (1991)
Rice	0	228	22	250	126
Wheat flour	0	35	0	35	12
Fruit	25	0	0	25	0
Animal feeds	0	25	29	54	7
Indust. flour	1	13	0	14	10
Rubber	29	0	0	29	2
Sugar	0	43	7	50	30
Sawn wood	0	15	0	15	4
Plywood	10	0	0	10	9
Asphalt	0	23	0	23	13
Fertilizer	0	110	11	121	50
Cement	0	92	37	129	57
Dang. cargo	0	14	1	15	8
Others	112	380	19	511	286
TOTAL	177	978	126	1281	614

The sum of columns (A), (B) and (C) indicates the throughputs for each of the commodities and the total throughput at the MPP in 2002: 1,281,000 tons. Of this total, 411,000 tons is expected to be carried by local vessels and 870,000 is estimated to be carried by interinsular and ocean going vessels.

In medium term, no significant changes are expected in the types and sizes of vessels calling at Pontianak. However, the sizes of individual shipments are predicted to increase by 20%, expect for the local vessels. With a mean load of 200 tons, these vessels are already at full capacity. The throughput by local vessels will be 411,000 tons; therefore the vessel traffic in 2002 for local vessels will amount to 2055 units.

The volume of 870,000 tons which is transported by the category of interinsular and ocean going ships consists of general cargo, bagged cargo and containerised cargo. A share of 80,000 tons is expected to be containerised, equal to 8000 TEU. Incoming container traffic accounts for 4000 TEU (50% full, 50% empty); outgoing traffic accounts for 4000 TEU (95% loaded, 5% unloaded). The average container load per interinsular/ocean going vessel is 60 TEU (30 TEU out and 30 TEU in); therefore the total number of vessels is estimated to be some 140. The containerised cargo leaves (870,000 - 80,000 =) 810,000 tons of other general cargo and bagged cargo, to be carried by interinsular and ocean going ships. With an average ship load of 576 tons, the number of vessels amounts to 1406. The total number of interinsular/ocean going vessels therefore adds up to 1546; the total number of all cargo carrying vessels is 3601.

For each of the commodities handled at the MPP the possibility of fluctuations to the forecast for 2002 has been researched. This has resulted in a standard deviation of the forecast for each commodity, from which the standard deviation of the total cargo flow has been deducted. The final standard deviation of the forecast for the total throughput of the MPP in 2002 is 168,000 tons, equal to approximately 13% of the mean prediction 1,281,000 tons. With the standard deviation it is possible to define three throughput scenarios for 2002:

- * *Low* scenario: 1,113,000 tons
- * *Medium* scenario: 1,281,000 tons
- * *High* scenario: 1,449,000 tons

The passenger traffic projection for 2002 indicates a growth to an annual total of 520,000 passengers, increasing the yearly number of calls to ca. 350.

7.3.2 Cargo handling and storage

The dwell times of cargo in 2002 are expected to remain the same as compared to 1991. The average dwell times are: 2 days for local traffic, interinsular traffic and export goods, 10 days for import goods, 5 days for cargo to be containerised, 15 days for containers. The share of incoming cargo which is classified as import cargo and requires a longer dwell time consists of asphalt in drums and of smaller quantities of other general cargo: the total amount

of import cargo is 60,000 tons.

The division of storage requirements in 2002 is also predicted to remain similar to the 1991-values: 15% of the throughput requires open storage, 67% of the throughput requires shed storage and 18% of the throughput is delivered directly from/onto trucks without using intermediate storage.

As specified in Paragraph 7.2.3, the output-rates for each of the two ship-types (local and interinsular/ocean going) and the two cargo-types (general cargo/bagged cargo) are quite low. Among others, this is caused by:

- * Manual handling of cargo, using only basic gear
- * Lack of sufficient transport for direct discharge of bags
- * Obstruction caused by the shed across the full length of quay 1
- * Passengervessels calling at quay 5

Often lack of sufficient storage area is also a cause for delayed cargo handling in port-types similar to the MPP. However, initially this is not a problem for the MPP: the storage occupancy is very low (see Paragraph 7.2.3). The output-rates can be improved by:

- * Better equipment: stevedoring pallets, special hooks for bagged cargo
- * Increasing ship working hours
- * Providing training for port employees
- * Improving the efficiency of discharge of bags (e.g. increasing transport capacity, using movable conveyors)
- * More supervision
- * Not using quay 5 for passengershops
- * Not using quay 1 (transforming it to a passenger terminal)
- * Improving container handling by purchasing new mechanical equipment
- * Increasing the sizes of the vessels and individual shipments

Several scenarios for the improvement of cargo handling rates have been developed as part of the port development study. It concerns *optimum*, *minimum* and *medium* improvements. The scenarios are based on the improvement suggestions, as described above. The optimum scenario includes considering an increase of the vessel sizes and shipment sizes and expanding the daily working time to 20 hours. The medium scenario incorporates a 16 hour working day (2 shifts) and improved handling techniques. The minimum scenario concerns improving handling techniques, increasing the transport capacity and applying better supervision. The output-rates (output per ship hour at berth) which are realized by each of the scenarios are shown in Table 7.6.

Table 7.6

CARGO HANDLING IMPROVEMENT SCENARIOS MPP			
Output per ship hour at berth (tons)	Local vessels	Interinsular/ocean going vessels: general cargo	Interinsular/ocean going vessels: bagged cargo
At present	4.0	13.7	14.0
Guaranteed improvement	5.0	20.0	20.0
Minimum improvement	5.0	23.1	40.4
Medium improvement	10	37	82
Optimum improvement	12	44	98

The optimum improvement scenario is not feasible in medium term. For the minimum scenario, improving the supervision and the handling techniques (training, using pallets, etc.) are within the influence of the port authorities. However, increasing the transport capacity is not. Therefore a fourth scenario is introduced: the *guaranteed* improvement. The output-rates for this scenario are also given in Table 7.6; the guaranteed improvement scenario solely incorporates handling techniques and supervision.

7.4 Problem analysis

As indicated in the previous paragraphs, the annual throughput of cargo at the MPP is expected to increase at a high rate: 108% growth in the period 1991-2002. The number of vessels calling at the MPP yearly is predicted to rise by 104% in the same period. The forecasts indicate a growth in the number of local vessels (159%) as well as interinsular and oceangoing vessels (60%) and an increase for the throughput of general cargo (105%) as well as bagged cargo (79%). For containers the expected rise is very much bigger: the predicted flow of containerised cargo for 2002 is twelve times the cargo flow of 1991.

Considering the current berth occupancy rates of 75-90% it can be expected that, in its current state, the MPP cannot cope with the predicted cargo and vessel traffic in medium term. Already the waiting times for vessels are high (30-100 hours). According to statistics of 1992 the ratio of time spent waiting at the anchorage divided by time spent at the quay is approximately 1 for interinsular and ocean going vessels and approximately 2 for local vessels. Therefore the cargo transshipment capacity of the Main Public Port must be

increased. There are two important ways of achieving this.

The first way is to decrease the time spent by vessels at the quay. This can be performed by improving the productivity: the rates with which ships are loaded and unloaded must be increased. Several cargo handling improvement scenarios have been established, of which the guaranteed improvement scenario and the minimum improvement scenario are feasible in medium term. The scenarios were discussed in the previous paragraph.

A second way of increasing the capacity of the MPP is creating extra quay length, implying that more ships can be served at the same time as is currently possible. The extent to which the total quay length must be increased depends on several parameters. The main parameter is the realised cargo handling rate improvement. Another aspect concerns possible changes in rules of allocating ships to quays. Passengerships can for instance be separated from cargo carrying vessels. Also fluctuations in the throughput forecast must be taken into account. In this context three throughput scenarios have been established, based on a deviation of the average throughput prediction (see Paragraph 7.3.1). Finally, also the desired berth occupancy rates and the desired waiting times for ships in medium term influence the requirements for extra quay length. The berth occupancy rates for 2002 may remain the same as the current rates (75-90%) but the vessels' waiting times must preferably be lower: the ratio of waiting time divided by time at quay must decrease from 1-2 in 1991 to ca. 1 for all vessels.

The cargo throughput increase in medium term will also affect the storage area requirements. For 1991 the available storage area is by far sufficient to meet the requirements, for covered storage in the sheds as well as for open storage on the terminal premises. Due to the cargo flow growth this situation might change; extension of the current storage area may be required. Naturally, this is also dependent of the development of the dwell times of cargo (known) and of the fluctuations in the intensity of the cargo flow (not known).

The combined requirements for extra quay length and extra storage area lead to a new lay out of the Main Public Port. With this new lay out, the MPP can cope with the supply of cargo and vessels in medium term.

7.5 Objective of the application

The development of congestion for the present port configuration due to a growing cargo throughput at the Main Public Port in Pontianak needs to be studied. Based on the predicted increase of cargo-movements in medium term (2002), research must be performed into an improved port lay-out and improved port operation procedures. These improvements concern,

among others, extra quay length, increased productivity rates and extra storage area. The research must consider the consequences to the port operations of these adaptations/extensions to the port facilities. The sensitivity of the adaptations/extensions must be tested. A comparison of alternatives for port development must be produced.

The performance of the MPP in medium term can be expressed in, among others, the waiting times and total port times of vessels and the occupancy rates of quays and storage areas. The port simulation model, which has been described in the previous chapters, can be applied to perform this research. The results of the study with the model can be compared to the outcome of the Haskoning port development study, which is based on the queuing theory.

8 Application of the model for Pontianak

8.1 Introduction

The model has been applied for the Main Public Port at Pontianak, in order to investigate the problems which were broached in Chapter 7. This chapter contains a description of the application. First the required input information is discussed (Paragraph 8.2): the characteristics of the vessels, the storage facilities and the 1991-quay configuration are given. The year 1991 is the starting point for the simulations. For this year a calibration of the model has been performed (Paragraph 8.3). Paragraph 8.4 looks at the development in the port in the period directly after 1991 (short term development). The occurrence of congestion due to the increase of the cargo throughput for vessels, berths and storage area is confirmed. Possible improvements to the present situation, which are feasible for implementation in short term, are also investigated. These improvements concern an increase in cargo handling rates and different berth allocation rules.

The main part of this chapter focuses on the development of the port in medium term. Paragraph 8.5 deals with the medium term port planning. In this paragraph the adaptations and extensions to the Main Public Port, which are proposed by the Haskoning port development study, are presented. This proposal is the starting point for the simulation-runs. Paragraph 8.5 also explains the variety in input-information with which the simulation-runs have been performed: three quay configurations (one proposed by the port development study and two alternatives), three cargo handling improvement rates and five throughput scenarios. This is followed in Paragraph 8.6 by an outline of the results of the simulation-runs. Paragraph 8.7 concludes the chapter, with a discussion of the results of the application. Annex 5 contains more extensive information of the input and output data for the short term and medium development.

8.2 Model input

Pontianak is modelled as a port with one terminal and an anchorage midstream on the river Kapuas Kecil. Vessels wait at the anchorage if they are delayed due to full occupancy of the berths. When sailing from the anchorage to the quay, vessels are not restricted by a tidal window.

All quays are modelled as *multiple berths*, meaning that more than one ship can be served at the berth simultaneously (see Figure 8.1). For example, in the begin situation for 1991, quays 3, 4 and 5 jointly form one multiple berth at which interinsular and ocean going vessels are served. Quay 1 and quay 2 are both multiple berths which serve local vessels.

These two quays can not be considered jointly because they are not connected (see lay out of MPP, Figure 7.3). The berth lengths are 115 m for quay 1, 75 m for quay 2 and 317 m for quays 3/4/5.

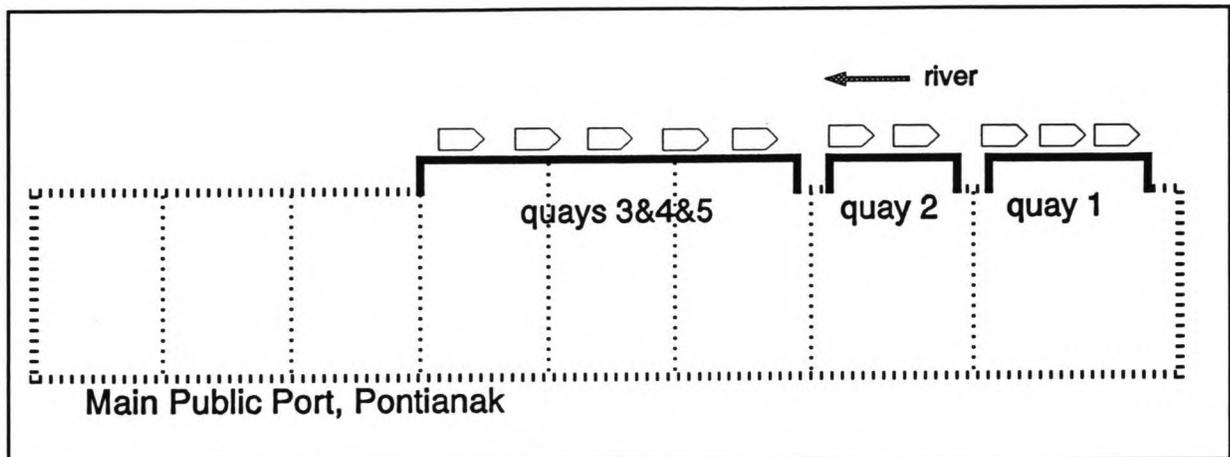


Figure 8.1: configuration of 5 quays (not to scale)

The vessels attending the MPP are divided in six shipclasses:

- * Local vessels carrying general cargo; 180 - 240 DWT; length 27 - 39 m
- * Interinsular vessels carrying general cargo; 700 - 800 DWT; length 50 - 60 m
- * Interinsular vessels carrying bagged cargo; 700 - 800 DWT; length 50 - 60 m
- * Ocean going vessels carrying general cargo; 900 - 1100 DWT; length 50 - 70 m
- * Ocean going vessels carrying containers; 900 - 1100 DWT; length 50 - 70 m
- * Passengervessels; length 100 m

The figures for dead weight tonnage and length indicate the lower and upper boundaries of the ranges from which the actual values for vessels are drawn. The ranges have been arbitrarily assigned to possess uniform distributions. The values for length indicate the total required berth length, including free space between adjacent ships. No draught restrictions exist for any of the shipclasses so values for the vessels' draughts are not of importance. The container carrying vessels and the passengervessels are given priority by the harbour-master.

The port simulation model operates with a discrete number of gangs per vessel and with the same daily amount of working hours for the whole terminal. In the real life situation the average number of gangs per vessel is 1 for local vessels, 2.5 for interinsular vessels with general cargo and 3.5 for interinsular vessels with bagged cargo. The number of working hours is 8, 10 and 8 respectively (see Paragraph 7.2.3). However, the output per hour of a crane c.q. gang in the model is dependent on the quay and not on the type of vessel it is serving. Therefore some simplifications have to be made; however the net output per ship

hour at berth must remain the same. The best fitting simplification is discussed as part of the calibration process in the next paragraph.

Table 8.1

STORAGE CHARACTERISTICS MPP	General cargo (local and interinsular vessels)	Bagged cargo (interinsular vessels)	General cargo (ocean going vessels)	General cargo (to be stuffed in containers)
Mean stackheight covered (m)	2.99	2.99	3.00	2.50
Mean stackheight open (m)	1.01	1.01	1.36	2.50
Mean density (ton/m ³)	0.407	0.407	0.410	0.630
Mean perc. of cargo stored under cover	81.7	81.7	81.7	100
Mean dwell time incoming cargo (days)	2	0	10	0
Mean dwell time outgoing cargo (days)	2	2	2	5

Cargo is stored open on the terminal premises at the five quays and under cover in the four sheds. The total storage area is 24,600 m². The characteristics which are used for determination of storage requirements are shown in Table 8.1. Two extra categories of general cargo are mentioned in this table. The first is general cargo which is carried by ocean going vessels and of which the incoming cargo is import cargo (with a mean dwell time of 10 days). The second is general cargo which is transhipped in containers; the outgoing general cargo of this category has a mean dwell time of 5 days, during which it is stuffed in containers; the incoming cargo of this category arrives in containers, which are directly transported of the terminal with trucks. A large share of the containers (50%) which arrive at the terminal by ship or by truck are empty containers; they are also stored on the terminal. With regard to the registration of container-storage a problem occurs in the simulation model. The storage-master can only register one cargotype for each shipclass which arrives at the terminal. However, the ocean going vessels which carry containers, generate a flow of general cargo as well as containers: the general cargo requires stuffing into the empty containers. Therefore the model has been adapted so that for every arriving, container carrying, vessel a flow of containers is generated; the containers have a mean dwell time of 15 days (see Paragraph 7.2.3). In this way the extra storage area requirement due to storage of empty containers in the MPP is also taken into account.

A multiplication factor 2 is applied to translate the net storage requirements into gross requirements. This is to account for travelling lanes and other gross area utilization due to cargo storage. The general and bagged cargo are transported to and from the MPP by trucks; their average load is 4.5 tons. Loading and unloading of vessels and inland transport take place on every day of the week. The length of a simulation run is set at 1200 days, in order to allow a sufficient number of ships to arrive at the terminal during a run.

8.3 Calibration

Before the port simulation model is used for making simulation runs to analyze the short term and medium term changes at the MPP, a calibration must be performed. This means the model is applied to simulate the current port situation; the produced results are compared to the present real life port performances. The calibration is executed for the year 1991; sufficient data are available for this year to make a reliable comparison.

Calibrating is an iterative process of changing input data and comparing the output-information to the 1991-data. The comparison of output-data is performed with regard to the following parameters: gross berth times of vessels, berth occupancy rates, waiting times of vessels and storage area requirements. Only a small share of the total input-information is available for modification. As is explained in the previous paragraph, most input-data have fixed values. The *input-parameters* which can be modified, when comparing the berth times and the berth occupancy rates, are the *daily number of working hours*, the *number of gangs* working on one vessel and the *net output per gang hour*. The input-parameters which can be modified, when comparing the waiting times, are the *number of vessels at one quay* and the so-called *mooring time* and *mooring restriction*. The extent of modifications of these input-parameters and the actual comparison will now be discussed.

The first comparison is made for the gross time spent at berth by the different type of vessels. Based on the cargo handling rates, average values for the berth times were calculated in Paragraph 7.2.3, for local vessels and interinsular/ocean going vessels carrying general cargo, bagged cargo and containers. The calculated values are shown in Table 8.2, together with data of statistics for August 1992. Three categories have matching calculated and measured values, a fourth one (bagged cargo carrying interinsular vessels) does not: an explanation for this dissimilarity may be the short period of measurement (one month). Calibration has lead to output figures of the port simulation model for 1991 which are also shown in Table 8.2.

In the process of achieving the figures in Table 8.2, the length of the daily shift at the MPP has been set at 8 hours for the whole terminal. The *number of gangs per vessel* is 1 for local

Table 8.2

MPP 1991 CALIBRATION	Calculated values	Measured values	Values of cali- brated model
AVERAGE BERTH TIME (hours)			
Local vessels	50.0	43-57	51.02
Int.ins./ocean going vessels (gen.cargo)	35.0	45	37.95
Interinsular vessels (bagged cargo)	34.3	3-6	36.23
Ocean going vessels (containers)	15.0	14	15.04
BERTH OCCUPANCY RATE			
Quays 1&2	0.786	0.802	0.809
Quays 3&4&5	0.770	0.767	0.765

vessels and 3 for all interinsular and ocean going vessels; the *net output per gang* is 12 tons/hours at quays 1 and 2 (for local vessels) and 13.75 at quays 3/4/5 (for all interinsular and ocean going vessels with bagged and general cargo). The main simplification which has been made in this context is that the cargo handling values are the same for all interinsular and ocean going vessels while in real life they vary (from 8 to 10 hours for daily working time per gang; from 2.5 to 3.5 for the number of gangs per vessel; from 12 to 13 tons for net output rate per gang per hour (see Table 7.4). All of these variations have been tested in the calibration-process. Among the ocean going vessels there is one exception to the net output rate of 13.75 tons per gang per hour: container carrying vessels. They use two gangs and ships gear with a combined net container handling rate of 12 TEU (full and empty) per hour.

The berth time distributions are similar to Erlang-2 distributions, in accordance with the discussions in Paragraph 6.2. The berth occupancy rate of the calibrated model is 0.809 for quays 1/2 and 0.765 for quays 3/4/5, which compare satisfactory to the measured values and calculated values (see Table 8.2).

The second comparison is made for the waiting times of vessels at the anchorage. In the process of calibration, five parameters appeared to have substantial influence on the waiting times:

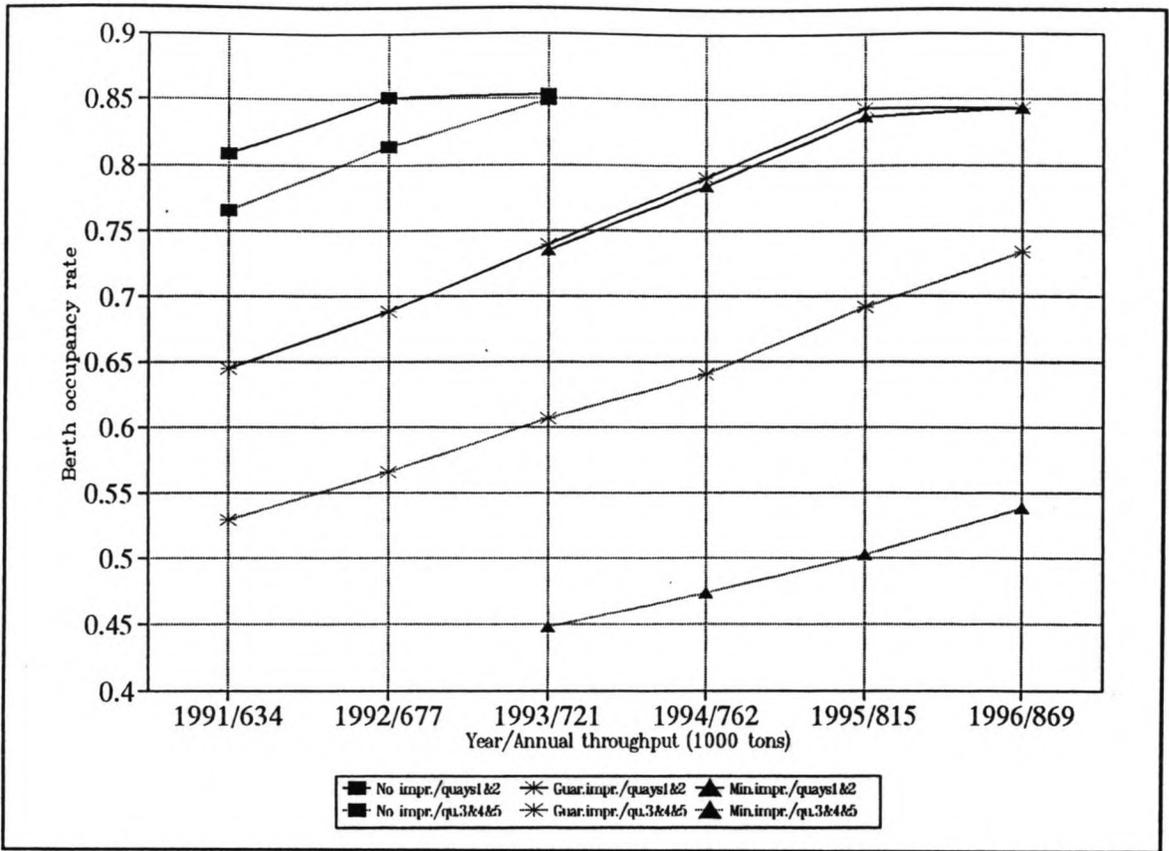


Figure 8.2: berth occupancy rates of quays 1&2 and quays 3&4&5 at MPP, for three cargo handling rate improvement scenarios, 1991-1996

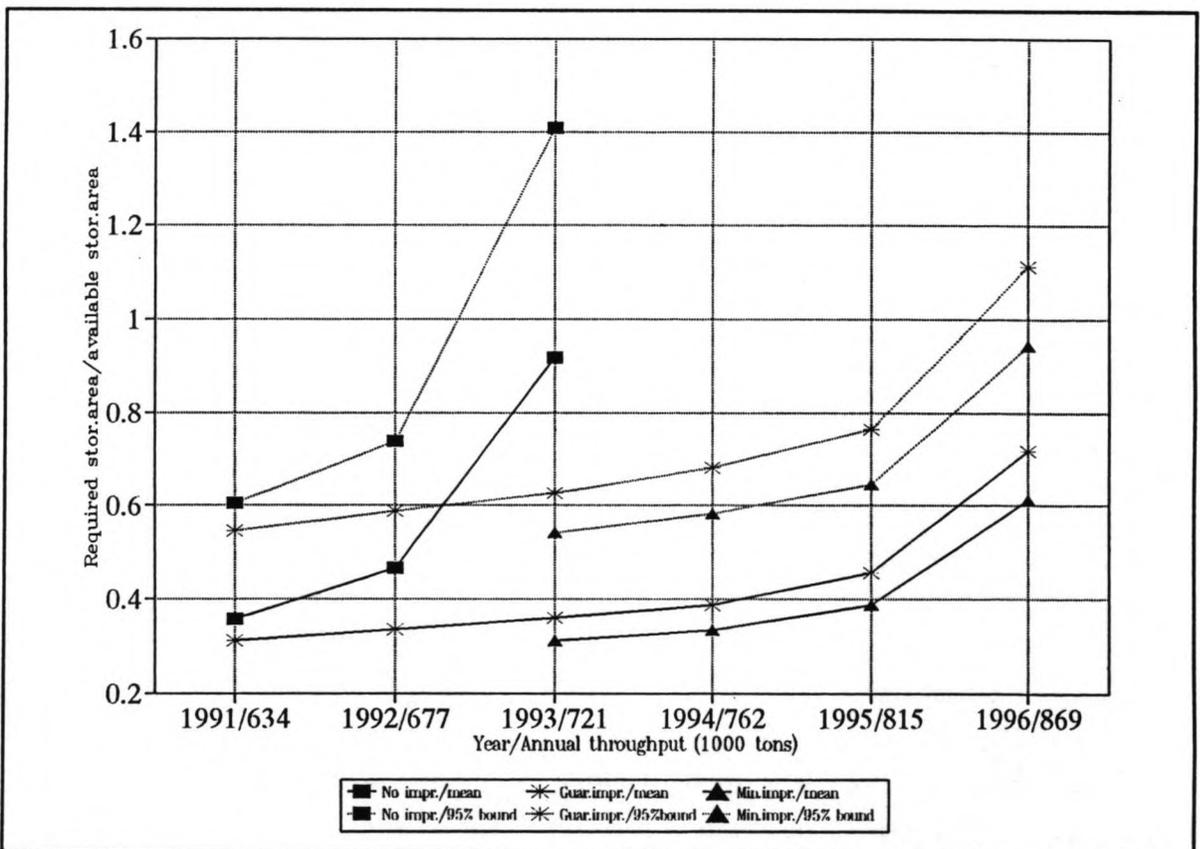


Figure 8.3: storage area occupancy rate (mean value and 95% bound. value) at MPP, for three cargo handling improvement rates, 1991-1996

- * Number of vessels attending the port; these are fixed data.
- * Cargo handling rates; these have been determined, as described above.
- * *Number of vessels* which can be served *at a quay* simultaneously; the maximum number of vessels at a multiple berth depends on the lengths of the vessels and the length of the quay.
- * Procedure of sailing from anchorage to berth; when a ship is allocated to a berth by the harbour-master, it requires time to sail from the anchorage to its berth (*mooring time*).
- * Restriction on ship-manoeuving in front of the quay; a vessel can not moor at a quay or leave a quay when another vessels is also manoeuvring in front of the same or an adjacent quay (*mooring restriction*).

As indicated in Paragraph 7.2.2, there is a large inconsistency in available information of present waiting times. With a vessel capacity of three at quay 1, two at quay 2 and five at the joint quays 3/4/5, a mooring time of 0.5 hours and a mooring restriction of 0.2 hours, the output figures of the calibrated simulation model for average waiting times are: 68.57 hours for local vessels, 38.99 hours for interinsular/ocean going vessels and 5.22 hours for container carrying vessels. The maximum number of vessels at a berth is equal to the berth length divided by the average vessel length. At quays 1 and 2 this is also the case, regardless of the fact that local vessels can tender at these quays. In the calibration-process, the value of the mooring time has been varied between 0.2 and 2.0 hours and the value of the mooring restriction has been varied between 0 and 0.4 hours. The waiting times appeared to be very sensitive to the mooring time and the mooring restriction. Examples of this sensitivity are given in Paragraph 8.6.

Precise historic data of the storage utilization are not available but estimates indicate a net average storage occupancy rate of approximately 20%; multiplied by the gross factor 2 this leads to value of 40%. The mean occupancy rate of storage area in the calibrated model is 0.357, which is sufficiently accurate regarding the uncertainty of the 40%-value. The standard deviation of the storage area occupancy rate distribution is 0.132 and the 95% boundary of this distribution is 0.604.

8.4 Short term development

Between 1991 and 2002 the annual throughput of cargo at the MPP increases at a rate of 6.76% per annum. This increase is due to smaller interarrival-times of vessels and larger loads of those vessels. The mean load of an interinsular/ocean going vessels increases with 1.67% per year, the annual number of vessels increases with 5.00%. The mean loads of local vessels do not alter. Due to the increase of the throughput of cargo, the utilization of port facilities at the MPP will increase if the terminal configuration does not change; eventually

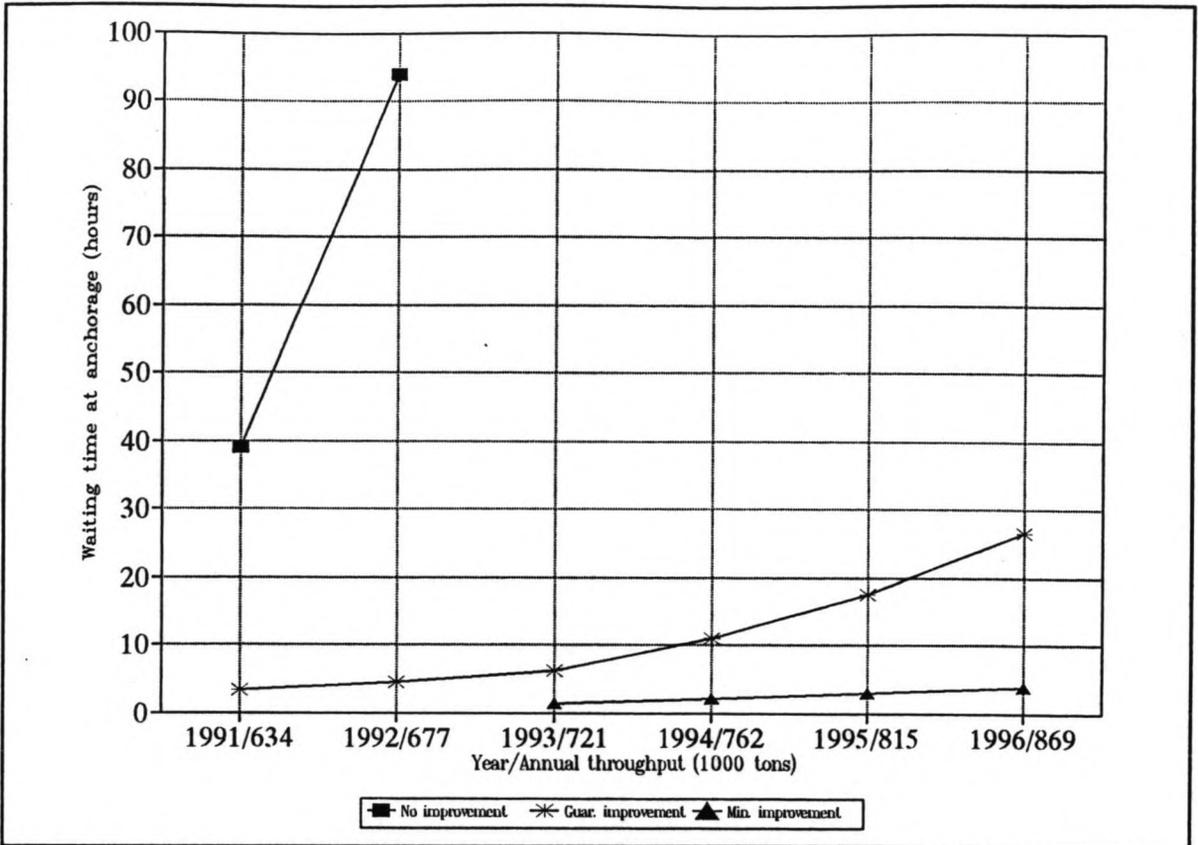


Figure 8.4: waiting times of interinsular/ocean going vessels at MPP, for three cargo handling improvement rate scenarios, 1991-1996

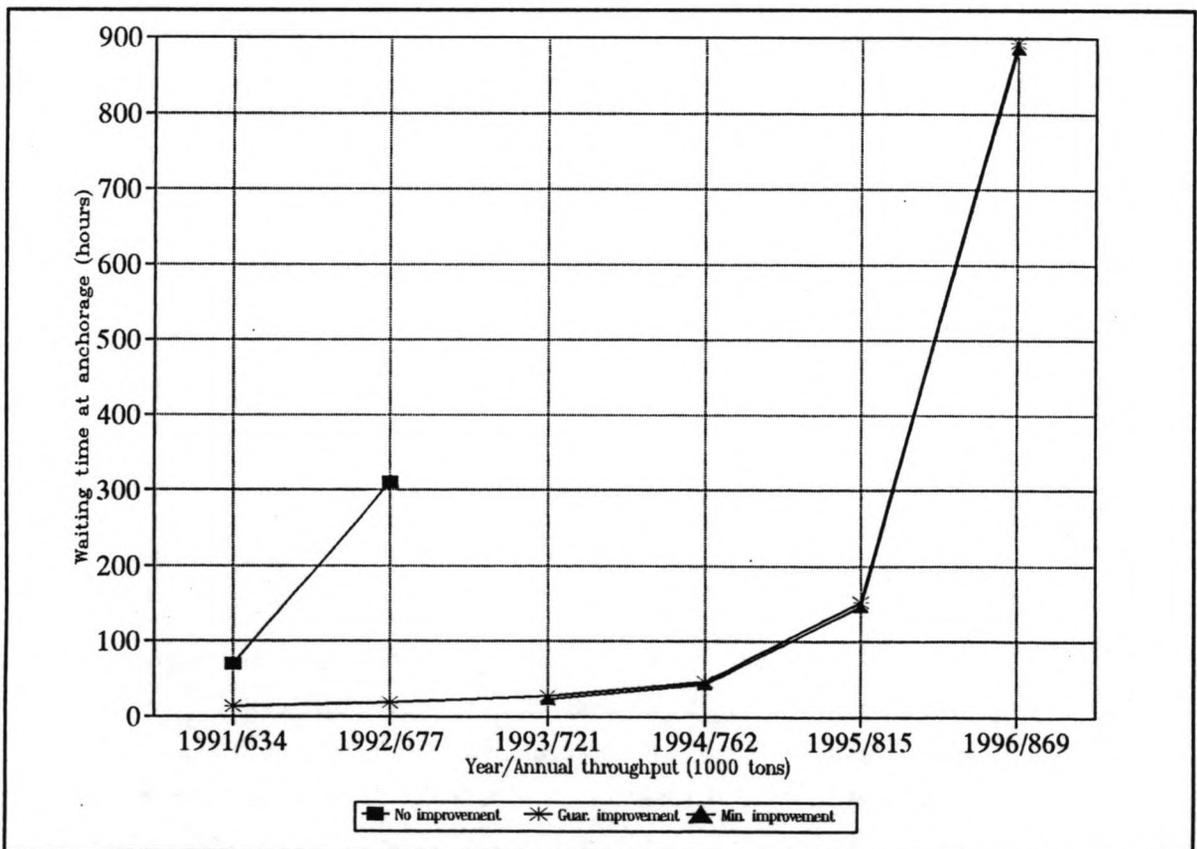


Figure 8.5: waiting times of local vessels at MPP, for three cargo handling improvement rate scenarios, 1991-1996

congestion will occur. The port simulation model has been applied to research the extent of the increase of utilization and to analyze when congestions will take place. This has been performed for the years 1991-1993, with annual increase in vessels arrivals and vessel loads as indicated above and with no improvement in the cargo handling rate. Figures 8.2 and 8.3 show the increase of utilization of berths and storage area, according to the simulation model. Figures 8.4 and 8.5 illustrate the growing waiting times for interinsular/ocean going vessels and local vessels, according to the simulation model.

The figures show that congestion for berths, storage area and vessels will take place quickly. The berth occupancy rate of quays 1&2, at which local vessels are served, barely increases after the 1992-throughput-level. The same applies to interinsular-vessels after the 1993-throughput-level. The berth occupancy rates do not reach the value of 1.00 because a 100% occupation is impossible, due to a discrepancy between the total quay length and the sum of ship lengths at a completely occupied quay. For example: quay 1 has a length of 115 m and can simultaneously handle a maximum of three local vessels with an average length of 33 m. On average, this leaves $(115 - 3 \cdot 33 =)$ 16 m unoccupied.

The occurrence of general congestion can also be concluded from the sharp rise in storage area requirements in 1993. Regarding the storage area occupation rates, it should be taken into account that this output-parameter is an indication for the storage requirement. In other words:

$$\text{Storage area occupancy rate} = \frac{\text{Required storage area}}{\text{Available storage area}}$$

Values bigger than 1.00 can occur; this implies that the available storage area is insufficient. The storage requirement data give information for general cargo, bagged cargo and containers together. For reasons of presentation, a separation between the cargo-types has not been made, although this implies that possible differences in storage requirements between cargotypes are not shown. It is reminded here that in the port simulation model an exceedance of the storage capacity does not delay the handling of vessels.

The mean waiting time for local vessels at the 1992-throughput-level is 310 hours. The waiting times of both vessel-categories for 1993 have such high values, that they are not displayed in Figures 8.3 and 8.4. Congestion is extreme in this situation, to such an extent that a *steady state* in the simulation-run is not achieved and that waiting times keep on growing during the run.

The experiments for increasing cargo throughputs have also been performed for improved cargo handling rates. Two scenarios (*guaranteed improvement* and *minimum improvement*,

as indicated in Paragraph 7.3.2) have been examined; the first scenario for 1991-1996, the other for 1993-1996. The cargo handling rate for local vessels is the same for both scenarios, the rate for cargo of interinsular/ocean going vessels differs. Again it is the category of local vessels that causes the first congestion to take place. The mean waiting time of this shipclass rises sharply in 1996 to 890 hours for both scenarios, while also the storage area occupancy rate rises sharply and the berth occupancy rate of quays 1&2 stabilises. For interinsular vessels the mean waiting time is still at an acceptable level for both scenarios in 1996.

The mean waiting time for local vessels in 1996 has an unrealistic value implying that congestion is extreme at the 1996-throughput-level. Therefore two alternative allocation rules have been tested. The first is to also use quay 3 for local vessels. The second is to construct an extra quay (*quay 6*). Both alternatives are feasible for implementation in 1996. Table 8.3 shows the results of these changes in allocation rules, for both cargo handling improvement scenarios. Allocation of local vessels to quay 3 is a suitable solution for the minimum improvement scenario; it sharply decreases the waiting time of local vessels and keeps the mean waiting of interinsular vessels at an level which is still 50% of the 1991-value. For the guaranteed improvement its effect is positive for local vessels but very damaging for interinsular vessels. In practice, allocation of local vessels to quay 3 already took place in the 1991-situation, but only if space at this quay was free and if no interinsular were waiting at the anchorage. However, it can be concluded that without a minimum improvement of the cargo handling rate, this alternative is not a sustainable solution.

Construction of a sixth quay (length 100 m) implies that local vessels will be handled at quays 1, 2 and 3 and that interinsular, ocean going and passenger vessels will be served at quays 4, 5 and 6. As Table 8.3 indicates, the waiting times for local vessels, in case of a guaranteed cargo handling improvement, and for both vessel categories, in case of a minimum improvement, are very low; this also applies to the berth occupancy rates (0.31 for quays 4, 5 and 6 for the minimum improvement scenario and 0.551 for quays 1,2 and 3 for both scenarios). However, this will change in the medium term, as is explained in the next paragraphs. Nevertheless, construction of a sixth quay is a suitable interim solution for coping with the cargo throughput growth in the period 1991-2002.

8.5 Medium term development

The occurrence of general congestion at the MPP in short term has now been established and the effect of new allocation rules (local vessels at quay 3, construction of a new quay) has been briefly introduced. However, the main objective of applying the simulation model for Pontianak is to look at the medium term. First the possible extensions and adaptations to the port facilities will be discussed; then the use of the model to test the effect of the extensions

Table 8.3

MPP 1996 ALTERNATIVE ALLOCATION RULES	Guaranteed prod. rate			Minimum prod. rate		
	No change in allocation	Local vessels at quay 3	6 quays	No change in allocation	Local vessels at quay 3	6 quays
Av. waiting time local vessels (h)	892.47	38.33	3.35	890.27	8.84	3.35
Av. waiting time of int.insular vessels (h)	26.5	132.67	30.88	3.89	19.2	4.42
B.O.R. quays 1&2 (1&2&3)	0.843	0.798	0.551	0.843	0.703	0.551
B.O.R. quays 3&4&5 (4&5&6)	0.734	0.804	0.751	0.538	0.667	0.531
Mean area occupancy rate	0.718	0.546	0.407	0.613	0.393	0.383
95% bound. of area occ. rate	1.113	0.931	0.708	0.944	0.695	0.673

and adaptations will be explained.

8.5.1 Medium term port planning

As part of the Haskoning port development study (see Paragraph 7.3), the berth length requirements for 2002 were calculated, using the queuing theory. The calculations were based on a (arbitrarily chosen) 20% reduction of the 1991 mean waiting time figures (as also calculated with the queuing theory: they are 20 hours for local vessels and 11.4 hours for interinsular and ocean going vessels). Furthermore the medium throughput scenario (1,281,000 tons) and the minimum production rate improvement scenario were applied, plus two variations: one for the throughput (high instead of medium throughput scenario), one for the production rate (guaranteed instead of minimum improvement). The results are shown in Table 8.4.

The quay configuration for 2002, proposed as a result of the port development study, is based on the medium throughput scenario and the minimum cargo handling rate improvement. The proposed quay configuration is as follows. Quay 1 is suggested to be

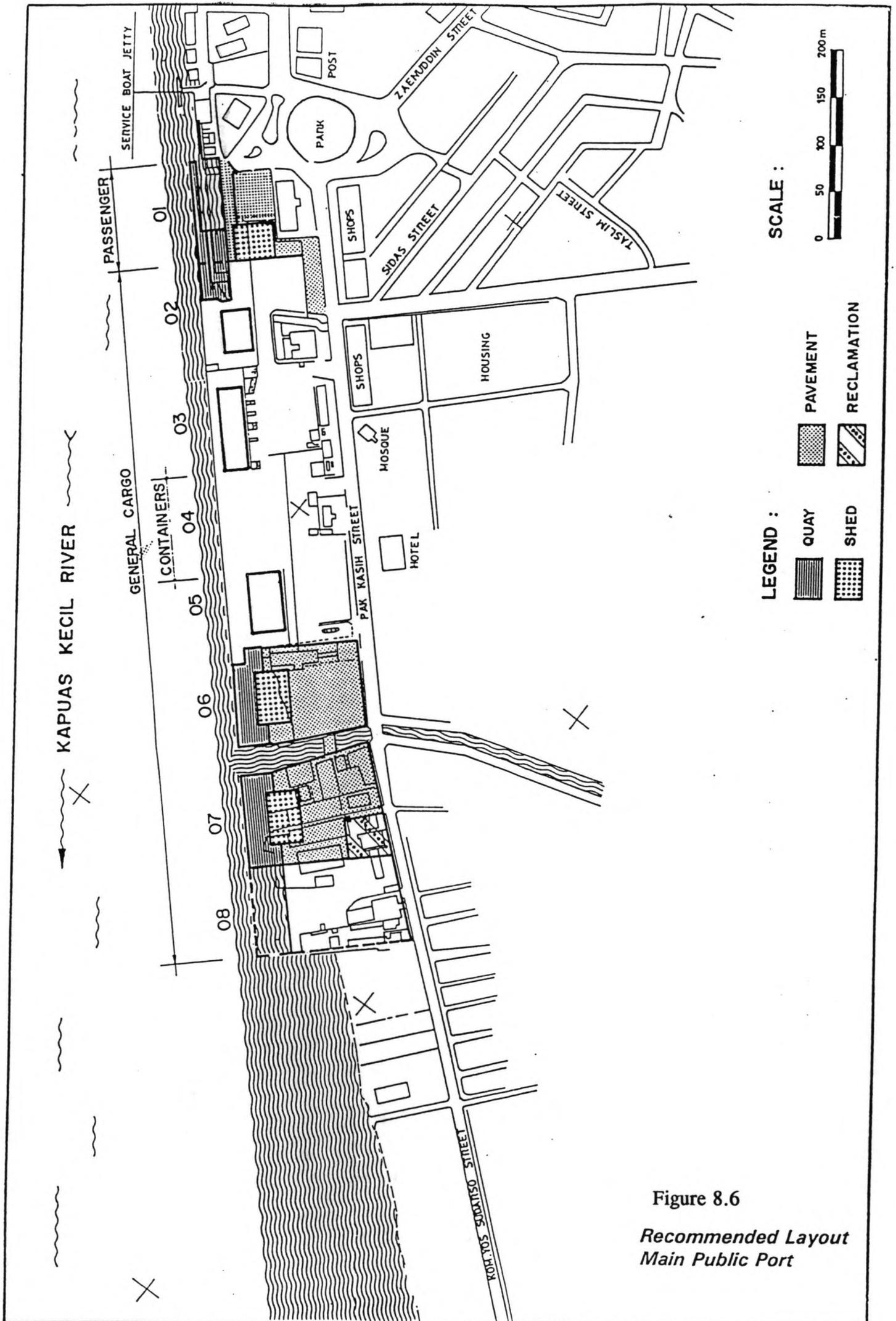


Figure 8.6
 Recommended Layout
 Main Public Port

Table 8.4

QUAY LENGTH REQUIREMENTS 2002 (m)				
Throughput scenario (tons)	Output rate scenario	Local vessels	Interinsular and ocean going vessels	Total
Medium (1,281,000)	Minimum	371	241	612
Medium (1,281,000)	Guaranteed	375	359	734
High (1,449,000)	Minimum	429	239	668

transformed into a passenger terminal and not to be used for cargo handling. Quay 2 can be extended by 25 m. Besides the MPP quay length can be increased by constructing two or possibly three extra quays (quay 6, quay 7 and quay 8). This will raise the total quay length for cargo handling to 612 m (or possibly 702 m):

- * Quay 1: 0 m
- * Quay 2: 75 + 25 = 100 m
- * Quay 3: 117 m
- * Quay 4: 100 m
- * Quay 5: 100 m
- * New quay 6: 95 m
- * New quay 7: 100 m
- * Possible new quay 8: 90 m

Vessels with containers will be allocated to quay 4. Local vessels will be allocated to quays 2, 3, 4 and, if necessary, 5. Interinsular and ocean going vessels will be allocated to quays 5, 6 and 7. Also according to handmade calculations, 7820 m² of new storage facilities (open and covered) need to be provided. At quays 6 and 7 sheds must be built. The joint requirements for extra quay length and extra storage space lead to a port lay out for the MPP as shown in Figure 8.6.

8.5.2 Simulation of medium term development

Simulation runs have been performed for quay configurations of 6, 7 and 8 quays and for

guaranteed, minimum and medium improvements of cargo handling rates. The runs have been made for the *medium* throughput scenario and for four variations of this scenario, each depending on the standard deviation (13%) of the cargo throughput forecast for 2002. Not only the *high* scenario (medium +13%) and the *low* scenario (medium -13%) but also two scenarios with less discrepancy to the medium scenario (medium +6.5% and medium -6.5%) have been tested. The annual cargo throughputs for the five scenarios are given in Table 8.5. The storage characteristics of cargo and the shipclasses which attend the port are the same as mentioned in Paragraph 8.2.

The starting point for the medium term simulation runs is the configuration proposed by the port development study: 7 quays, medium throughput, minimum cargo handling improvement. The 7 quays are modelled as 4 *multiple* berths (quay 2, quays 3&4, quays 5&6, quay 7), with a combined length of 632 m, and 1 *single* berth (quay 1). Figure 8.7 illustrates the configuration of 7 quays schematically. The allocation of ships to quays takes place according to the rules which are described in the previous paragraph.

Table 8.5

MPP 2002 THROUGHPUT SCENARIOS	Discrepancy to <i>medium</i> throughput level	Annual cargo throughput (tons)
<i>Low</i>	- 13 %	1.113.000
<i>Semi-low</i>	- 6.5 %	1.197.000
<i>Medium</i>	0 %	1.281.000
<i>Semi-high</i>	+ 6.5 %	1.365.000
<i>High</i>	+ 13%	1.449.000

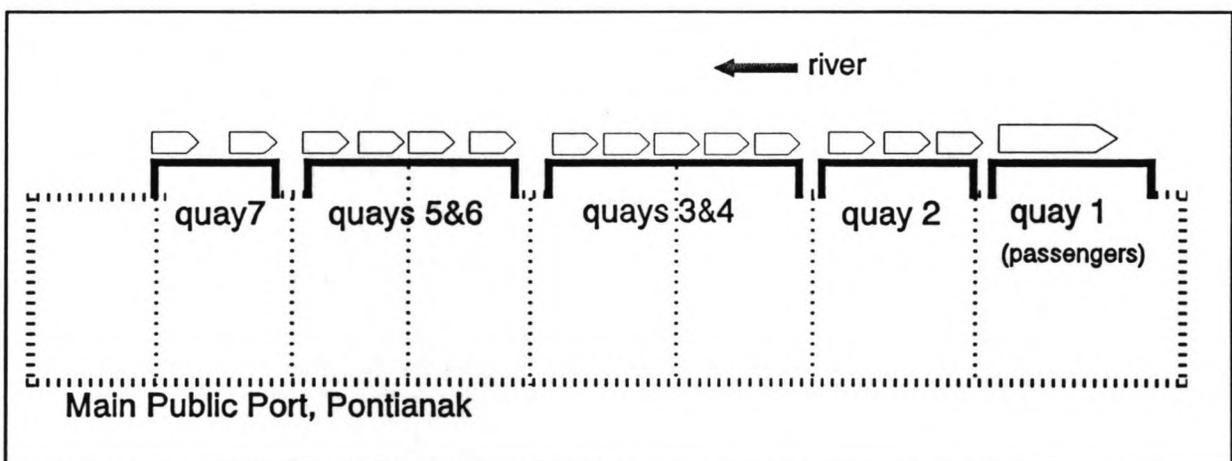


Figure 8.7: configuration of 7 quays (not to scale)

Table 8.6

MPP 2002 NET OUTPUT PER GANG (TON/HOUR) FOR CARGO HANDLING RATE IMPROVEMENT SCENARIOS	Guaranteed improvement (one 8-hour shift per day)	Minimum improvement (one 8-hour shift per day)	Medium improvement (two 8-hour shifts per day)
Local vessels (1 gang per vessel)	15.0	15.0	15.0
Int.ins./oc. going vessels with general cargo (3 gangs per vessel)	20.0	23.1	18.5
Int.ins. vessels with bagged cargo (3 gangs per vessel)	20.0	40.4	41.0

The characteristics of the cargo handling rates are shown in Table 8.6. In the medium term quay configurations bagged cargo and general cargo of interinsular and ocean going vessels are handled at the same berths (for example quays 5, 6 and 7) but in the minimum and medium scenarios of cargo handling improvement, they are handled at different rates. However, the simulation model originally did not allow different handling rates at one berth. Therefore the process of the terminal-master in the model is extended, by making him raise the unloading/loading rate of bagged cargo (for example: for the minimum improvement scenario the rate is increased from 23.1 to 40.4 tons per ship hour at berth). The same principle applies to the general cargo of local vessels which is handled at quay 5 (the rate is decreased from 23.1 to 15.0 tons per ship hour at berth). In Annex 5 the input data for the cargo handling rates are given in detail.

In the configuration of 8 quays (total quaylength 702 m), the fourth multiple berth (quay 7) is extended to quays 7&8 (see Figure 8.8). In the configuration of 6 quays (total quaylength 512 m) the number of multiple berths is diminished to three (see Figure 8.9). The precise quay configurations and quay allocation rules (indicating which shipclass moors at which quay) are given in Annex 5. The configurations are based on the allocation rules and the physical partitions between quays.

By increasing the number of quays to seven, 7820 m² extra storage area becomes available. However, 6210 m² is lost due to the transformation of quay 1 and its storage area to a passenger terminal, leaving a total of 26210 m². In the configuration of 8 quays, the total storage area is 29710 m²; in the configuration of 6 quays, the total storage area is 21750 m².

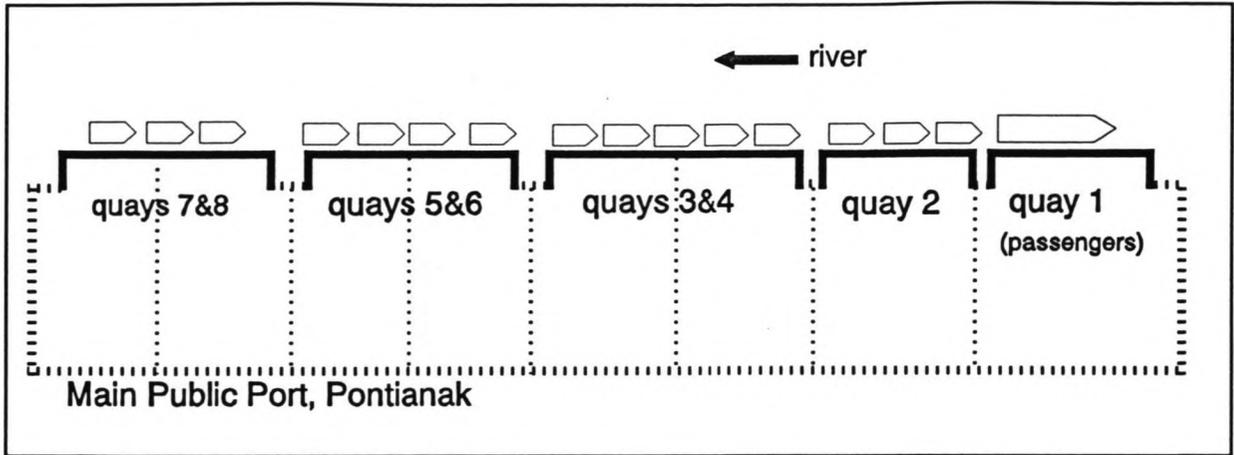


Figure 8.8: configuration of 8 quays (not to scale)

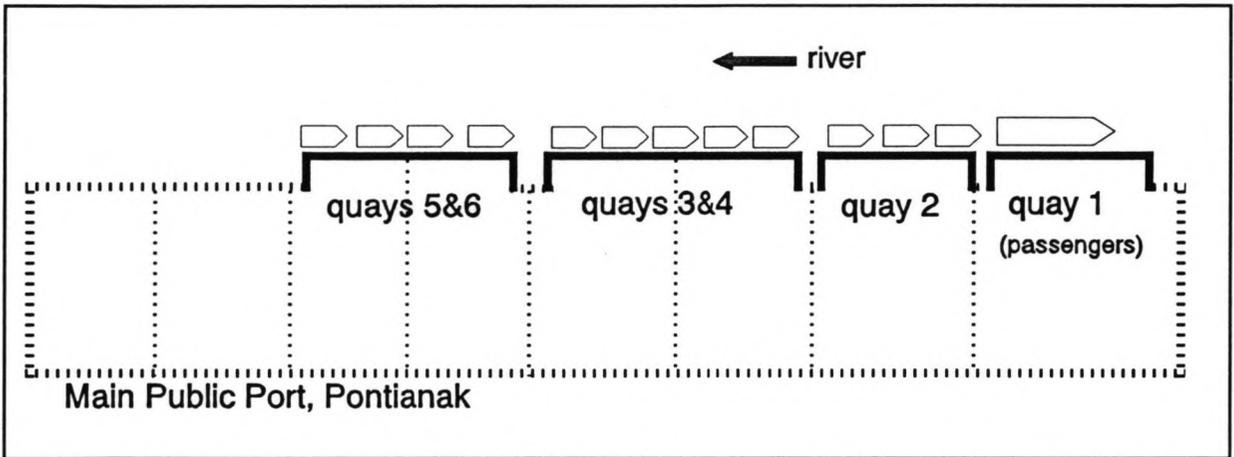


Figure 8.9: configuration of 6 quays (not to scale)

8.6 Results of simulation-runs

This paragraph contains five figures which depict the performance of vessels, berths and storage area in 2002 as a function of the throughput-level for six combinations of the number of berths and the cargo handling improvement scenario. Figures 8.10 and 8.11 show the values of the waiting times for interinsular/ocean going vessels and local vessels respectively. Figures 8.12 and 8.13 illustrate the storage utilization. The storage area occupancy rates in these figures are indications for the storage requirements, so values > 1.00 imply a shortage of storage area. Figure 8.14 shows the quay utilization as a function of the throughput-level for the six combinations.

The two combinations with guaranteed handling rates are only depicted for low throughput-levels because they show too much congestion for high throughput-levels. The two combinations with medium handling rates are only depicted for high throughput-levels. Three other possible combinations of quay length increase and cargo handling rate improvement have not been considered: the combinations of 6 berths and a guaranteed or minimum cargo handling rate improvement, both of which cause extremely high waiting times, and the combination of 8 berths with a medium cargo handling rate improvement, which has a unrealistically high vessel and cargo handling capacity.

For all simulation runs with a configuration of 7 quays, the length of quay 7 has been set at 120 m instead of 100 m. Quay 7 is not connected with other quays in this configuration, allowing sterns or bows of vessels to partly stick out beyond the ends of the quay. This increases the possibility for two vessels to moor at quay 7 and thereby increases its occupancy rate and decreases the waiting times for interinsular vessels. For example: the berth occupancy rate is 0.539 for a length of 100 m, 0.637 for 110 m and 0.819 for 120 m (with a medium throughput level and a minimum cargo handling improvement).

The performance of vessels, in case of a medium throughput level, are described in greater detail in Tables 8.7/8.8/8.9 for three combinations of interest, including the combination, proposed by the port development study (7 quays, minimum cargo handling improvement).

Table 8.7: vessel performances (medium cargo throughput level, minimum cargo handling rate improvement)

MPP 2002 7 QUAYS	Av. time at anchorage (h)	Av. time at berth (h)	Total port time (h)	Ratio (time at anch./ time at quay)
Local vessels	20.44	41.31	61.75	0.495
Int. ins. vessels with gen. cargo	35.38	26.06	61.44	1.358
Int. ins vessels with bag. cargo	36.40	14.96	51.36	2.433
Oc. going vessels with gen. cargo	41.42	28.54	69.96	1.451
Oc. going vessels with containers	12.81	15.35	26.99	0.834

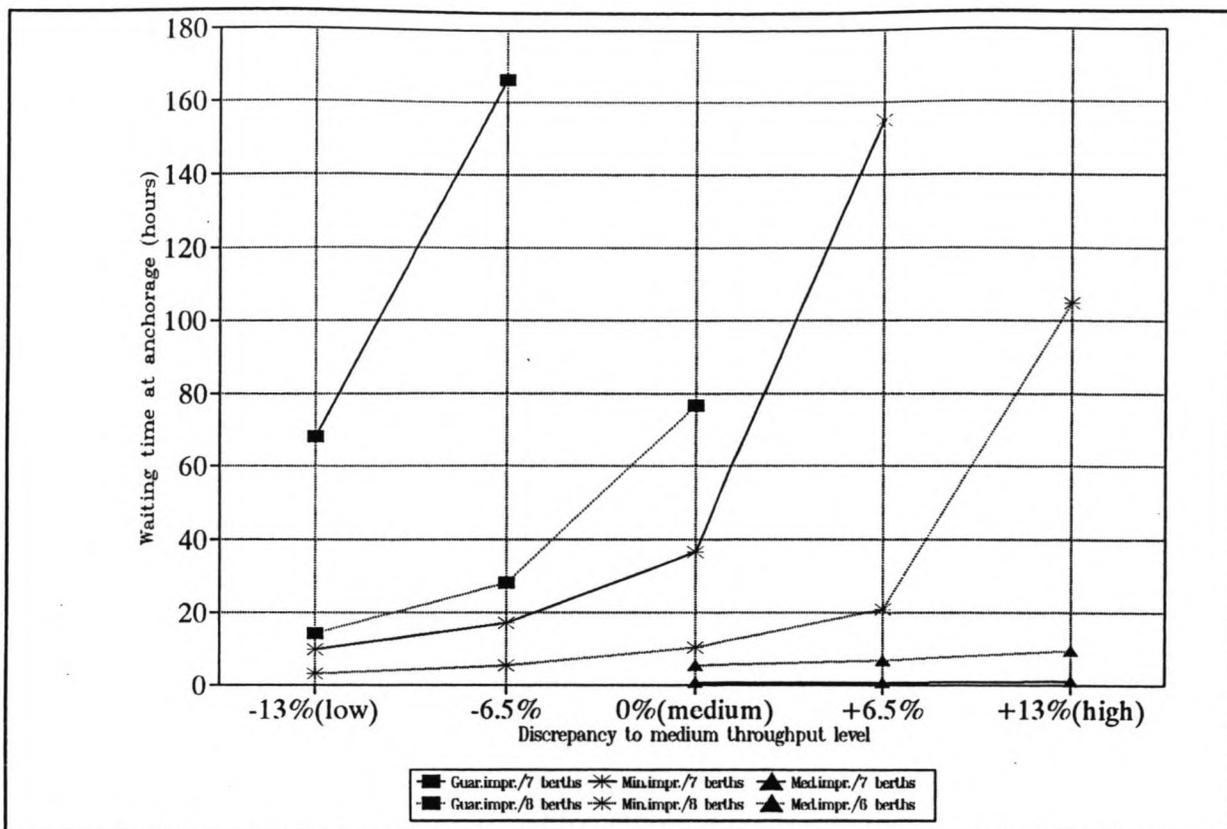


Figure 8.10: waiting times of interinsular/ocean going vessels at MPP in 2002, for six combinations of quay length increase and cargo handling rate improvement, for five cargo throughput levels

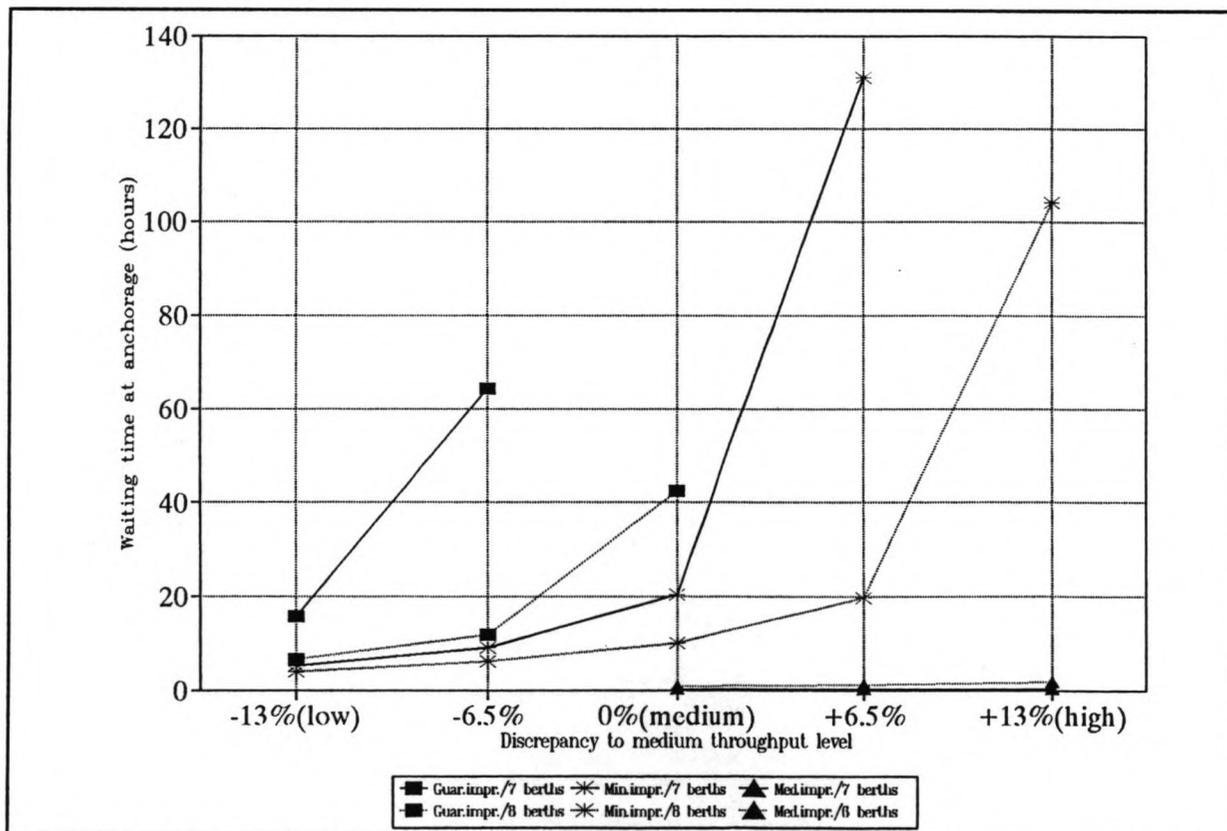


Figure 8.11: waiting times of local vessels at MPP in 2002, for six combinations of quay length increase and cargo handling rate improvement, for five cargo throughput levels

Table 8.8: vessel performances (medium cargo throughput level, minimum cargo handling rate improvement)

MPP 2002 8 QUAYS	Av. time at anchorage (h)	Av. time at berth (h)	Total port time (h)	Ratio (time at anch./ time at quay)
Local vessels	9.99	41.07	52.06	0.243
Int. ins. vessels with gen. cargo	9.95	25.71	35.66	0.387
Int. ins vessels with bag. cargo	10.78	15.07	25.85	0.715
Oc. going vessels with gen. cargo	10.59	28.35	38.94	0.374
Oc. going vessels with containers	12.69	15.60	38.29	0.680

Table 8.9: vessel performances (medium cargo throughput level, medium cargo handling rate improvement)

MPP 2002 6 QUAYS	Av. time at anchorage (h)	Av. time at berth (h)	Total port time (h)	Ratio (time at anch./ time at quay)
Local vessels	0.76	20.49	21.25	0.037
Int. ins. vessels with gen. cargo	5.32	16.12	21.44	0.330
Int. ins vessels with bag. cargo	5.08	7.48	12.56	0.679
Oc. going vessels with gen. cargo	5.90	17.73	23.63	0.333
Oc. going vessels with containers	1.51	8.10	9.61	0.186

The calibration of the model for 1991 has produced a value of 0.2 hours for the length of the mooring restriction and 0.5 hours for the mooring time. Several extra simulation runs have been performed to analyze the sensitivity to vessel performances of these two parameters. Tables 8.10 and 8.11 show the effect of both parameters to the ratio of time spent at the anchorage divided by the time spent at the quay. The effect is considerable. It can be

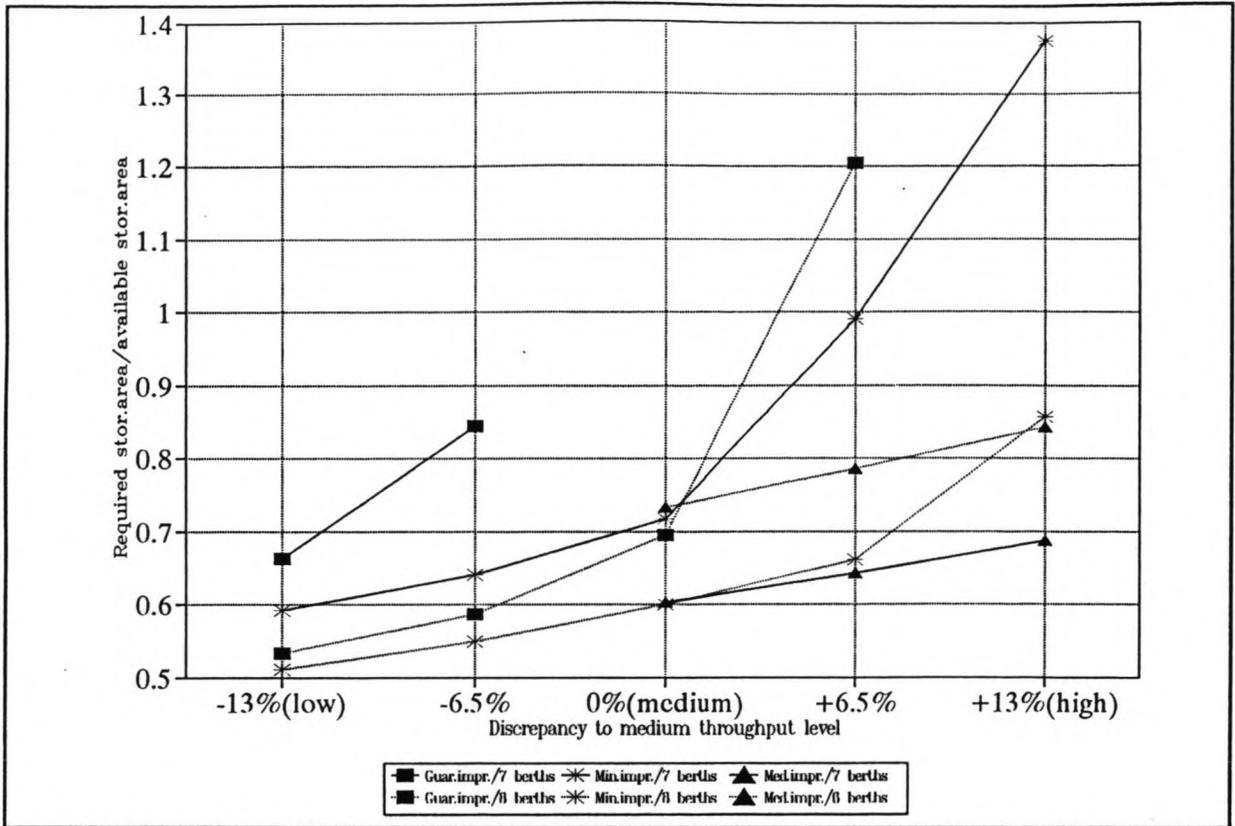


Figure 8.12: mean storage area occupancy rates at MPP in 2002, for six combinations of quay length increase and cargo handling rate improvement, for five cargo throughput levels

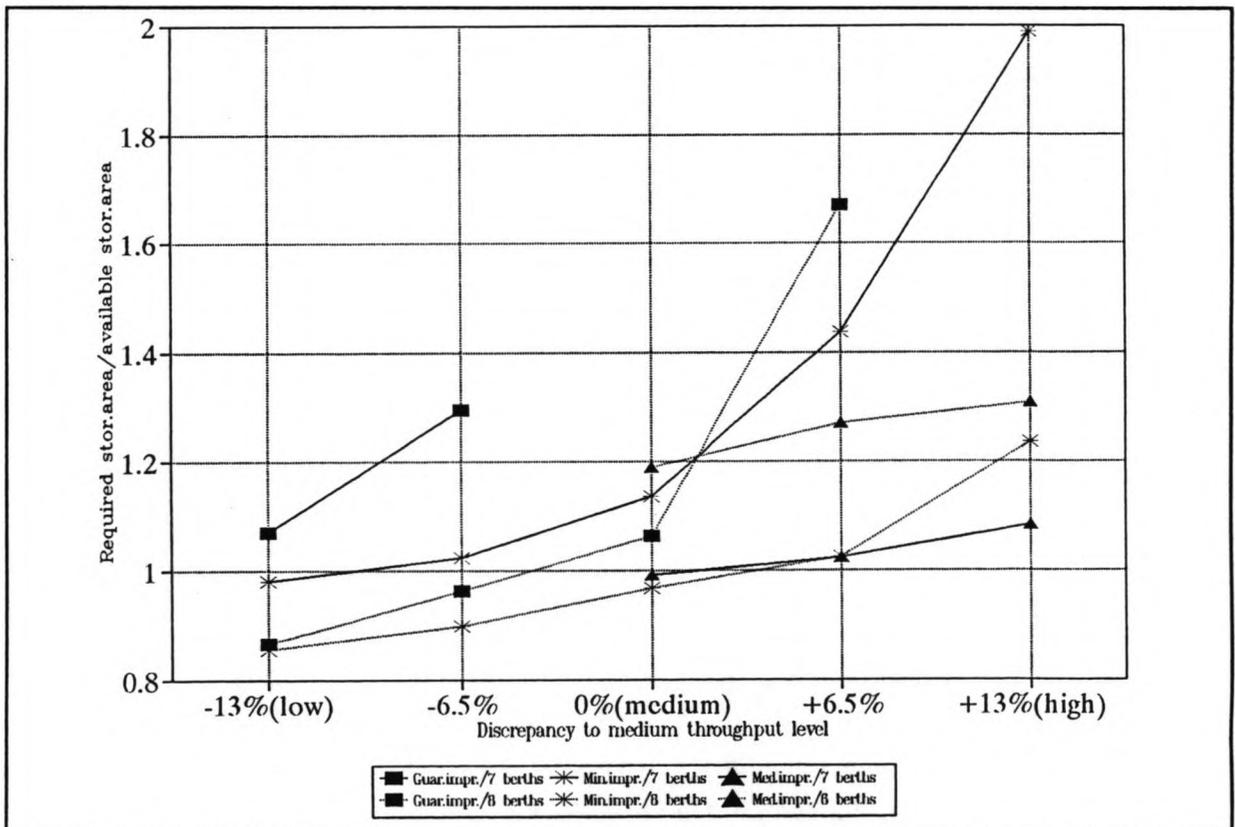


Figure 8.13: 95% bound. of storage area occupancy rate distributions at MPP in 2002, for six combinations of quay length increase and cargo handling rate improvement, for five cargo throughput levels

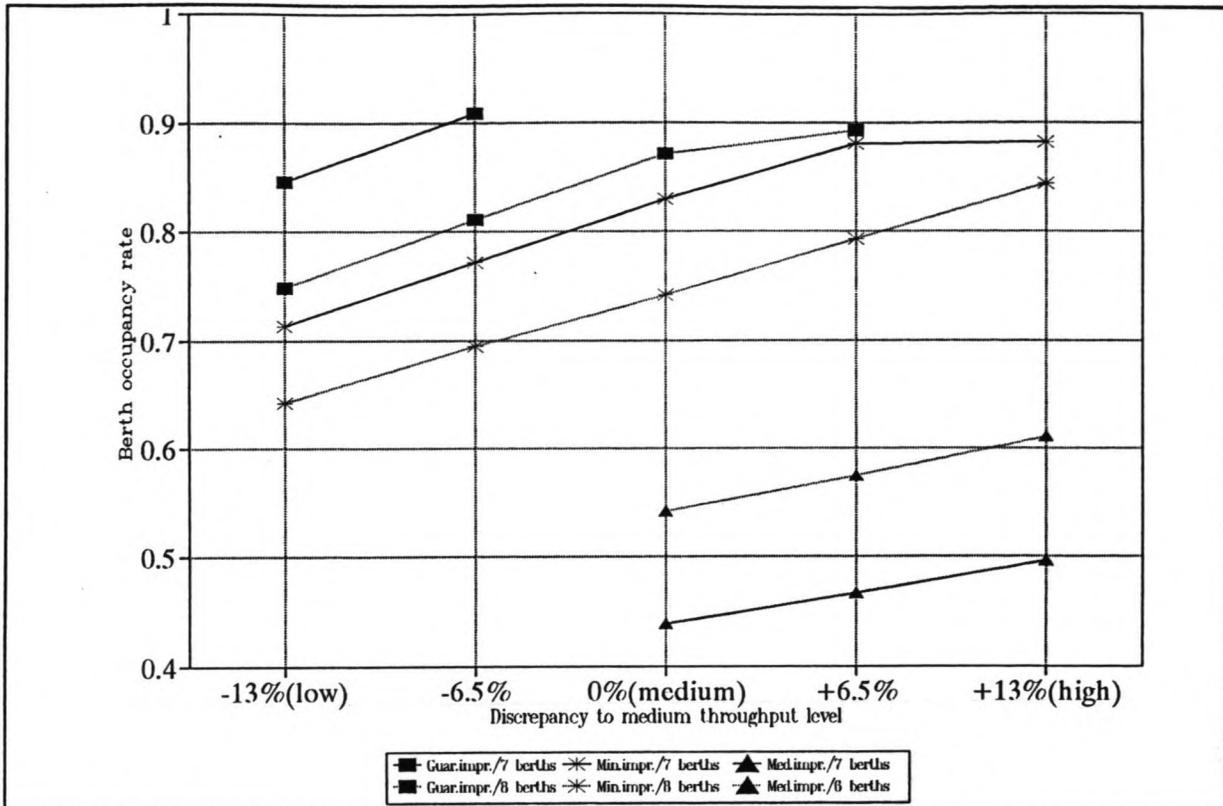


Figure 8.14: berth occupancy rates at MPP in 2002, for six combinations of quay length increase and cargo handling rate improvement, for five throughput levels

explained due to the high number of vessels movements (approximately 4000 annually, including passenger vessels). However, the used values for mooring time and mooring restriction can be assumed sufficiently accurate, regarding the fact that the anchorage is near the port (midstream on the river in front of the MPP) and that waiting vessels will already manoeuvre towards the quay before having been allocated to a berth.

One of the advantages of the port simulation model is the possibility to test the effect of restrictions on the port activities. Although strikes are considered not to occur and bad weather (hard rains) has already been included in the gang productivity rates, several simulation runs have been performed for these two restrictions. The effect to the ratio of time spent by vessels at the anchorage divided by the time spent at quay of one annual two-day-strike and three annual one-day-bad weather periods are outlined in Table 8.12.

For the quay configuration proposed by the port development study, the distributions of waiting times for local vessels, interinsular/ocean going vessels with general and bagged cargo and ocean going vessels with containers are described in Table 8.13. The distributions of the daily number of arriving and departing trucks are given in Table 8.14. It only concerns loaded trucks; every loaded truck therefore brings about one extra truck movement (if empty

Table 8.10: effect of mooring time variation (medium cargo throughput level, minimum cargo handling rate improvement)

MPP 2002 7 QUAYS		
Ratio (av. time at anch./ av. time at quay)	Local vessels	Int.ins. vessels
Mooring time = 0.5 h	0.495	1.711
Mooring time = 0.75 h	0.721	2.208
Mooring time = 1.0 h	1.205	3.430

Table 8.11: effect of mooring restriction variation (medium cargo throughput level, minimum cargo handling rate improvement)

MPP 2002 7 QUAYS		
Ratio (av. time at anch./ av. time at quay)	Local vessels	Int.ins. vessels
Mooring restriction = 0 h	0.368	1.248
Mooring restriction = 0.2 h	0.495	1.711
Mooring restriction = 0.4 h	1.523	4.186

Table 8.12: effect of strikes/bad weather (medium cargo throughput level, minimum cargo handling rate improvement)

MPP 2002 7 QUAYS		
Ratio (av. time at anchorage/ av. time at quay)	Local vessels	Int.ins. vessels
No strikes/bad weather	0.495	1.711
Strike interval time = 365 days No bad weather	0.571	1.869
No strikes Bad weather interval time = 120 days	0.775	2.339
Strike interval time = 365 days Bad weather interval time = 120 days	0.902	2.666

Table 8.13: waiting times of vessels (medium cargo throughput level, minimum cargo handling rate improvement)

MPP 2002 7 QUAYS	Mean	Standard deviation	95% bound.	Maximum
Waiting time local vessels (h)	20.48	22.63	64.92	139.92
Waiting time int.ins. vessels (gen.cargo) (h)	35.38	28.09	86.13	139.93
Waiting time int.ins. vessels (bag.cargo) (h)	36.40	30.86	96.29	140.92
Waiting time oc. going vessels (gen.cargo) (h)	41.42	29.67	93.55	129.43
Waiting time oc. going vessels (containers) (h)	12.86	11.21	34.70	63.78

Table 8.14: inland transport performance (medium cargo throughput level, minimum cargo handling rate improvement)

MPP 2002 7 QUAYS	Mean	Standard deviation	95% bound.	Maximum value
Daily number of truck arrivals	133	87	305	629
Daily number of truck departures	667	334	1232	2062

return trucks are assumed). The mean and 95% boundary values of both distributions are considerably higher than the mean values for 1991: approximately 50 loaded truck arrivals and 350 loaded truck departures.

The length of all simulation-runs, which have been performed for the 2002-situation, is 850 days. This is approximately equal to a two year period plus 100 days, which are taken into account to rule out the unfavourable effects of starting with an empty port system (no vessels at the anchorage, no cargo in the storage at $t=0$). Additionally, six simulation-runs have been performed for a 300-day period, to research the fluctuation of the mean values for waiting times of vessels, the storage area occupancy rate and the berth occupancy rate. For each of the six runs, different seeds were used to generate the inter-arrivaltime distributions of the shipclasses. The standard deviation of the mean value for the parameters in the six runs is

Table 8.15: effect of change of seeds for six simulations runs to the waiting times of vessels, berth and storage area utilization (medium throughput level, minimum cargo handling rate improvement scenario)

MPP 2002 7 QUAYS	Average value for the six 300-day runs	Standard deviation for the six 300-day runs	Mean value for the 850-day run
Mean waiting time (hours)			
Local vessels	24.68	12.93	20.44
Int. ins. vessels with general cargo	37.86	14.69	35.38
Int. ins. vessels with bagged cargo	38.90	15.66	36.40
Oc. going vessels with general cargo	40.14	16.14	41.42
Oc. going vessels with containers	11.68	1.56	12.81
Berth occupancy rate (quays 2-7)	0.835	0.021	0.830
Storage area occupancy rate	0.710	0.054	0.717

shown in Table 8.15. The waiting times of vessels have relatively large standard deviations. Three of the 300-day simulation-runs produced waiting times which differ less than 10% from the 850-day run. Two runs produced approximately 30% lower waiting times and one run produced 100% higher waiting times. For this last run the total cargo throughput was 1,355,000 tons, which is almost the same as the *semi-high* throughput scenario. Table A5.6 in Annex 5 gives a complete view of the results of the six 300-day runs.

The last experiment which is dealt with in this paragraph is a variation in the dwell time distribution of cargo. No data are available on the dispersion of the dwell time distributions, so all cargo is assumed to have a dwell time equal to mean value for the dwell time as indicated in Table 8.1. A run has been performed to test the influence of a standard deviation of the dwell time of 33.3% for incoming as well as outgoing cargo of all cargotypes (for the quay configuration proposed by the port development study). Naturally the mean storage area occupancy rate remains the same (0.717); the standard deviation of the storage area occupancy rate distribution decreases from 0.232 to 0.219 and the 95% boundary value of this distribution decreases from 1.137 to 1.117.

8.7 Discussion of results

The quay configurations, each of which depend on the number of quays and the chosen cargo handling rate improvement scenario and which have been tested in the previous paragraph will now be discussed, based on vessel performances, berth and quay utilization. The first part of the discussion concerns the medium throughput forecast for 2002; the effect of the higher throughput scenarios will also be taken into account.

The performance of vessels is judged on the waiting time of vessels at the anchorage and the ratio of time spent at the anchorage divided by time spent at the quay. For the waiting times, the same criterion is applied as has been used for the queuing theory in the Haskoning port development study: a 20% reduction of the waiting times in 2002 in comparison with the simulated waiting times of 1991 (69 hours for local vessels, 39 hours for interinsular/ocean going vessels, 5 hours for container carrying vessels). The waiting time/time at quay-ratio in 2002 is requested to have a maximum value of ca. 1.

In general it can be concluded that ocean going vessels carrying general cargo have slightly higher waiting times than interinsular vessels, due to their greater lengths. The difference varies between 15% for quay configurations with average waiting times of approximately 20-80 hours (7 berths/guaranteed improvement, 7 berths/minimum improvement) and 5% for quay configurations with average waiting times of less than 20 hours (8 berths/minimum improvement, 6 berths/medium improvement). Ocean going vessels with containers have short waiting times for all quay configurations because they receive priority when being allocated to a berth. Vessels with bagged cargo have higher waiting time/time at quay-ratios than vessels with general cargo (in case of minimum and medium cargo handling rate improvements) because they have shorter times at berth.

The guaranteed cargo handling rate improvement scenario does not fulfil both vessel performance requirements, with seven nor with eight quays. Seven quays combined with a minimum productivity rate improvement (average berth occupancy rate 0.830) give 35-40 hour waiting times for interinsular/ocean going vessels (which is the same as in 1991), 20 hours (a major decrease) for local vessels and 13 hours for container carriers (a major increase) and waiting time/time at quay-ratios of 0.50 for local vessels, 0.83 for container carriers, 2.4 for bagged cargo carrying vessels and 1.4 for general cargo carrying vessels. This combination therefore only partly fulfils the vessel performance criterions. It is remarked here that the waiting times for the combination of seven quays and a minimum cargo handling rate improvement, calculated with the queuing theory, are 16 hours for local vessels and 9 hours for interinsular/ocean going vessels.

Eight quays combined with a minimum productivity rate improvement (average berth

occupance rate 0.742) does fulfil both criterions: this combination has waiting times of approximately 10 hour for all vessel classes and ratios of 0.24 for local vessels, 0.38 for containers and bagged cargo carrying vessels and 0.70 for general cargo carrying vessels. The combination of seven and six quays with a medium cargo handling improvement have even lower values for the ratios and waiting times; their average berth occupancy rates are also low (0.439 and 0.575 respectively). Taking into account the low berth utilization, this rules out the combination of seven quays and medium cargo handling improvement as a serious alternative.

The 95% boundary value of the storage area occupancy rate distribution is a good parameter for the judgement of storage utilization. It indicates the peak burdens on the storage area. In the rare occasions that the storage area requirements exceed the 95% boundary, extra storage capacity can be created by temporarily increasing the stackheights. For the combinations of seven quays/minimum improvement and six quays/medium improvement, the 95%-values are 1.14 and 1.19 respectively, implying that in both cases the available storage area is insufficient. For the combination eight quays/minimum improvement, a rate of 0.97 is the 95% boundary.

If the actual cargo throughput at the MPP is 6.5% or 13% higher in 2002 than predicted, the quay configuration proposed by the port development study (seven quays/minimum improvement) will show severe congestion, for vessels, storage area as well as berths. The same applies to a 13% throughput increase in case of eight quays and a minimum cargo handling rate improvement. If the throughput is only 6.5% higher for this configuration, acceptable values are achieved for all parameters: waiting time/time at quay-ratios of 0.5 for local vessels, 0.8 for interinsular/ocean going vessels with general cargo and containers, 1.4 for vessels with bagged cargo, a 95%-boundary of the storage area occupancy rate of 1.026 and an average berth occupancy rate of 0.79. The combination of seven and six quays with a medium cargo handling improvement shown no signs of congestion for higher throughput levels in 2002, except for the already mentioned lack of storage area during peak situations in the configuration with six quays.

9 Conclusions and recommendations

9.1 Conclusions

Port simulation model

Although the port simulation model was originally created to be used in a port development study for the Taiwanese port of Kaohsiung, it has proved flexible enough to be adapted to the different circumstances at the port of Pontianak and to be applied for the Main Public Port (MPP) in this Indonesian city. A comparison of simulation results with a port development study by Haskoning was carried out.

Pontianak, short term development

According to the port simulation model, congestion for berths and vessels will take place at the MPP by 1993. If the cargo handling rate is improved, according to a guaranteed or minimum improvement scenario, congestion will take place by 1996. It is therefore advised that extension of the quaylength (construction of a sixth quay) is performed before 1996.

Pontianak, medium term development

The recommendation of the Haskoning port development study, for accommodating a predicted cargo throughput of 1,281,000 tons at the MPP in 2002, consists of an extension of the quaylength with two quays (quay 6 and quay 7) and of an improvement of the cargo handling rate according to a minimum improvement scenario. The proposal is based on calculations with the queuing theory. The following conclusions concerning the proposal have been drawn from the results of the simulations.

- * *General conclusion.* Experiments with the port simulation model indicate that the proposed configuration is a suitable solution. No congestion for vessels and berths occurs. It is advised that the length of quay 7 is increased from 100 m to 120 m, allowing a higher occupancy of this quay. The mixed allocation of local vessels with general cargo and vessels with containers to quay 4 in this proposal may be dangerous to the gangs which are working on the vessels at this quay.
- * *Berth occupancy and vessel performances.* For the configuration of 7 quays and a minimum cargo handling rate improvement, the berth occupancy rate (0.83) and the waiting times of interinsular and ocean going vessels (35-40 hours) are at the same level as for 1991. Only the waiting times for local vessels will decrease (from 69 to 20 hours), implying that the objective of decreasing the waiting times with 20% for all vessels is not achieved.

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- * *Storage requirements.* According to the port simulation model, the configuration of 7 quays and a minimum cargo handling rate improvement has insufficient storage area: the storage requirements exceed the capacity 13.6% of the time. It is advised that the storage capacity is increased by 15%, for example by using the land area at the site of a possible eighth quay or by allowing higher stacking of cargo; this reduces the storage capacity exceedance to 5% of the time.
- * *Capacity of inland transport for discharge of bagged cargo.* The guaranteed cargo handling rate improvement scenario is insufficient for any number of quays and for any cargo throughput. It is therefore necessary that the increase of the truck capacity for the direct discharge of bagged cargo, which is the difference between the guaranteed and minimum improvement scenarios, is achieved.
- * *Exceedance of predicted throughput level for 2002.* If the throughput of cargo at the MPP increases faster than expected and a deviation of the forecast of 6.5 occurs, serious congestion for vessels and terminal facilities will take place for the combination of 7 quays and a minimum cargo handling rate improvement. It is therefore advised, in case new cargo flow forecasts indicate a higher increase of the cargo throughput in 2002, to construct an eighth quay.
- * *Alternatives for quay length increase and cargo handling improvement.* As concluded above, the lack of storage area and congestion in case of a 6.5% higher cargo throughput can be avoided by constructing an extra quay (quay 8). However, in case of a 13% increase of the cargo flow forecast, congestion for berths and vessels will also occur for this configuration. No congestion will occur for such a deviation of the forecast if the medium cargo handling rate scenario (incorporating two daily 8-hour shifts instead of one) is applied. For this scenario and this cargo throughput, the extension of the quay length of the MPP by only one extra quay (quay 6) is sufficient to handle all vessels (the average berth occupancy rate is 0.84).

9.2 Recommendations

Storage requirements of containers and containerized cargo

Containers are stripped and stuffed on the terminal premises. The containers and the cargo which is stripped and stuffed, have separate dwell time periods on the terminal. This double storage requirement is schematized quite roughly in the port simulation model. Further study of this aspect of storage occupation is required.

Detailed study on the inland transport capacity

If the quay configuration, proposed by the Haskoning port development study, is planned to be executed, the following recommendation is given: extra study of the inland transport capacity (e.g. the number of trucks). The inland transport capacity is currently an important cause for delays and it is not foreseen that a large number of extra trucks will become available in the future. However, a major increase of this capacity is required because the minimum cargo handling rate improvement must be achieved and large fluctuations of the inland transport requirements are predicted.

Analysis of the combination of 6 quays and a medium cargo handling rate improvement

Taking into account the vessel performances and the berth utilization, an interesting alternative for a configuration of seven or eight quays with a minimum cargo handling improvement is a combination of six quays with a medium cargo handling improvement. It is recommended that research is performed to analyze whether achieving the medium improvement (16 working hours per day) instead of the minimum improvement is economically more attractive than constructing two or possibly three extra quays instead of constructing one new quay.

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