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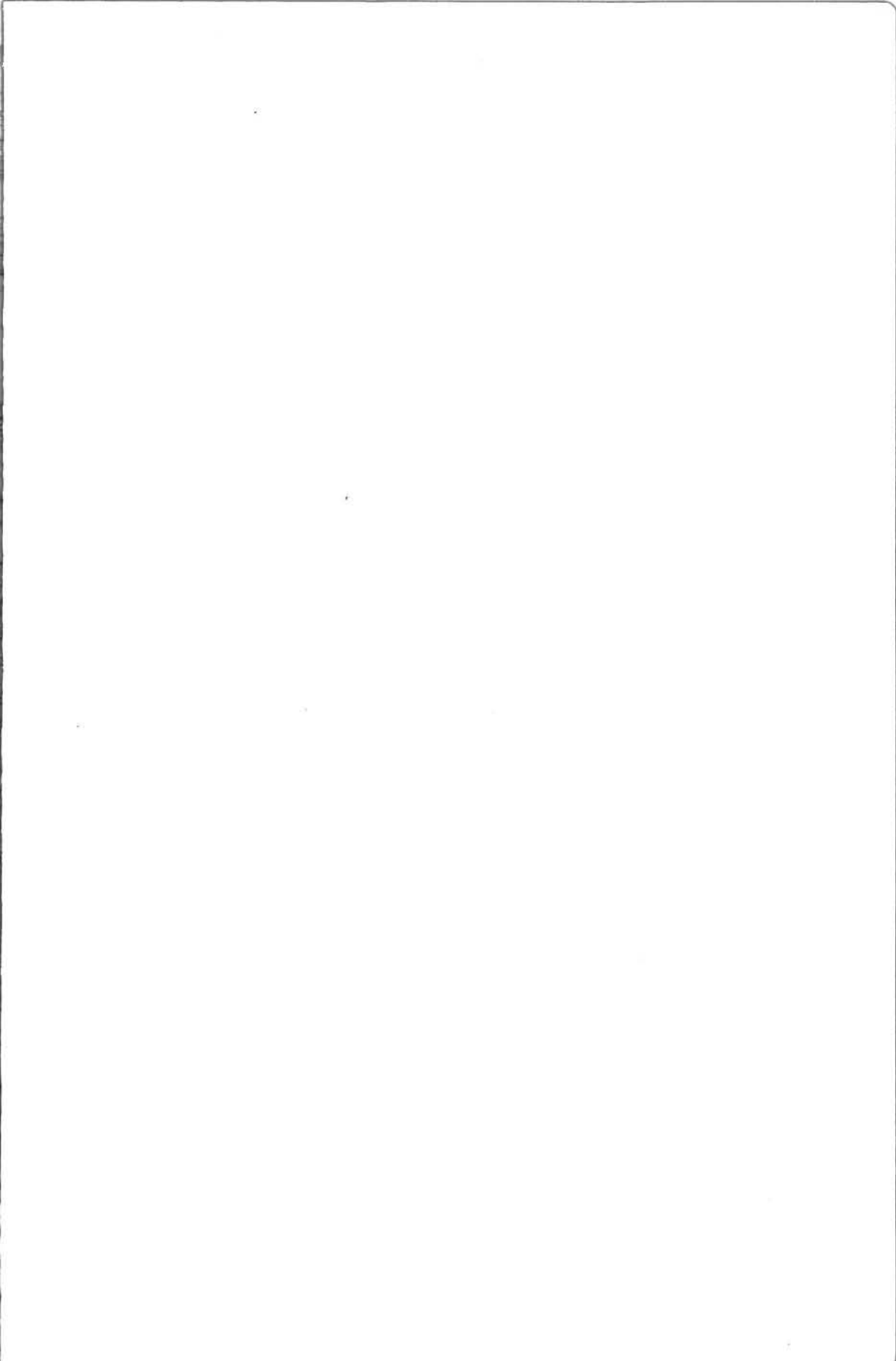
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INNOVATION IN
CHEMICALS
SHIPPING
PORT AND SLOPS MANAGEMENT

PROF. DR. IR. N. WIJNOLST

DELFT UNIVERSITY PRESS



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INNOVATION IN CHEMICALS SHIPPING PORT AND SLOPS MANAGEMENT

SOLVING NOT SHIFTING

Prof. dr. ir. N. Wijnolst
Editor

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INNOVATION IN CHEMICALS SHIPPING PORT AND SLOPS MANAGEMENT

SOLVING NOT SHIFTING

prof. dr. ir. N. Wijnolst
Editor

In collaboration with

ir. J.D. Kalverkamp
ir J.D. Doornbos
ir J.A. de Waart
ir. R. Heijliger
ir. F.A.J. Waals

This book is dedicated to the doyen of the Dutch naval architects, who has been over the last five years a great source of knowledge, creativity and inspiration to me and my students: **ir. Ernst Vossnack.**

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Table of Contents

INTRODUCTION	3
PART I - PORT TIME ANALYSIS OF CHEMICAL TANKERS IN THE PORT OF ROTTERDAM	7
CHAPTER 1: ECONOMICS AND ACTIVITIES OF A PORT CALL	8
CHAPTER 2: THE DIFFERENT ASPECTS OF A PORT CALL	13
CHAPTER 3: PORT TIME ANALYSIS	19
CHAPTER 4: VESSEL SPECIFICATIONS.	28
CHAPTER 5: PORT TIME PROGRAM.	41
CHAPTER 6: PROGRAM RESULTS	47
CHAPTER 7: RECOMMENDATIONS AND CONCLUSIONS.	60
PART II - PORT TIME ANALYSIS OF CHEMICAL TANKERS IN THE PORT OF HOUSTON	69
CHAPTER 1: INTRODUCTION	70
CHAPTER 2: PORT CALL OF A CHEMICAL TANKER	73
CHAPTER 3: DISTURBANCE ANALYSIS	79
CHAPTER 4: PORT COSTS	95
CHAPTER 5: MODELING THE ACTIVITIES IN PORT	100
CHAPTER 6: ARRANGEMENT OF THE INPUT DATA	116
CHAPTER 7: THE COMPUTER PROGRAM	129
CHAPTER 8: THE USERS GUIDE	142
CHAPTER 9: TESTING AND USING THE ROUTE SIMULATION SOFTWARE	153
CHAPTER 10: CONCLUSIONS AND RECOMMENDATIONS	181
PART III - SLOPS TREATMENT ONBOARD; THE SEATREAT SYSTEM ...	191
CHAPTER 1: ENVIRONMENTAL REGULATIONS	192
CHAPTER 2: SLOPS PRODUCTION ON SHORTSEA CHEMICAL-TANKERS	200
CHAPTER 3: SLOPS COSTS	207
CHAPTER 4: SLOPSTREATMENT	213
CHAPTER 5: OUTLINE SPECIFICATION FOR A SLOOPS TREATMENT SYSTEM ON BOARD	228
CHAPTER 6: CHEMICALTANKER DESIGN CONSTRAINTS	239
CHAPTER 7: ECONOMIC EVALUATION	265

PART IV - SEA-RIVER CHEMICALTANKER	289
CHAPTER 1: SEA-RIVER LANES INFRASTRUCTURE	290
CHAPTER 2: SEA-RIVER SHIPS	295
CHAPTER 3: INTRA-EUROPEAN CHEMICAL TRADES	301
CHAPTER 4: TRANSPORT ALTERNATIVES	303
CHAPTER 5: SEA-RIVER CHEMICALTANKER	306
CHAPTER 6: EVALUATION OF TRANSPORT COSTS	311
CHAPTER 7: HOW TO IMPROVE THE COMPETITIVENESS?	315
CHAPTER 8: INNOVATION: THE CYLINDERTANKTYPE CHEMICALTANKER	317

INTRODUCTION

Chemical tankers are complex and expensive ships, as they often carry hazardous cargoes. A lot of experience and know how has been gathered over the last decades and formalized in detailed design-rules and regulations from the International Maritime Organization and the Classification Societies.

From a technical point of view, the present generation double-hull chemical tankers forms a milestone in design and safety.

In spite of the increased technological sophistication of chemical tankers, one major problem seems difficult to solve over the years: the time spent in port (porttime) of chemical tankers remains very long in relation to the time spent at sea.

A major chemical tanker owner and operator, faces a porttime of its entire fleet of deepsea chemical tankers of around 40 percent. This means that the 30 vessels spent per annum a staggering 4320 days in port. As the charterhire of these vessels is around \$20.000 per day, the wastage is evident, as well as the potential for improvement!

As a chemical tanker only makes money for its owner while transporting cargoes at sea, this company wanted to understand in more detail the reasons why, in spite of all the professional efforts already allocated to this problem, they did not succeed in a substantial reduction of the porttime of their fleet.

At the Faculty of Mechanical Engineering and Marine Technology of the Delft University of Technology, my Chair in shipping, innovation in shipping and maritime business studies, addresses this kind of issues.

One of my graduate students, **Jaap Kalverkamp**, attacked the problem and wrote his thesis report on Porttime Analysis, in which he analysed in detail the port calls of chemical tankers in one of the busiest chemicals ports in the world, Rotterdam. Based on a simulation of the portcall, he defined a number of areas for operational improvement, as well as areas for further research. The essence of his work is described in **Part I**.

For example, a chemical tanker has to shift often its berth from one tankterminal or chemical plant to another. These berths are sometimes occupied by another vessels, which causes delays.

How can you improve the routing of a chemical tanker through a port? This question is very relevant for another chemical tanker operator in the port of Houston. This port has some 40 different chemical terminals and some of them have a very high utilisation, which causes delays and of course demurrage.

This company wanted to understand the extent of the delay-problem in the port of Houston and create a decision support system in order to reduce the overall porttime and related costs.

Introduction

Another graduate student, **Jaap Doornbos**, worked, partly in Houston, on this challenging project which resulted in a practical planning tool, as described in **Part II**.

Chemical tankers carry many different products, which are often incompatible. Therefore tanks have to be cleaned before loading another product. This not takes time, for washing and inspection, but also creates a lot of wastewater, the so-called slops. Some of these slops can be pumped over board while at sea, but some have to be brought to slop reception facilities, where they are treated and neutralized.

There are basically two ways to solve this problem:

- * Reduce the volume of slops; and
- * Treat the slops on board the chemical tanker.

The first solution requires a fundamental re-design of the chemical tanker, while the second option leads to a small slop treatment plant on board the vessel.

Part III summarizes the graduate work of **Jan de Waart**, with a major shortsea shipping chemical tanker company on the slop management issues, which led to the Seatreat-system; a small, on board treatment plant developed by the Rotterdam-based company Encon.

The fundamental reduction of slops can be achieved by using innovative tank-forms, such as the cylindertype. **Part IV** contains a summary of the graduate work which **Rob Heijliger** carried out with the Rotterdam-based Maritime Economic Research Centre (MERC) on a shallow-draught chemical tanker for coastal trading. The small tanker in this study is equipped with many small cylindertanks.

In order to prove the advantages of this independent tanktype for larger vessels, a major chemical tanker owner commissioned a study, which was carried out by ir. Ernst Vossnack and myself. The innovative chemical tanker design, as briefly discussed in **Part IV**, can achieve a major slops reduction in comparison with conventional chemical tankers.

This book is intended to show the potential for innovation in chemicals shipping as especially from the engineering and operating perspective.

This research could only take place with the full co-operation of a number of companies. I am grateful for their support and for the unique experience they offered my students.

I am grateful to my students who have the intelligence, drive, curiosity and creativity to challenge conventional wisdom and help me understand the "First principles" of our "metier".

The motto of this book "SOLVING NOT SHIFTING" has been borrowed from mr. P. Bergmeijer, of the Directorate General of Shipping and Maritime Affairs of the Dutch Ministry of Transport. It underlines the change in design and enginee-

ring principles, which are now aimed at developing a **sustainable** economic growth in this world, especially in the field of chemicals transportation. I do hope that the case-studies in this book may help to achieve this fundamental change.

Acknowledgements

I should like to thank the following companies and individuals for their support of these researchprojects:

- * Jo Tankers A.S., Bergen and Jo Tankers B.V., Rotterdam
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- * ir. R. Heijliger
- * ir. J.D. Kalverkamp
- * ir. J.A. de Waart

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PART I - PORT TIME ANALYSIS OF CHEMICAL TANKERS IN THE PORT OF ROTTERDAM

Table of Contents

CHAPTER 1:	ECONOMICS AND ACTIVITIES OF A PORT CALL	8
CHAPTER 2:	THE DIFFERENT ASPECTS OF A PORT CALL	13
CHAPTER 3:	PORT TIME ANALYSIS	19
CHAPTER 4:	VESSEL SPECIFICATIONS.	28
CHAPTER 5:	PORT TIME PROGRAM.	41
CHAPTER 6:	PROGRAM RESULTS	47
CHAPTER 7:	RECOMMENDATIONS AND CONCLUSIONS.	60

PART I - PORT TIME ANALYSIS OF CHEMICAL TANKERS IN THE PORT OF ROTTERDAM

CHAPTER 1: ECONOMICS AND ACTIVITIES OF A PORT CALL

PORT TIME.

The time a ship spends in port affects its efficiency and earning potential. Port stays are necessary as a ship has to be loaded and discharged, has to bunker and change its crew. This has to be done as quickly as is reasonably possible in order to maintain a high ratio of time at sea and time in port.

The average number of sailing days of the chemical tankers which are used as the subject of this study is 232 days a year. That means on average about 119 days is spent in port per ship per year (Figure 1). This is equal to 36.5 percent of the year spent in port.

The average time spent in port per year is even higher for the largest vessels: 143 days, which is equal to about 40 percent.

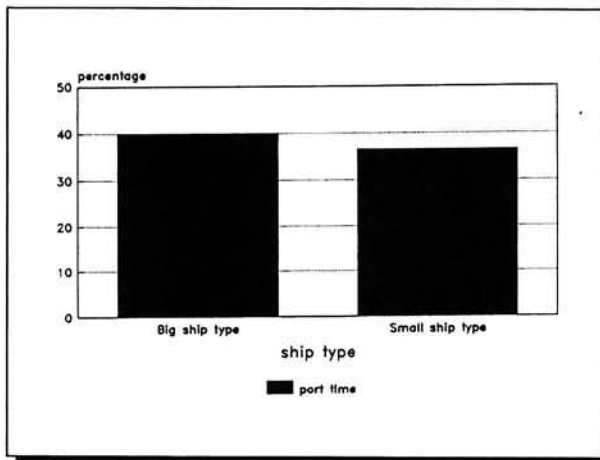


Figure 1: Percentage of time spent in port

PORT COSTS

More than 30 percent of the total voyage costs from the chemical tankers in the year under study was related to port expenses. If one only looks at the largest vessels, this figure even increases to 40 percent. Figure 2 shows the breakdown of voyage cost of the 40,000 dwt ship type.

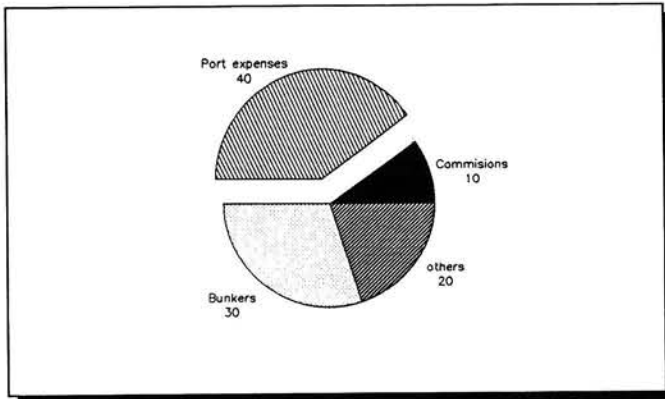


Figure 2: Voyage costs, 40,000 dwt ship

For a smaller ship of 12,000 dwt, the port expenses make up around 55 percent of the voyage costs (Figure 3).

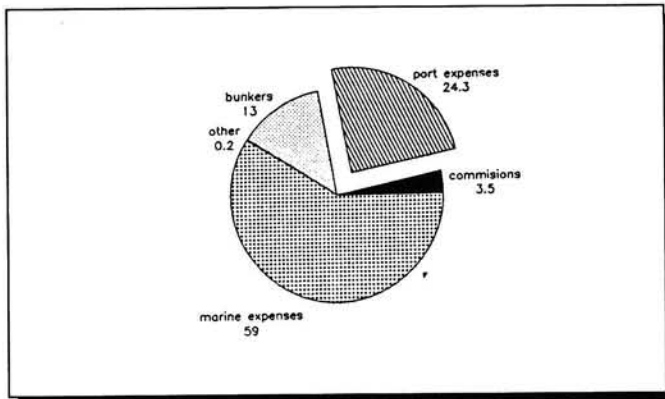


Figure 3: Voyage costs, 12,000 dwt ship

The Figures clearly illustrate the importance of the time spent in port, which can be translated into lost charter revenues, and the out of pockets cost in port, which make up a large part of the voyage costs.

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

OBJECTIVE

The main objective of this project is to get a better understanding of all the factors which influence the duration and the costs of port stays, to analyse these factors and to formulate recommendations for improvements.

Common sense tells us that factors like the large number of terminals visited in one port, the large variety of products that have to be loaded or discharged and the number of other activities like bunkering and crewchanges influence the port time.

ANALYSIS

This study contains an analysis of the port times of two types of ships, one big ship (40,000 dwt) and one small ship (12,000 dwt). **Figure 4** and **Figure 5** illustrate these ships. These two ship types were chosen as it might be interesting to see the differences in port times and as they are ships with good crews and good equipment.

The port calls which will be analysed are all in Rotterdam, as it is one of the two main chemical ports in the world, with a multitude of activities and frequently visited by the two selected ships, while the company has a good documented history of port calls at its disposal.

A port time program has been written which can serve as a decision support system for the planning and management of the port calls. It is able to calculate the impact of different factors on the duration of the port time, and facilitate the comparison of heterogeneous portcalls of many ships.

This program should be able to calculate the theoretical minimum port time for the forementioned type of vessels in the port of Rotterdam. In order to be able to analyse a port stay, this theoretical time should be subdivided in terminal times and shifttimes and the terminal times should be subdivided in product-load and discharge times.

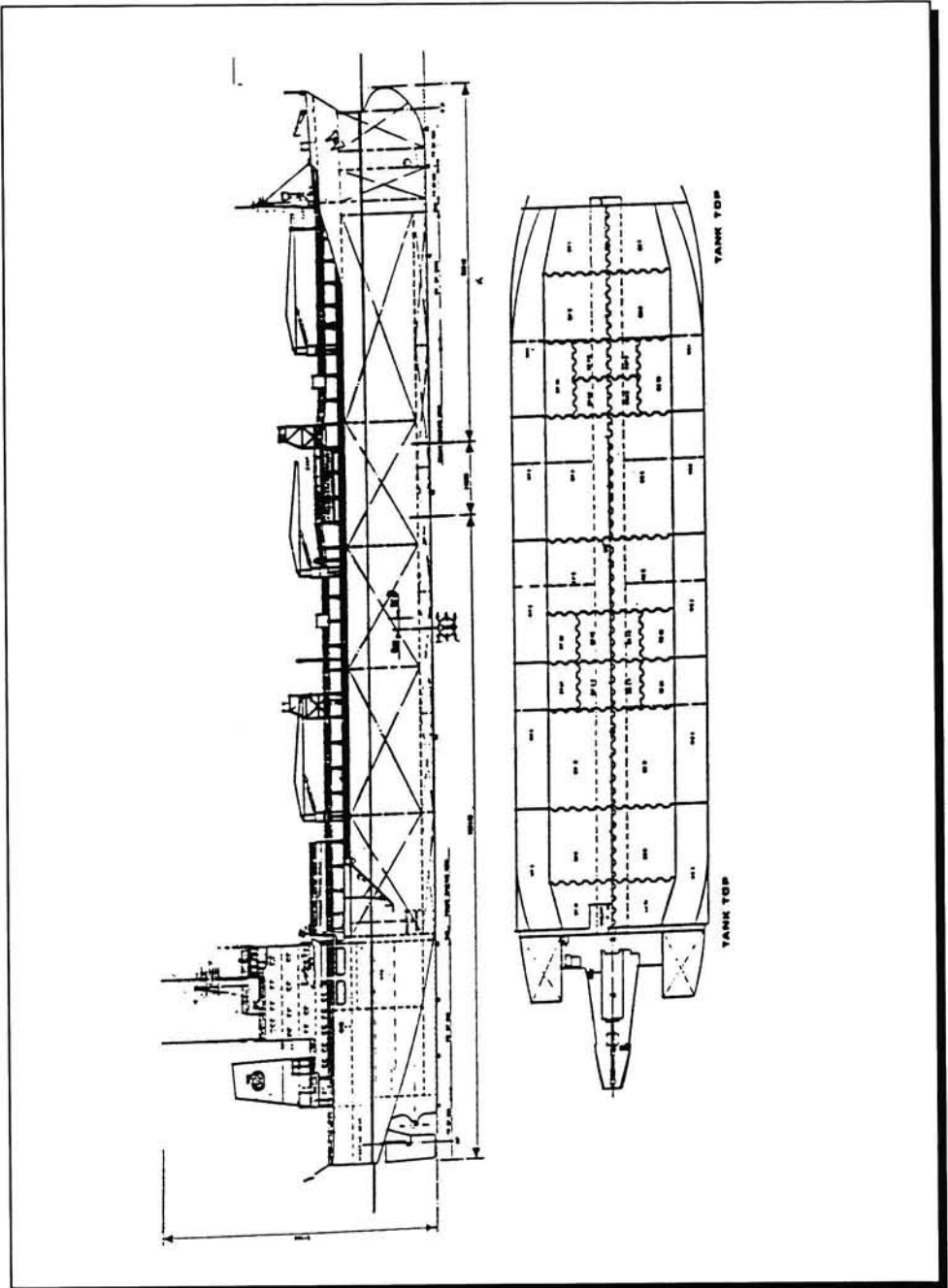


Figure 4: General arrangement, 40,000 dwt ship

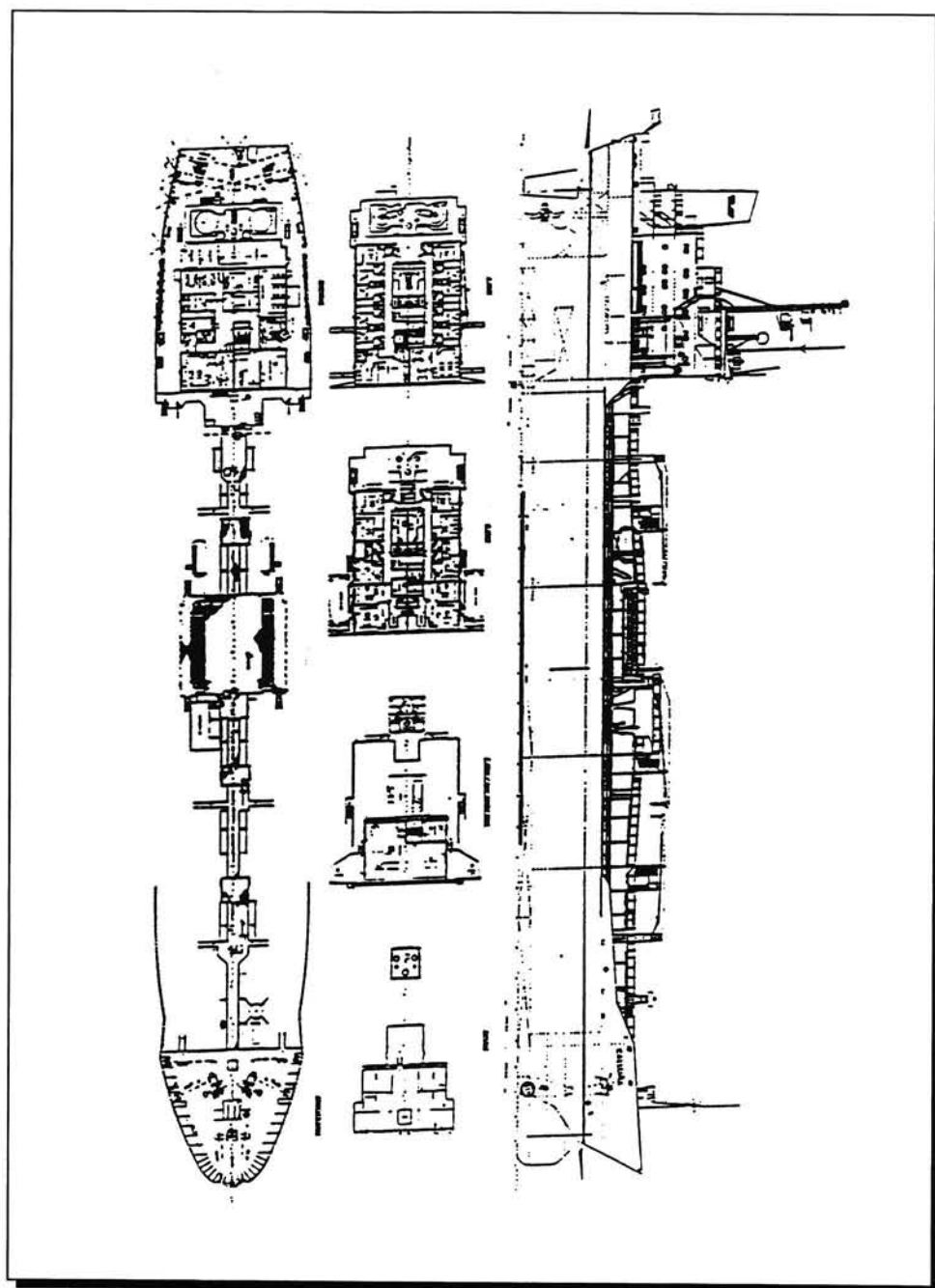


Figure 5: General arrangement, 12,000 dwt ship

CHAPTER 2: THE DIFFERENT ASPECTS OF A PORT CALL

After entering the port of Rotterdam a chemical tanker goes through a lot of different activities before it leaves port again. In order to get a better understanding of the important factors leading to a long port stay, the activities of a port call will be described in this chapter.

PORT ACTIVITIES.

When a chemical tanker enters Rotterdam it has a number of activities to perform before it can leave. The more important activities are:

- * Shifting from one terminal to another;
- * Analysis of the cargo or the cargotanks;
- * Connecting or disconnecting of the hoses;
- * Loading from a terminal or a barge/coaster;
- * Discharging to a terminal or a barge/coaster;
- * Cleaning tanks;
- * Bunkering;
- * Crew changes.

SHIFTING.

When all the cargohandlings have been performed at a certain terminal, the ship has to leave for the next terminal. Permission to shift the vessel to another terminal is only granted if the harbour pilot is onboard and the tug(s) are available. A lot of time can be lost if the ship has to wait for the tugs and the pilot to arrive, due to communication problems or because they are not available at that moment.

Planning problems can arise if the next berth isn't available and the ship has to wait at a buoy before it is allowed to berth at the next terminal.

ANALYSIS OF THE CARGO OR THE CARGOTANKS.

After the ship is berthed at a terminal and the notice of readiness is tendered and before the cargohandling is allowed to be started, the cargo and/or the cargotanks which will be used have to be analysed by an independent surveying company.

These analysis take some time because the samples have to be brought to a laboratory for this analysis. The samples are then tested on a lot of different aspects and have to fulfil requirements demanded by the customer or owner of the cargo.

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

A distinction has to be made between an analysis before loading a cargo and an analysis before discharging a cargo.

Analysis before discharging.

The survey company takes samples from the cargo, the discharge line of the ship, the load line of the terminal and the cargotanks of the terminal. The analysis of the cargotank of the terminal is mostly done before the ship arrives. The other analysis can be done eight hours in advance but in reality they happen just after the ship arrives at the terminal.

Analysis before loading.

The survey company takes samples from the cargo, the discharge line of the terminal, the load line of the ship and the cargo tank of the ship, after a foot of cargo has been loaded they take the so-called footsample. The loading has to be stopped until the footsample has been analysed and approved of.

Time losses can occur when samples are not approved, this can mean that the cargotank or the cargohose has to be extra cleaned or that the cargo is polluted. Time losses can also occur when surveyors are not present due to communication problems and because of traffic jams between the laboratory and the terminal.

Connecting or disconnecting of the cargohoses.

All the cargolines on board the ship come together at the manifold (**Figure 6**), which is the centre point of all cargohandlings. Every cargotank has its own connecting point at each side of the ship.

If the ships own cargohoses are used, they can be connected to the ship before arrival. Then they still have to be connected to the terminal or the barge/coaster but this is not done by the ship's crew. If cargohoses from the terminal are used, the crew has to connect them to the ship just after arriving at the terminal. The connecting points, flanges, are screwed together with bolts.

LOADING FROM A TERMINAL OR A BARGE/COASTER.

After the cargotank has been approved of, the loading of the cargo can commence. The loadrate of a terminal or barge/coaster is influenced by the pump-type used and the physical properties of the product. Low loadrates are induced by small pipe diameters, malfunctioning valves and other miscellaneous accidents like: leaking hoses, loadstops from the terminal. The siphon effect also has an influence on the loadrate.

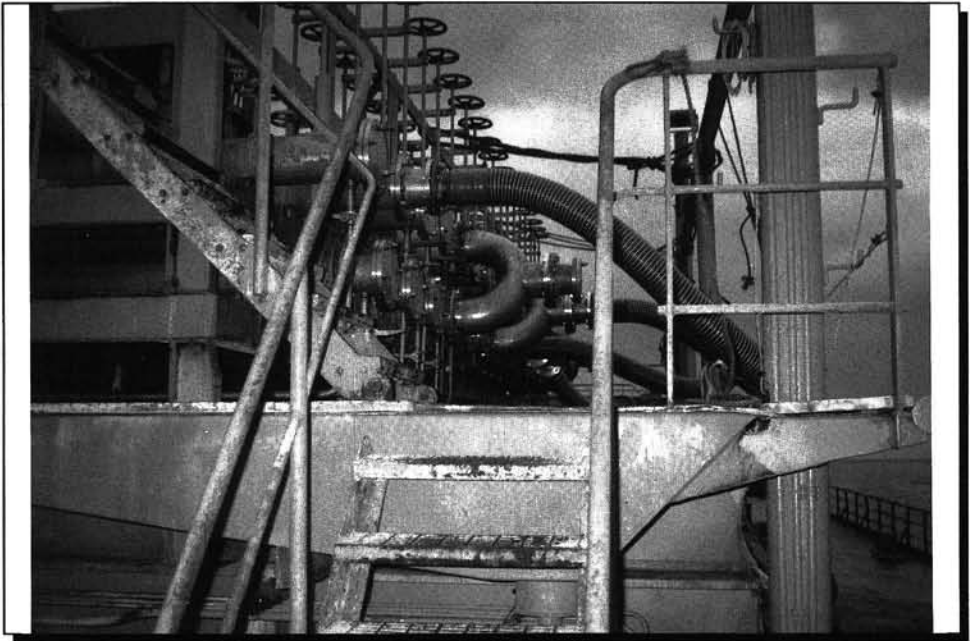


Figure 6: Manifold

DISCHARGING TO A TERMINAL OR A BARGE/COASTER.

After the cargo has been checked, the discharge of the cargo can commence. The discharge rate of the ship is influenced by the pump type used and the physical properties of the product. Low discharge rates are induced by small pipe diameters, malfunctioning valves, low hydraulic pressure, terminal requirements, long discharge pipes and other miscellaneous accidents.

CLEANING TANKS.

Cleaning of cargo tanks is necessary in order to allow the different cargo types to be transported in the same tank. A lot of research has already been done on the subject of cleaning the tanks.

The time necessary for cleaning tanks can vary from one hour to four or five hours and sometimes even longer. The cleaning time of a cargo tank is influenced by the size of the tank, the construction of the tank, the amount of residu left behind in the tank, the type of cleaning machine used, the cleaning procedure used, the amount of ventilation necessary, the type of product that was carried in the tank, the laws and the specification of how clean the tank should be.

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

Time losses occur when tanks are not cleaned to specification and are refused by the surveying company thus resulting in extra cleanings, extra analysis and due to that, planning problems.

BUNKERING.

Bunkering does not influence the duration of port stays unless they interfere with the cargo handlings that take place.

CREW CHANGES.

Crew changes do not have to influence the duration of a port stay, unless the change interferes with the cargohandlings. For instance when a chief officer goes on leave at the arrival in a discharge port he takes a lot of information with him about the cargo which is not always written down and could influence the cargohandlings.

SHELL TARGET TIMES

When berthing at the Shell Pernis terminal in Rotterdam, the terminal uses a checklist with target times for all the activities. These can be divided into standard and non-standard activities.

The following tables illustrate all the activities related to a port call of a chemical tanker. It is used by Shell to evaluate and investigate the reasons for unwarranted delays.

N/ST. Code	Description	Target time
CO	Tank cleaning (only)	:
RB	Bunkering (only)	:
RS	Stores (only)	:
SO	Hospitality owners Acc't	:
TA	Awaiting berth Shell	:
YA	Harbour steaming in	:
YB	Mooring	:
YC	Connecting	00:40
YD	Discharging	:
YE	Disconnecting	00:30
YF	Unmooring	:
YL	Loading	:

Table I: Standard Activities

Part I: Port Time Analysis of chemical tankers in the port of Rotterdam

N/ST. Code	Description	Target time	Mandatory grade Nr.	Before Nor
BA	Awaiting ballast ullage	:	N	N
BB	Ballasting	:	N	N
BD	Deballasting	:	N	N
CC	Tank cleaning charterers	:	N	N
CM	Tank cleaning marpol	:	N	N
CO	Tank cleaning owners	:	N	Y
CT	Tank cleaning shore request	:	N	N
DC	Crude oil washing	:	Y	N
DD	Internal draining	:	Y	N
KK	Awaiting cargo	:	N	N
KO	Off spec cargo	:	N	N
KS	Awaiting ullage shoretank	:	N	N
LC	Changing tanks	00:15	Y	N
LF	Line flushing	01:00	N	N
LG	Changing grade	00:30	N	N
LS	Line setting on ship	:	N	N
LT	Line setting on terminal	00:20	N	N
NA	After nominated date	:	N	N
NB	Before nominated date	:	N	Y
NV	Awaiting voyage orders	:	N	Y
PA	Awaiting agent	:	N	N
PC	Awaiting customs	:	N	N
PH	Awaiting harbour	:	N	N
PI	Awaiting immigration	:	N	N
PL	Awaiting mooring launches	:	N	N
PM	Awaiting mooring crews	:	N	N
PP	Awaiting pilots	:	N	Y
PQ	Awaiting pratique	:	N	N
PS	Shifting berth	:	N	Y
PT	Awaiting tugs	:	N	N
PZ	Strike	:	N	N
QD	Awaiting documents	01:00	N	N
QF	Analysing Footsamples	02:00	Y	N
QI	Inspection by independent surveyor	02:00	N	N
QL	Line displacement check	00:20	Y	N
QO	Tank Inspection by shore	00:30	N	N
QQ	Sampling/sample testing	03:00	N	N
QS	Ship figures	:	N	N
QT	Shore figures	00:30	N	N
QW	Waiting for independent surveyor	:	N	N
RB	Bunkering	:	N	N
RS	Replenishing Stores	:	N	N

Tabel II: Non standard activities (1)

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

N/ST. Code	Description	Target time	Mandatory grade Nr.	Before Nor
SA	Awaiting ship readiness	:	N	Y
SB	Ship breakdown	:	Y	N
SC	Awaiting charterer's instructions	:	N	N
SH	Heating cargo prior discharging	:	N	N
SO	Owners purposes	:	N	N
SS	Awaiting shifting berth others	:	N	N
SZ	Pre-arranged sailing/ship	:	N	N
TA	Awaiting berth	:	N	N
TB	Shore breakdown	:	Y	N
TC	Awaiting tide (dis)connecting	:	N	N
TJ	Waiting jetty operator	:	N	N
TL	Cargo planning	00:30	N	N
TO	Awaiting personnel terminal plant	:	N	N
TP	Awaiting personnel terminal plant	:	N	N
TR	Awaiting shore readiness	:	N	N
TS	Scadas	:	N	N
TZ	Pre-arranged sailing terminal	:	N	N
WC	Awaiting current	:	N	N
WD	Awaiting daylight	:	N	N
WL	Awaiting at lay/by berth	:	N	N
XT	Awaiting tide	:	N	N
WW	Awaiting weather	:	N	Y
XT	Transfer third party	:	N	N
XX		:	N	N

Tabel III: Non standard activities (2)

CHAPTER 3: PORT TIME ANALYSIS

In order to understand the reasons of long port stays and to obtain information which can be used in the port time program, the port call reports of the two ship types at Rotterdam over a three-year period were analysed. The port coordinator reports and some reports written on this subject were studied as well.

TIME ANALYSIS AND PUMPRATE ANALYSIS.

Because of the multitude of activities taking place in port, a lot of things can go wrong and do go wrong. Many causes of delay are not directly induced by the ship or its crew but are the result of things going wrong or taking long on shore.

In an effort to compare the different reasons of a too long port stay, all the causes of delay that cost valuable time were analysed. In this first effort the actual time lost due to these causes of delay was not looked at but only the number of times they occurred. The analysis was not split at this stage into the two ship types but rather tried to get an overall view.

The port coordinator reports of the last four years and port reports of the last three years were analysed. In all, 23 types of causes of delay were found to be relevant, which are shown by category in Figure 7.

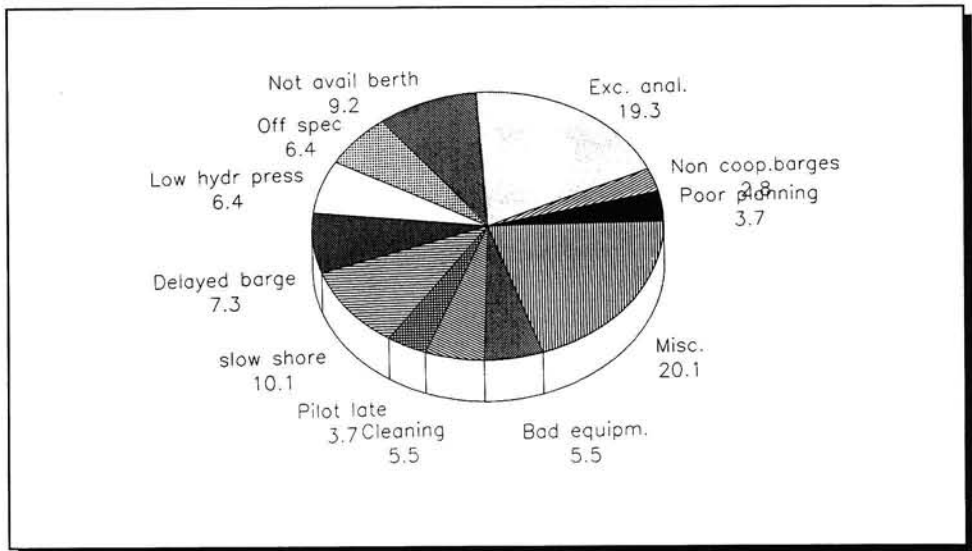


Figure 7: Overall disturbance analysis

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

Disturbance		Percentage
1.	Poor planning	3.7
2.	Non oop. barges	2.8
3.	Excessive. Analysis	19.3
4.	Pump on barge down	0.9
5.	Crewchange	0.9
6.	Non available berth	9.2
7.	Off spec.	64
8.	Purge	1.8
9.	Low hydr. press.	6.4
10.	Drying while raining	1.8
11.	Leaks	1.8
12.	Barge delayed	7.3
13.	Slow shore	10.1
14.	Pilot late	3.7
15.	Cleaning tanks	5.5
16.	Bad equipment	5.5
17.	Lack of experience	1.8
18.	No vapour return line	0.9
19.	Bunkering	1.8
20.	Weather	3.7
21.	Clogged line	2.8
22.	Crew	0.9
23.	Shift shoregang	1.8

Tabel IV: Detailed causes of delay analysis

Especially excessive analysis, not available berths, low hydraulic power, delayed barges and "a slow shore" came out as being the main reasons of losing time in port. This doesn't tell us what disturbances induce most of the lost time, it only tells us which disturbances happen most of the time.

In order to analyse the disturbances that induce most of the total port time lost, the two ship types were analysed separately and in more detail.

The 40,000 dwt ship

The port stays in Rotterdam of the last three years were analysed. This represented about 2,000 hours of port time of which 26.4 percent is time lost due to different types of disturbances (Figure 8). This lost time is for 42.9 percent due to excessive analysis, for 22.8 percent due to waiting for ready berths and for 13.9 percent due to delayed barges.

If these results are compared with the overall analysis, the main difference is the number of types of disturbances recorded, 23 in the overall analysis and 10

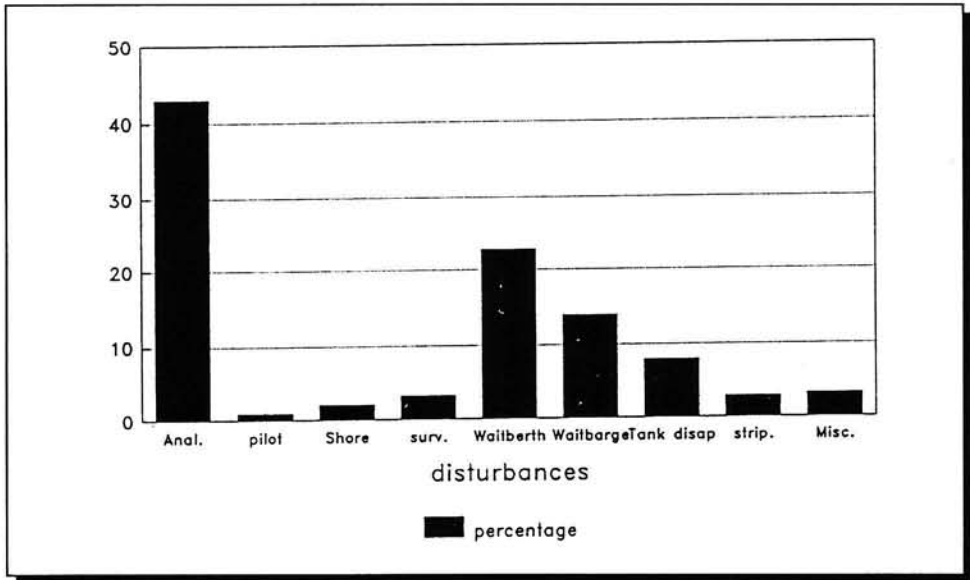


Figure 8: Port handling disturbances

in 40,000 dwt ship analysis.

Reasons for this discrepancy are the following: poor planning will never be recorded in the port reports but will only be recognized by the port coordinator. Time lost to bad equipment, low hydraulic pressure, lack of experience, slow shore, etc., is not always recorded in the port reports but they do influence the load and discharge rates. Off spec. tanks and cargoes are a part of excessive analysis.

In order to analyse the influence of bad equipment, low hydraulic pressure, lack of experience, slow shore, etc is, the pump rates of the ship, terminals and the barges have been analysed separately.

The mean pumprates of both the terminal (180 mt/hr) and the barges (190 mt/hr) were rather low. The pumprates of the terminals varied from 500 (mt/hr) to 50 (mt/hr). The pumprates of the barges varied from 350 (mt/hr) to 70 (mt/hr). There is a tendency that the bigger the parcelsize the higher the pump-rate.

The calculation of the mean pumprates of the ship is difficult due to the fact that the ship uses four types of pumps to discharge. To anticipate the mean pumprate for parcels smaller than 1,000 mt, parcels between 1,000 and 2,000 mt and parcels above 2,000 mt were determined. The pumprates were also divided into pumprates into a barge and into a terminal. These pumprates are summarized in Figure 9.

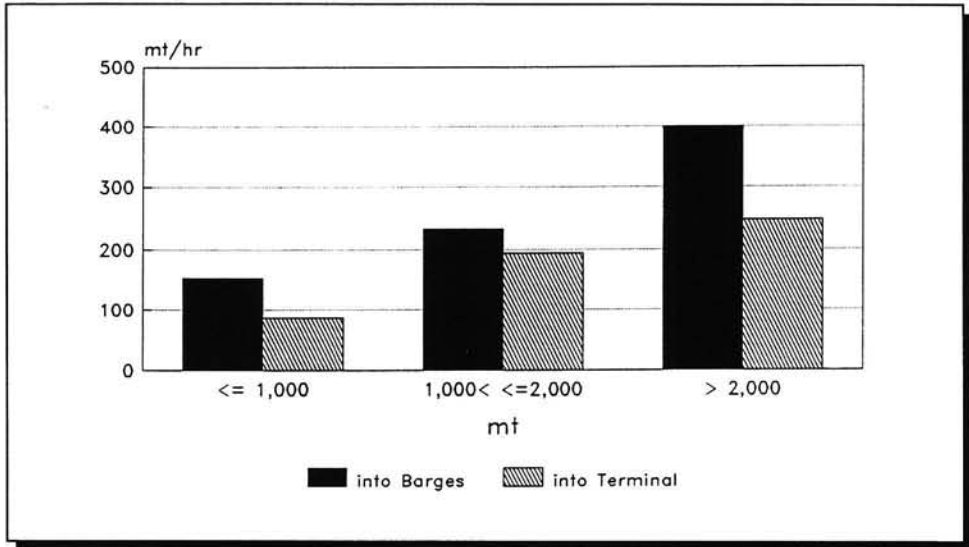


Figure 9: Mean pumprates, 40,000 dwt ship

The 12,000 dwt ship

The port calls at Rotterdam of 12,000 dwt ship type were analysed. Twenty percent of the total time spent in port was lost time due to disturbances, which is 6.4 percent lower than the time a 40,000 dwt ship type losses.

This lost time is for 40.4 percent due to excessive analysis, for 37.2 percent due to waiting for ready berths and for 11.2 percent due to waiting for barges (Figure 10). For the 12,000 dwt ship type the same discrepancy concerning the number of types of disturbances as for the 40,000 dwt ship type can be noticed. The reasons are similar.

In order to analyse the influence of bad equipment, low hydraulic pressure, lack of experience, slow shore, and the like. The pump rates of the ship, the terminals and the barges were analysed.

The mean pumprates of the terminals and the barges are of course the same as with the 40,000 dwt ship type.

The mean pumprate of the 12,000 dwt ship type into the mean pumprate for parcels smaller than 1,000 mt and for parcels bigger than 1,000 mt in the case of discharging into a barge. The mean pumprates, when discharging into a terminal are divided into the mean pumprate for parcels smaller than 2,000 mt and bigger than 2,000 mt (Figure 11).

Part I: Port Time Analysis of chemical tankers in the port of Rotterdam

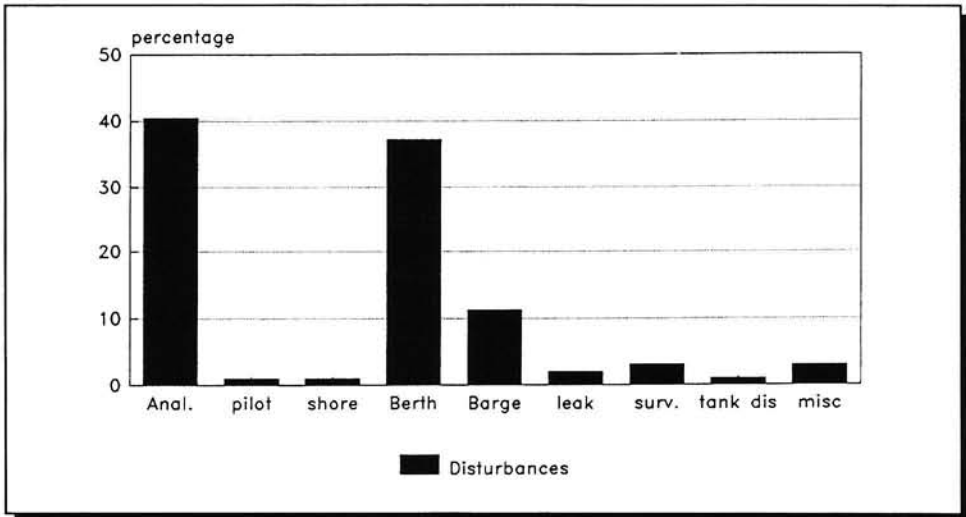


Figure 10: Port handling disturbances, 12,000 dwt ship

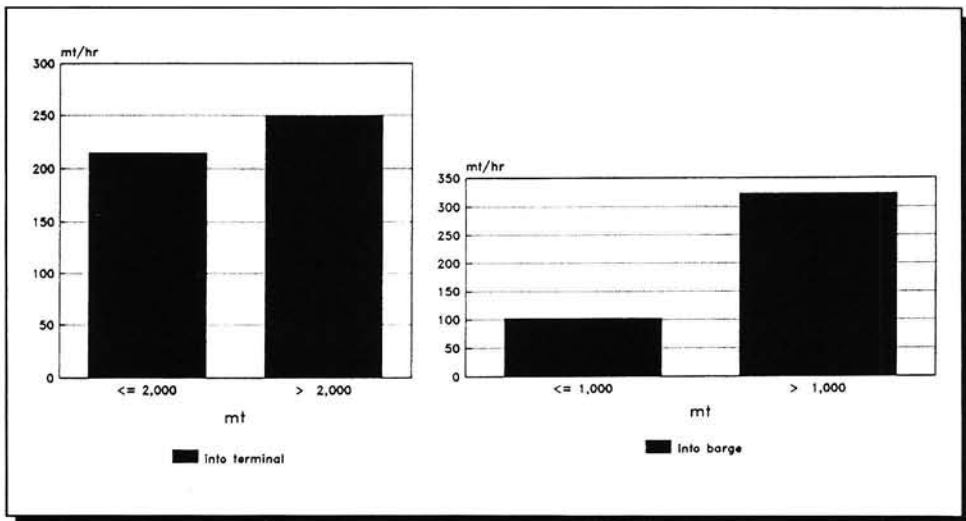


Figure 11: Mean pump rates, 12,000 dwt ship

SHIFTTIMES

As the shifftimes in the port time program are used, they have to be analysed in more detail. The shifftime between two terminals can of course be influenced by weather influences, late pilots and a busy port as can be seen from the overall analysis.

CONNECT ANALYSIS.

The mean hose connecting time to a terminal was 84 minutes and the mean disconnecting time was 28 minutes. The mean connecting time with a barge was 48 minutes and the disconnecting time was 24 minutes (Figure 12).

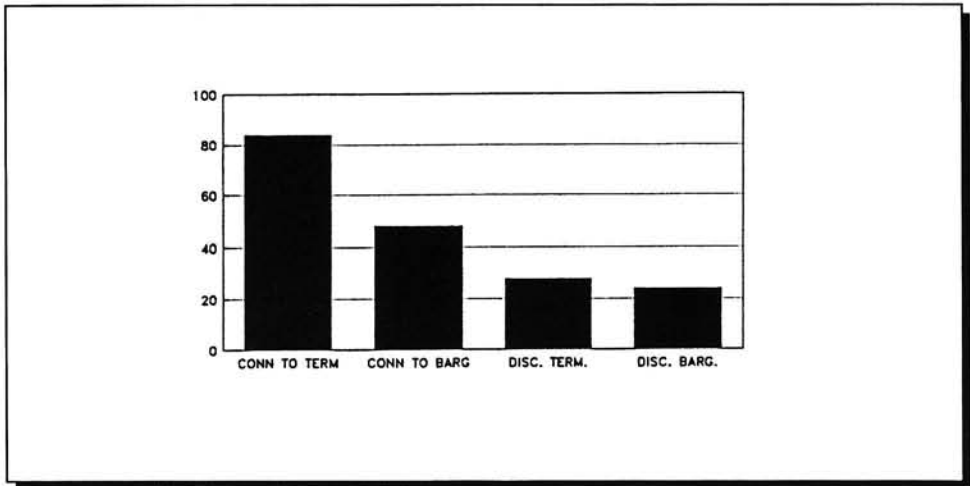


Figure 12: Connect analysis

PORTCOST ANALYSIS

The 40,000 dwt ship.

The port charges are the main part of the port costs (Figure 13). The running costs of the ship are not incorporated in these figures, only the costs which are a result of the port visit and the cargo handlings. The port charges consist mainly of harbour dues, shifting expenses, pilotage and agency fees (Figure 14). The cargo expenses consist mainly of discharge and loading expenses, cleaning expenses and survey expenses (Figure 15). The vessel expenses consist mainly of stores and repairs (Figure 16). As a result the port costs are about 12,000 USD/day for the 40,000 ship type. The loss of charter revenue is about 20,000 USD per day for the 40,000 ship type.

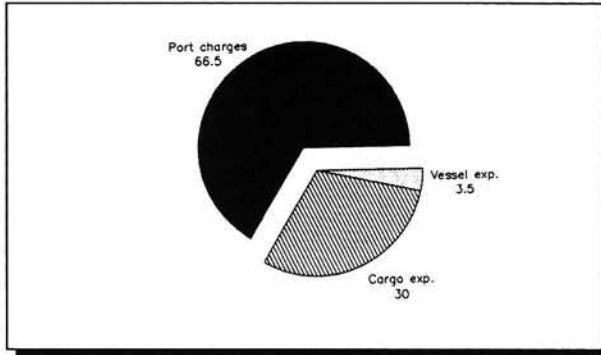


Figure 13: Port costs, 40,000 dwt ship

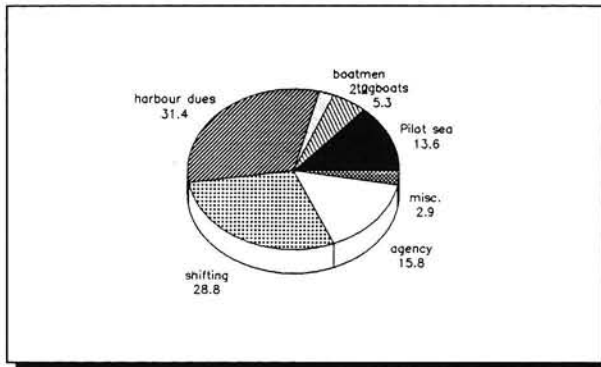


Figure 14: Port charges, 40,000 dwt ship

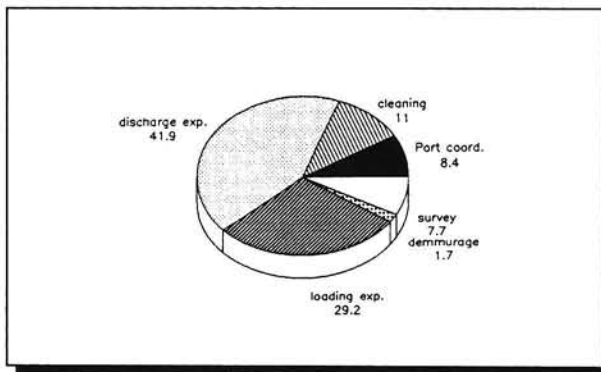


Figure 15: Cargo expenses, 40,000 dwt ship

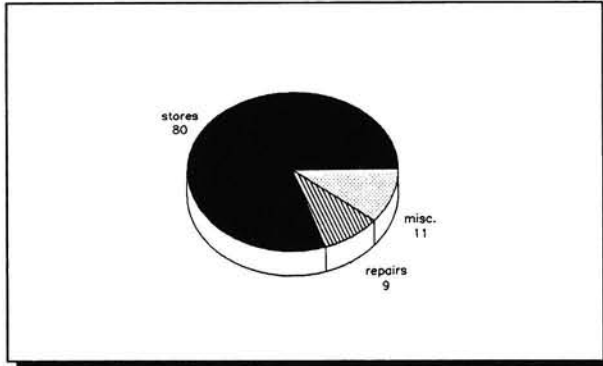


Figure 16: Vessel expenses, 40,000 dwt ship

The 12,000 dwt ship.

With this ship type the port charges form an even bigger part of the port costs (Figure 17). The running costs are again not incorporated into these figures, only the costs that are a result of the port visit and the cargo handlings. The port charges (Figure 18), cargo expenses (Figure 19) and vessel expenses (Figure 20) division is almost the same as with the 40,000 dwt ship type. As a result the port costs are about 5,000 USD/day for the 12,000 dwt ship type. The loss of charter revenue is about 12,000 USD per day for the 12,000 dwt ship type.

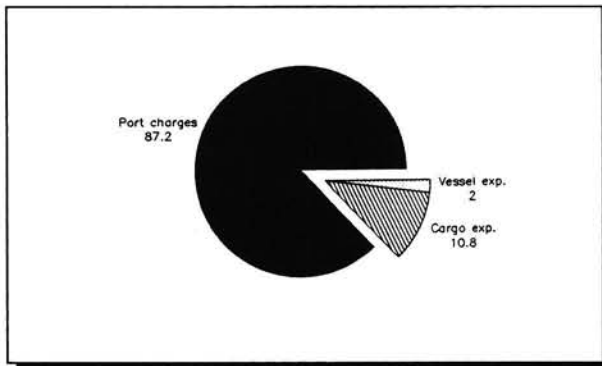


Figure 17: Port costs, 12,000 dwt ship

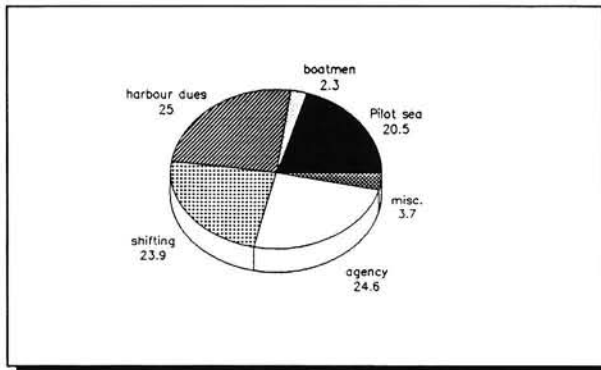


Figure 18: Port charges, 12,000 dwt ship

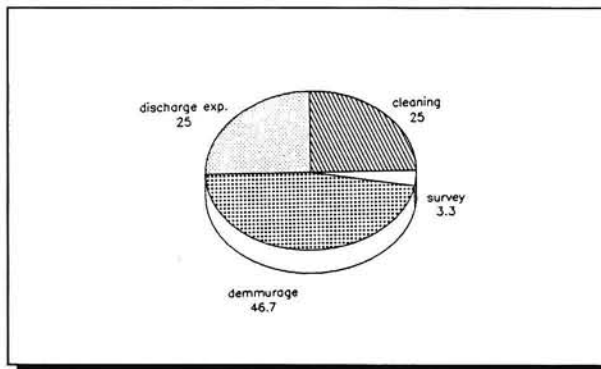


Figure 19: Cargo expenses, 12,000 dwt ship

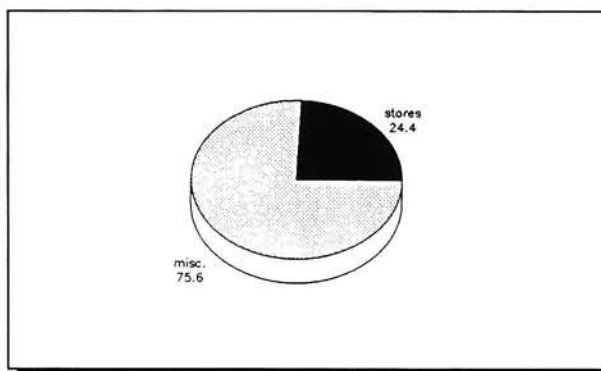


Figure 20: Vessel expenses, 12,000 dwt ship

CHAPTER 4: VESSEL SPECIFICATIONS.

The two ship types which have been chosen for this study will be discussed in this chapter in more detail.

THE 40,000 DWT SHIP

This ship was built in the early 1980's.

General description

This ship is a single screw diesel motor driven chemical/oil tanker with centre tanks of stainless steel, and coated wingtanks. Deepwell pumps are in all cargo tanks. The machinery and accommodation are situated aft. The ship has four deck cranes (Figure 21).

It has a Det Norske Veritas classification as a tanker for chemicals and a tanker for oil.

Principal dimensions

Length over all	175.00	m
Length between PP	168.20	m
Breadth moulded	32.00	m
Depth moulded to main deck	14.25	m
Draught on summer loadline	10.73	m
Trial speed on design draught	15.90	knots
Deadweight on summer loadline	39273.00	mt

Important equipment

Machinery

General: The propulsion system consists of one two stroke diesel engine driven a fixed pitch propeller.

Main engine: Aker B* W diesel engine of standard design, 2 stroke singel acting, reversible type with turbocharging. MCR is 11,200 kW at 123 r.p.m, 7 cylinders.

Propeller: Four bladed propeller with 6050 mm diameter.
Type: fixed pitch. Maker: Lips Drunen.

Boiler plant: Two oilfire boilers. Steam capacity is 14 tons/h, working pressure 15 bar. One exhaust gas boiler with a capacity of 4 tons/h.

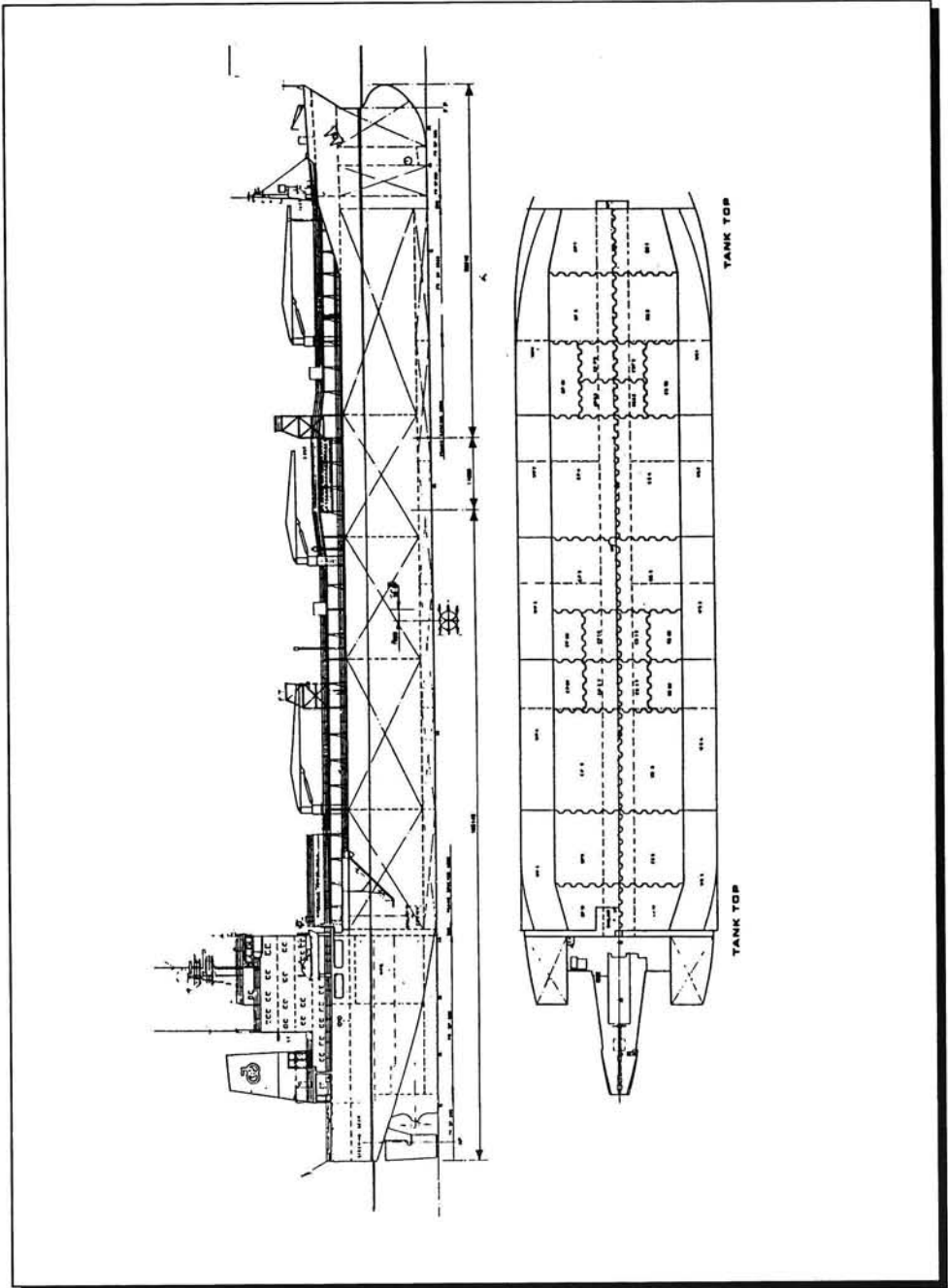


Figure 21: General arrangement, 40,000 dwt ship

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

Auxillary machinery: Two turbocharged diesel engines 1145 kW at 720 r.p.m., two alternators 1080 kW 440 volts at 720 r.p.m. and one waste heat recovery turbogenerator.

Hydraulic system

Hydraulic power: 8 Framo electrical/hydraulic units. To the hydraulic system are connected: 38 cargo pumps, 2 ballast pumps, 2 transfer pumps, 1 cleaning pump, 2 cargo booster pumps, 1 high pressure tank cleaning pump, 1 bow thruster, 2 windlasses, 4 mooring winches and 4 deck cranes.

Cargo system: Framo cargo pumps of the deep well type and operated from the cargo control room (**Figure 22**).

- Centre tanks:*
- 6. Type SPS 8 400 cu.m./h 80 m sp.gr. 1.025.
 - 6. Type SDS 6 250
 - 4. Type SDS 5 150
 - 12. Type SDS 5 100
- Wing tanks:*
- 2. Type SPS 8 400
 - 8. Type SDS 6 250
- Transportable:* 2. Type TK 4 70 cu.m./h 70 m sp. gr. 1.025.
- Booster pumps:* 2. Type Centrifugal 800 cu.m./h 8 bar.

Material: AISI 316 I in deep well pumps and piping in contact with cargo.

Cargo heating: Heating coils - 0.04 sq.m./cu.m. (**Figure 23**)

Cargo temperature: Central temperature indication is provided in all cargo tanks.

Cargo agitation: Tanks CP1, CS1, CP2, CS2, CP4, CS4, CP5, CS5, CP8, CS8, CP9, CS9, CP10, CS10, are provide with four pipes in each tank for agitation of cargo with low pressure air.

Tank level indication: Level gauging system with remote indication in cargo control room.

High level alarm: Overflow control system with 95% alarm and 98% alarm shut down.

Inert gas system: One inert gas generator with a capacity of 4000 cu.m./h.

N2-system: The system is served by 24 bottles (50 l each) stowed outside hydraulic power pack.

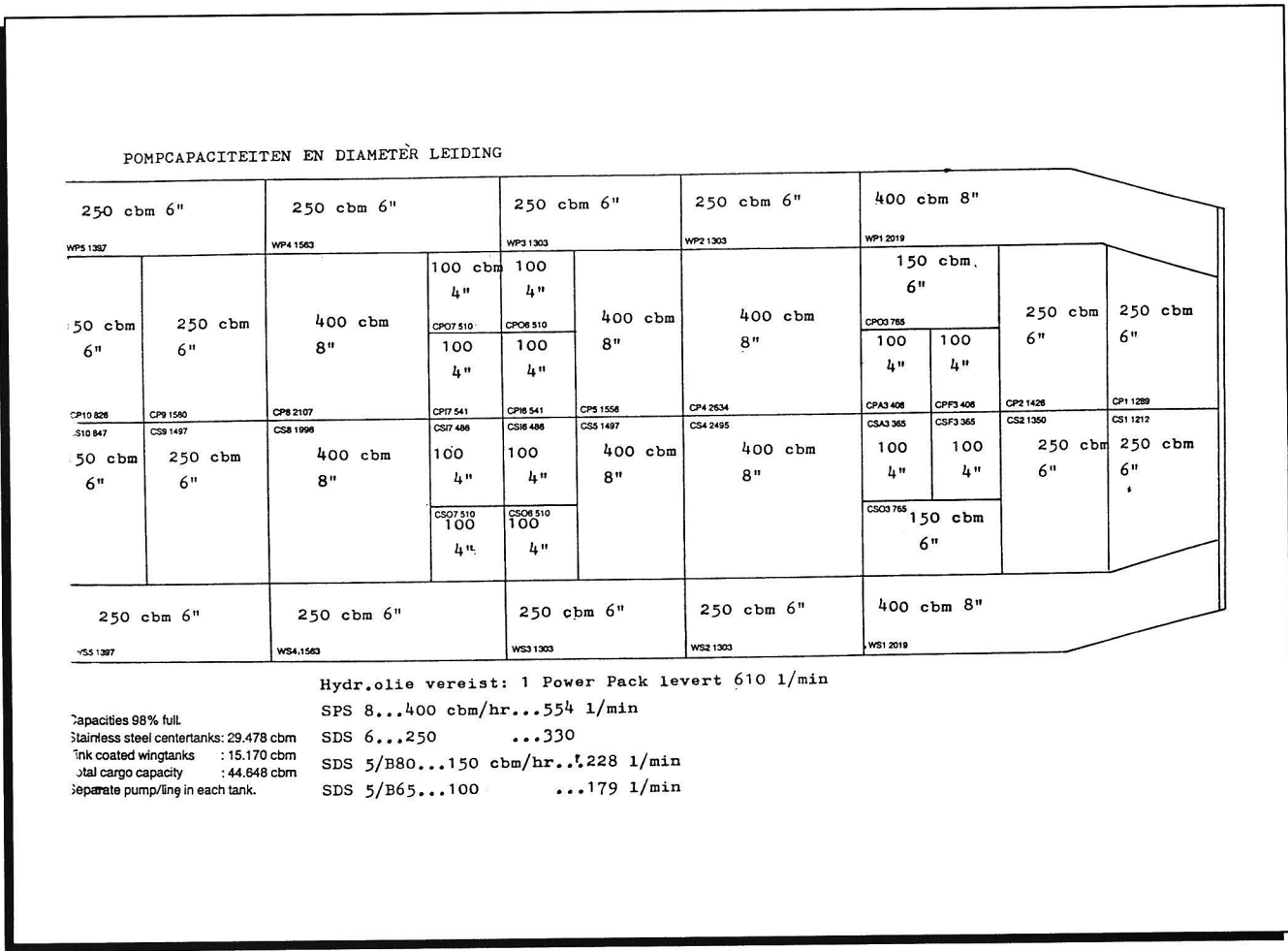


Figure 22: Cargo system, 40,000 dwt ship

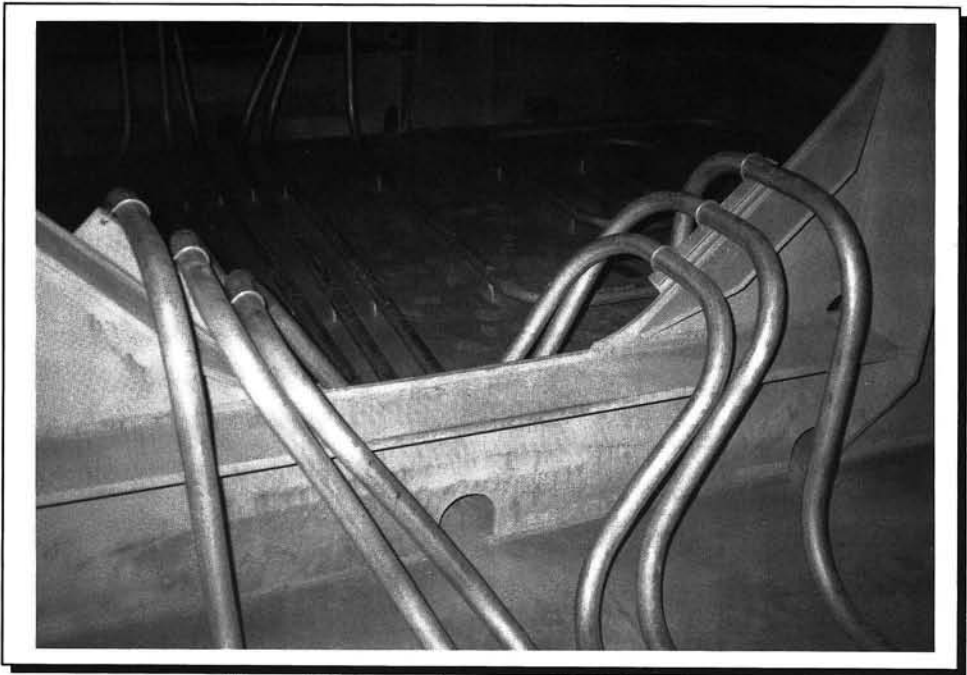


Figure 23: Cargo heating, 40,000 dwt ship

THE 12,000 DWT SHIP

This ship was built mid 1980's (Figure 24).

General description

This vessel is designed as a motor tanker for chemicals and oil products. Cargoes for IMO "IBC" code ship 2/3 can be carried in twenty centre tanks of acid resistant steel in quality AISI 316 LN. In the wing tanks, coated with zinc silicate, oil products and solvents in the range of tank coating resistance and IMO 3 regulations can be carried.

Ship and machinery are built under survey of Lloyd's Register of Shipping and she has the notation 100 A1 Chemical tanker, oil tanker.

It is a single screw motor vessel. The engine room and all accommodation are arranged aft.

Each cargo tank is served by a hydraulically driven submersible pump.

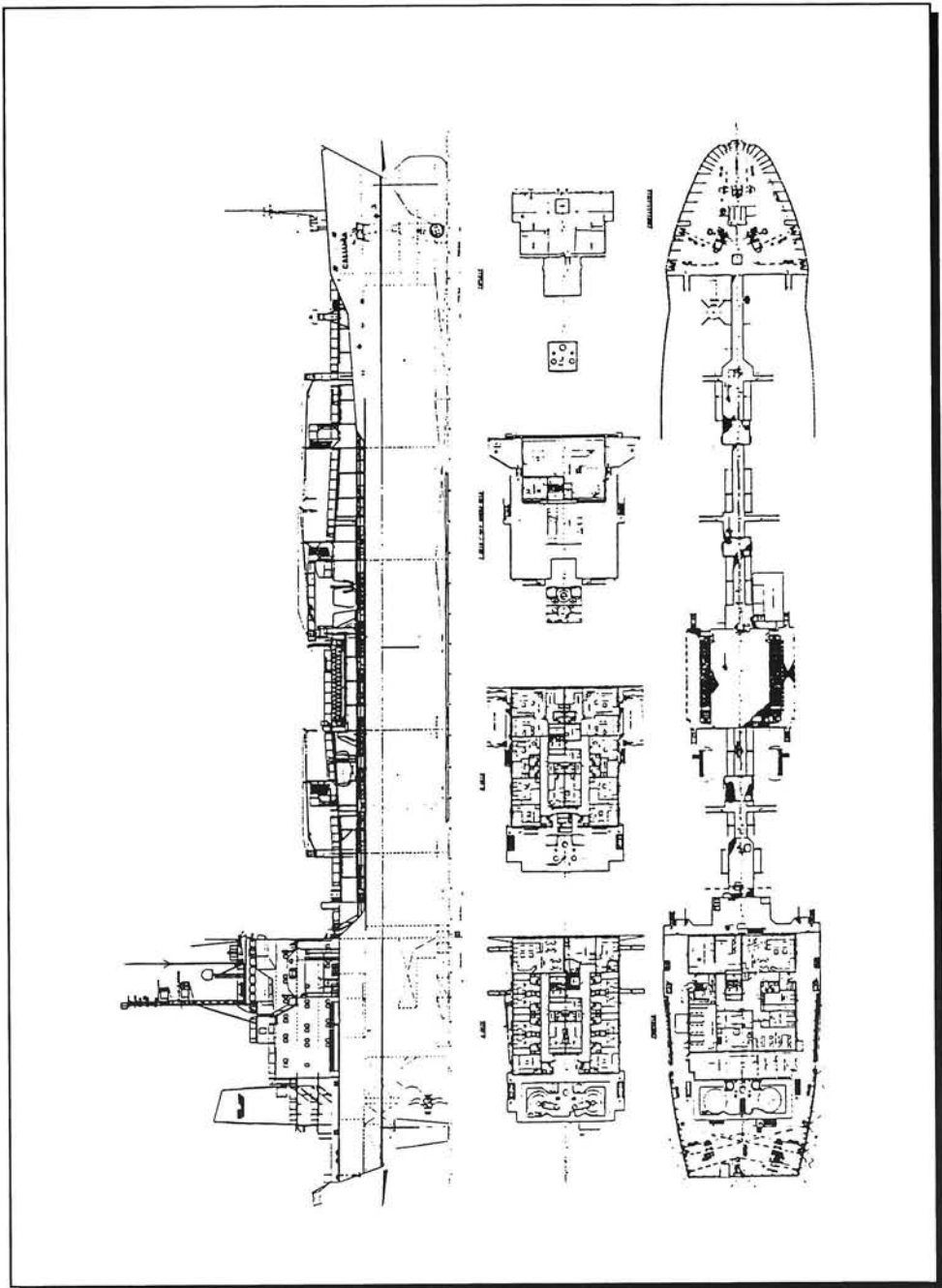


Figure 24: General arrangement, 12,000 dwt ship

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

Principal dimensions

Length over all	136.46	m
Length between PP	124.95	m
Breadth moulded	20.60	m
Depth moulded to main deck	10.70	m
Draught to summer load line	8.42	m
Deadweight on summer load line	12185.00	mt
Trial speed	14.10	knots

Important equipment

The main engine is of 4 - stroke cycle, non reversible, turbo charged, and Stork Werkspoor design. MCR is 4100 kW at 580 r.p.m.

Two oil fired boilers with a steamcapacity of 10000 kg/h of 10 bar each. One exhaust gas boiler with a capacity of 1.5 ton/h.

Two auxillary engines with a power output of 670 kW at 720 r.p.m. each. One emergency aggregate with a power output of 124 kW at 1800 r.p.m.

One shaft generator of 650 kW is connected to the p.t.o. of the main reduction gear box gives 650 kW at 1200 r.p.m. The shaft generator can run parallel with the diesel driven generators.

Cargo equipment

Each cargo tank is equipped with a separate submerged hydraulically driven centrifugal pump type FRAMO (Figure 25).

22. Type: SD 125 HH063 A325	120 cu.m./h.
6. Type: SD 125 HH090 A325	200 cu.m./h.
2. Type: SD 150 HH125 B330	275 cu.m./h.
1. Type: TK 5	120 cu.m./h.

Pump material is AISI 316 L.

The hydraulic pump aggregates consist of 4 equal aggregates driven by electric motors. Power output is 225 KW at 1785 r.p.m., oil delivery is 540 l/min each.

Feed power packs: 2 electric/hydraulic pumps with a power output of 15 kW at 1760 r.p.m. and an oil delivery of 750 l/min.

The feed power packs are intended for boosting of hydraulic suction oil side to main hydraulic power packs.

WT5P 253	WT4P 348		WT3P 489		WT2P 313		WT1P 414	
		CT6PO 384		CT4PO 384				
CT8P 589	CT7P 458	CT6PI 301	CT5P 917	CT4PI 301	CT3P 168	CT2P 1304		CT1P 815
		CT6SI 292		CT4SI 279				CT1S 825
CT8S 582								
	CT7S 452	CT6SO 384	CT5S 905	CT4SO 384	CT3S 172	CT2S 1315		
WT5S 253	WT4S 348		WT3S 489		WT2S 313		WT1S 414	

Figure 25: Cargo system, 12,000 dwt ship

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

Pilot power packs: 2 electric/hydraulic pumps with a power output of 2.3 KW at 1730 RPM and an oil delivery of 19 l/min. The pilot pumps are intended for control of variable hydraulic pumps on main power packs. Maintaining a pressure of about 4 bar in the hydraulic system when the main system isn't working.

Cargoheating is taken care of by a steam/water system. Each cargotank is equipped with two separate sets of heating coils, which are made of stainless steel 316 L.

A dehumidification/ventilation unit is placed in the forecastle. The mainline on deck is of GRP and has 8 branches to cover all cargotanks with the use of flexible hoses.

Inert gas system: A central nitrogen line is installed on the maindeck with the necessary valves and quick couplings for making connections with the cargo tank venting line by means of a hose. 16 N2 bottles are placed before the accomodation.

The cargo control room is installed in the accomodation and most of the cargo handling operations take place there, by means of the following equipment:

Load master: Integrated tank level gauging, pressure and temperature monitoring control system.

Remote reading of loading and discharging pressure.

Cargo valve control system.

Gas warning system.

Tankcleaning systems and equipment

Two tank wash-systems are installed, one for sea- and one for fresh water. One freshwater and one seawater supply line are incorporated in railingwork on the port and starboard side of the main deck. Sufficient branches are fitted to cover with short hoses all cargo tanks.

Two stainless steel tanks are installed on the main deck, for detergents.

Pumps

40,000 dwt ship:

Hydraulic pump set each:	610	l/min.
Hydraulic pump sets total:	4880	l/min.

Part I: Port Time Analysis of chemical tankers in the port of Rotterdam

Bow thruster:	4400	l/min.
Cargo pump SPS8:	554	l/min.
Cargo pump SDS6:	330	l/min.
Cargo pump SDS5 (150 cu.m./h):	228	l/min.
Cargo pump SDS5 (100 cu.m./h):	179	l/min.
Portable pump TK4:	145	l/min.
Tank cleaning pump 7HF2:	380	l/min.
Tank cleaning pump L11:	175	l/min.
Ballast pump:	256	l/min.
Circulation pump:	23.5	l/min.
Transfer pump:	60	l/min.
Booster pump:	755	l/min.

Under cold climatic conditions the hydraulic oil should be allowed to circulate so that the oil attains a temperature of approximately 40 degrees Celsius before the cargo oil pumps are started.

Pumping operations involving cargoes with high specific gravity or viscosity require high power output, and consequently also higher oil pressure. Maximum oil pressure must not, however, exceed 180 bar at the panel.

12,000 dwt ship

Hydraulic pump set each:	540	l/min.
Hydraulic pump sets total	2160	l/min.
Bow thruster:	2054	l/min.
Cargo pump SD125 (120 cu.m./h):	160	l/min.
Cargo pump SD125 (200 cu.m./h):	242	l/min.
Cargo pump SD150 (275 cu.m./h):	321	l/min.
Portable pump TK5 (120 cu.m./h):	100	l/min.

CARGO TANK CLEANING EQUIPMENT

Cleaning systems exist since the 1960's. At that time Butterworth developed a cleaning system which replaced the handwork. Since that time cleaning is worldwide called "buttering".

The "Butterworth" system consists of a machine which turns around its axis and whereby the nozzles make circular movements perpendicular to the machine's movements.

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

The speed of the movements is controlled by cogwheeltransmission in the machine. The drive of the nozzles is done with the help of the cleaning medium, by pressing it through the machine with a certain pressure.

In the seventies there has been a lot of research for new cleaning systems. There were some interesting new systems developed but none of them was a commercial success.

These days the "old" Butterworth system is still used, although the system is now much more advanced.

The use of cleaning systems is nowadays the last step in the cleaningproces of the cargo tank. The cargo tank has to be emptied with the use of "efficient stripping and pumping" until it is environmentally clean. After that the tank can be cleaned (if that is allowed) at sea where the amount of cleaning water isn't that important anymore.

In certain cases, where prewashing is required and in the case of return cargo, the efficient use of cleaning water is very important in order to reduce the amounts of slops.

Both the ship types use the Toftejorg standard tankcleaning equipment (Figure 26).

TERMINALS

In the port of Rotterdam there are two types of terminals for chemical tankers. Production terminals and transshipment terminals. Examples of the first type are Dow, Shell, Esso and BP. Examples of the second type are the Nieuwe Matex Botlek, TTR Botlek, Paktank Botlek and various others.

This results in a different approach to the chemicaltankers from the terminals. The transshipment terminals almost always allow board/board handlings during terminal handlings while the production terminals almost never allow this.

Also the number of cargoes that can be handled simultaneously by the terminals varies. Production terminals only have one or two load and or discharge lines. There is however an exemption, for instance Dow Botlek can handle up to 8 parcels at the same time; TTR Botlek can handle up to 3 parcels at the same time and the NMB can handle 4 parcels simultaneously.

Some terminals also allow interjetty handlings to take place. Figure 27 shows the major terminals in Rotterdam.

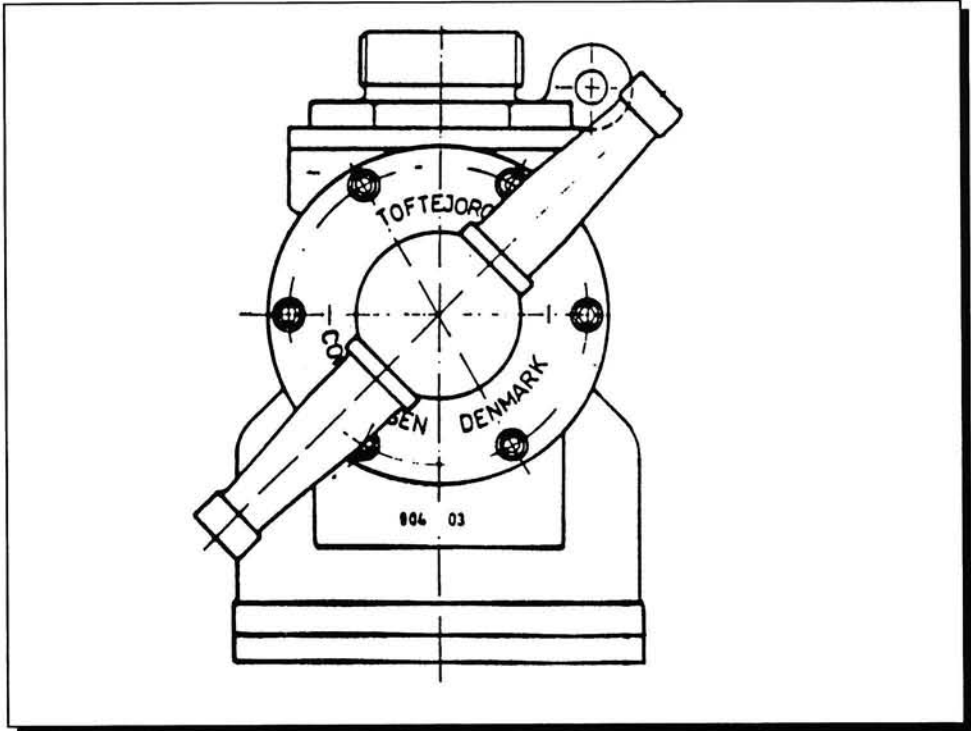


Figure 26: Tank cleaning equipment

SURVEY COMPANIES

Surveys have a big impact on the duration of the port stay. What are the reasons for these excessive analyses?

- * The survey companies are under a lot of pressure from the cargo owner and the transporter to do their work right. In order not to fail they don't make quick decisions but do their work very thoroughly.
- * The laboratories which the surveyors use to test the samples, are a half hour drive from the port of Rotterdam. However on certain days and at certain times there are a lot of traffic jams resulting in excessive time losses.

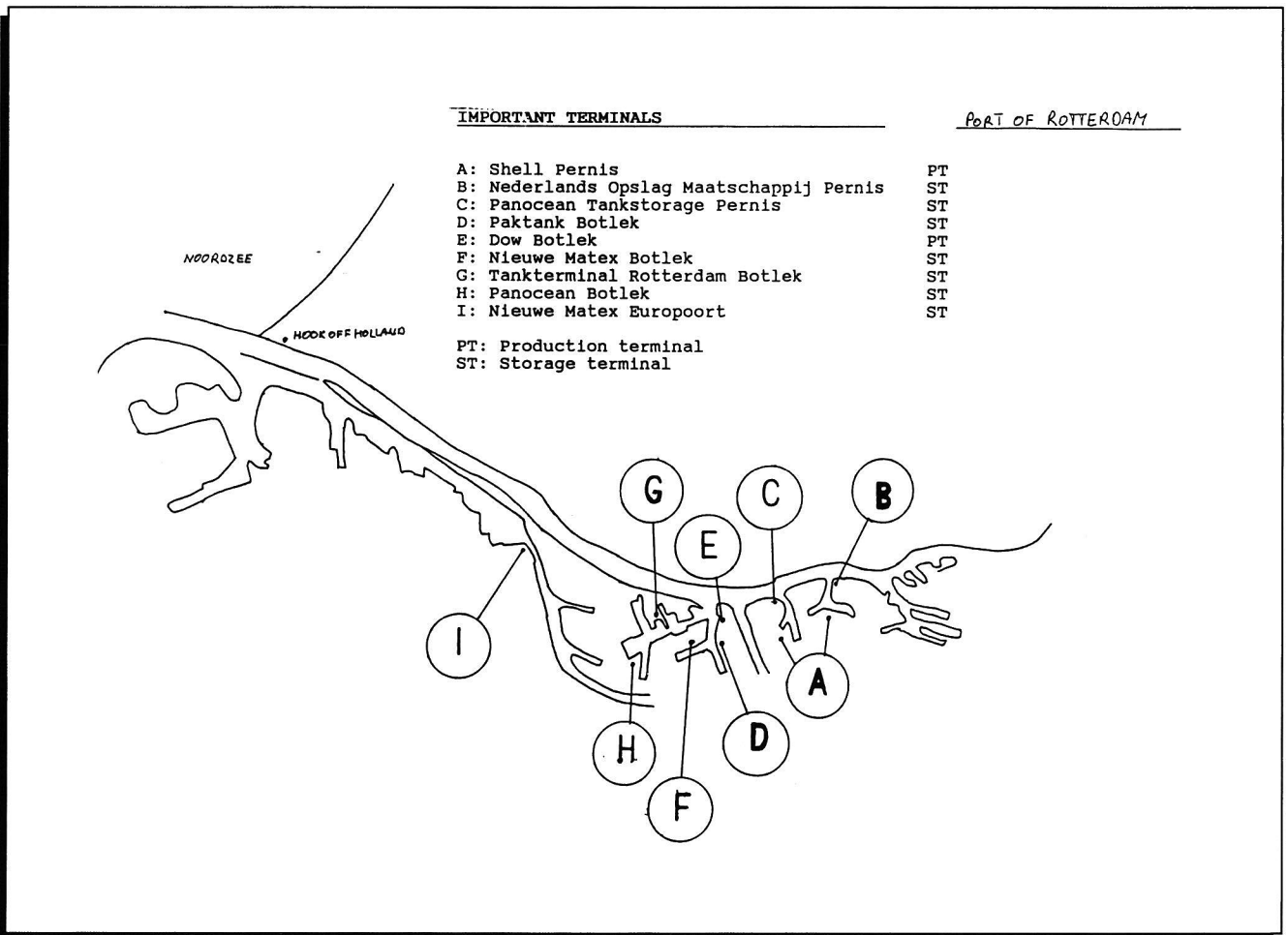


Figure 27: Overview of the terminals in the port of Rotterdam

CHAPTER 5: PORT TIME PROGRAM.

PROGRAM OUTLINE

To obtain a tool to plan port stays in advance, to compare different port stays and to analyse the factors leading to long port stays, a port time program has been developed. The program is made for two ships types, a 40,000 dwt ship type and a 12,000 dwt ship type. The model is calibrated for the port of Rotterdam. The values which are stored in and used by the program are determined by analysis of port calls or from the ship type particulars.

PROGRAM CONDITIONS

In order to analyse a port stay it is decided that the sequence of the terminal-calls will not be changed by the program to optimize the port time. The number of different terminals that can be put into the program is limited to nine, which in almost all the cases will be sufficient.

This approach is not the case with the products handled per terminal; the program will look for the optimal sequence of handlings in order to optimize the time spent at the terminal. The pump capacity of the terminals and the barges/coasters is a given fact, it will not be corrected for the specific gravity of the handled product because there isn't enough information on that subject available.

The number of products that can be handled per terminal is limited by the program to fifteen which will be enough in almost all the cases. The number of products which can be handled simultaneously varies per terminal.

The program assumes that all the cargopumps (with a maximum of ten) can be run at full capacity. It also assumes that there are no shore stops due to leakage or other incidents. It supposes that barges arrive on time and that there are no timelosses due to excessive analysis.

The program uses a lot of information from practical experience in which sometimes timelosses are incorporated, this is not entirely true but all in all the program assumes that the conditions are ideal for the ship.

The programming language and structure

The port time program is written in Turbo Pascal, as it is an easy to learn language, it has a clear structure and uses a lot of elements also used in other languages.

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

Turbo Pascal is a compiler, a disadvantage of a compiler is that the user of the program has to wait until his program is translated before he is able to use it. The big advantage of a compiler is that after the program is translated it runs much faster than a program that has to be interpreted.

The structure of the port time program (Figure 28) consists of five individual parts.

1. Input module.
2. Procedures.
3. Database.
4. Main program.
5. Output module.

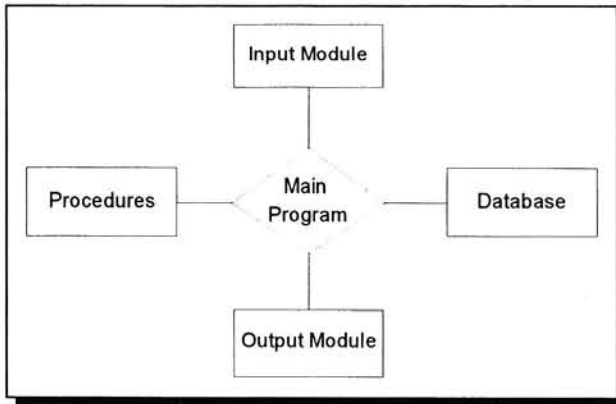


Figure 28: Structure of the port time program

The program starts with the input module, in this part all the relevant input is asked. This input is then later used by the main program to perform its calculations. After all the relevant input has been entered, the program starts performing its calculations in the fourth module, the main program.

The main program calculates the different terminal times with the help of the database and the procedures. After all the calculations have been done the program switches to the last part, the output module, which shows the end results to the user of the program.

Input module:

The flow diagram of the input module (Figure 29) asks a number of questions to obtain all the necessary data for the main program. After a choice is made about

Part I: Port Time Analysis of chemical tankers in the port of Rotterdam

the type of ship it starts to ask for the number of terminals that will be visited by that ship.

Then it asks per terminal, the name of the terminal, the number of commodities handled at that terminal, if board-board handlings are allowed at that terminal, if loading and discharging simultaneously is allowed at that terminal.

Then it asks per commodity the name of that commodity, the quantity of that commodity, the tanknumber of the tank in which it is handled, the specific gravity of that commodity and if it is loaded or discharged.

After all this information has been entered into the program it will start with the main program.

The procedures

The main program uses five procedures for its calculations. Four of these procedures are used for determining the optimal sequence of handlings of commodities at a terminal. One procedure is used to correct the pumpcapacity for the specific gravity of the product that has to be pumped.

- * Procedure 1: This procedure is a sorting procedure, it makes use of the straight insertion method. This is not the fastest sorting method but it uses a straight and easy to understand method.
- * Procedure 2,3 and 4: These procedures determine the maximum or minimum of two figures. There are more of these procedures because the program works with different kind of variables which need different procedures. The main program uses these procedures to attain the optimal turnaround time at a given terminal.
- * Procedure 5: This procedure corrects the pumpcapacity of the tank with the specific gravity of the product that has to be pumped from that tank. It uses the pumpcharacteristics for that task.

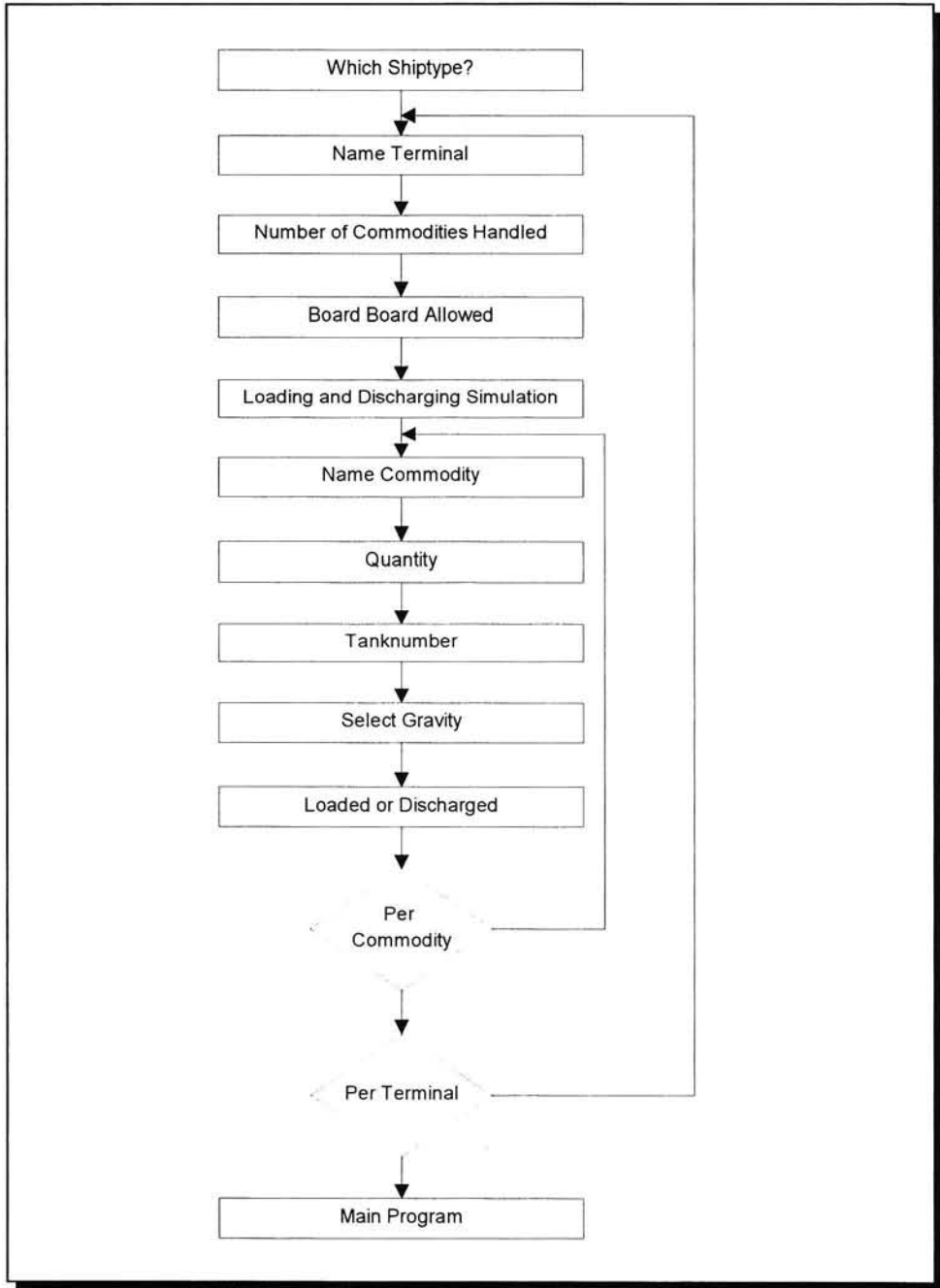


Figure 29: Flow diagram of the input module

The database

The main program uses a number of different databases:

1. Shifttimes between terminals;
2. Pumptypes per tank;
3. Pumpcapacities of the terminals;
4. Pumpcapacities of the barges/coasters;
5. Number of commodities that can be handled simultaneously;
6. Number of barges allowed alongside;
7. Cleaning times.

These databases are used by the main program to determine the optimal terminaltime and overall port time.

The main program

The main program starts to calculate (Figure 30) per terminal per commodity the net discharge or load time. To do this it uses data from the input module and database 2, 3 and 4 and it uses the specific gravity procedure. To obtain the gross load or discharge time, the hose connect time and the hose disconnect time have to be added with the net load or discharge time. The same calculation is then done for the barges and coasters.

After all these calculations have been made the program sorts these gross times per terminal by using the sorting procedure. The next step is to calculate the optimal terminaltime per terminal for which the program uses the maximum/minimum procedures.

After this has been done for all the terminals, the program determines the total port time by adding up the terminaltimes with the shifttimes.

The output module

The output module shows the calculated times to the user of the program so he or she is able to use them.

Per terminal, per commodity the output module gives the hose connection time, the pumptime (loading or discharging), the hose disconnecting time, the cleaning time and the pumprate of the ship (only when discharging). These figures are also displayed in a bar graph.

The output module also shows the terminal time and barge time at every terminal visited. The total time in port and the total shifttime are also shown.

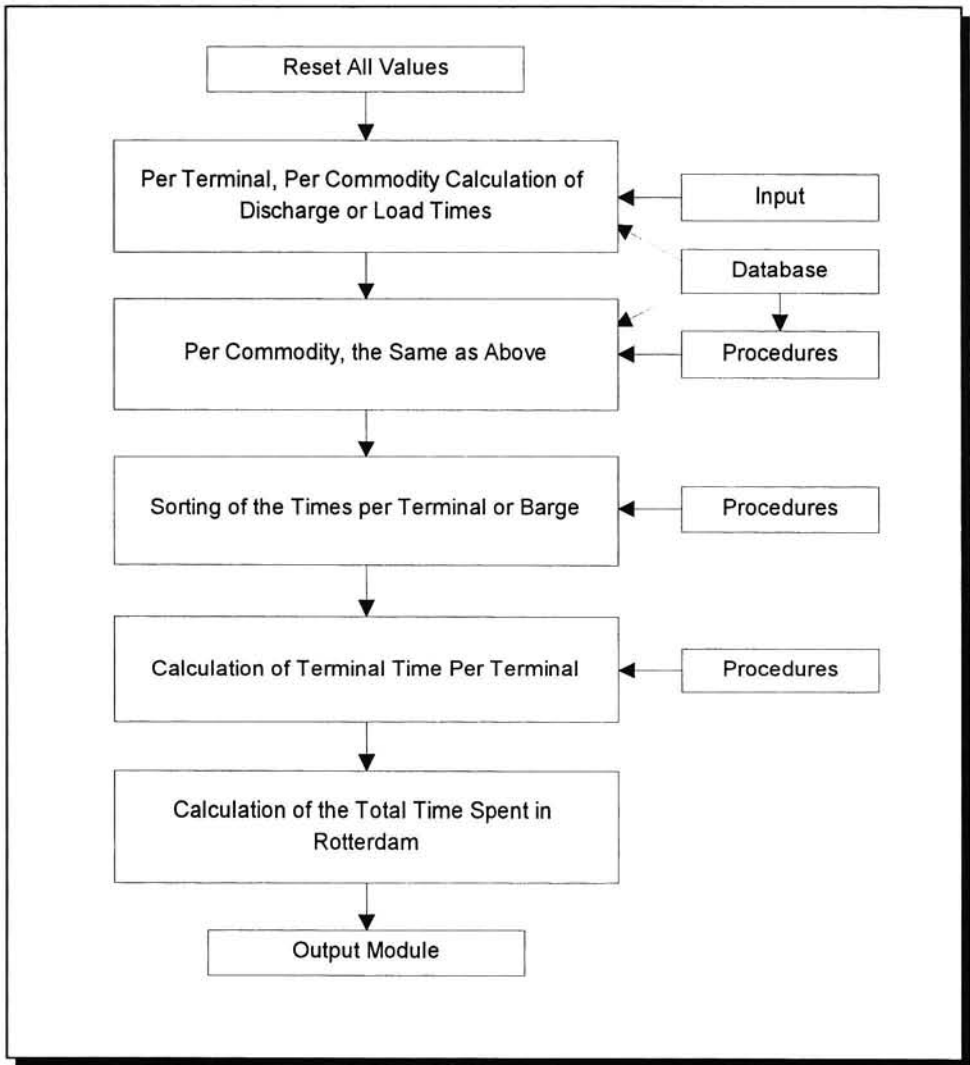


Figure 30: Flow diagram main program

CHAPTER 6: PROGRAM RESULTS

In this chapter the results of the port times of four port calls, actually performed by the ship, will be shown. These results will be compared with the actual port times and the results of that comparison will be analysed. Two of the port calls will be of a 40,000 dwt ship type and the other two will be of a 12,000 dwt ship type.

40,000 DWT SHIP PORT TIME RESULTS

The first port call

The ship visited seven terminals in Rotterdam, handled eight barges/coasters and 34 parcels. Discharged 33,476 metric tonnes and loaded 16,666 metric tonnes. In the following overview (D) means discharged and (L) means loaded.

First terminal: TTR Botlek		
Operation	Commodity	Quantity (mt)
Shore (D)	Aniline oil	2,500
Board/b (D)	Trichloethylene	1,050
Board/b (D)	Methy. chloride	1,017

Second terminal: Dow Botlek		
Operation	Commodity	Quantity (mt)
Shore (D)	MEA	529
	DEA	525
	TEA 85	359
	Prop. Glycol	1,875
	Dowfroth	211
	Ethy. Glycol	1,591
	Glycerine	525
	AEAA	199
	Hydroxyethyl acr.	125
	Prop. Glycol	230
	Versene 100	420
	Versenex 80	315
	ECH	903
	MDEA	210
board/b (D)	TCE	525

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

Third terminal: Panocean Pernis		
Operation	Commodity	Quantity (mt)
Shore (D)	Fishoil	4,900
	Fishoil	999
	Fishoil	3,998
	Cornoil	950
	Cornoil	1,050
Board/b (D)	Ethanol	2,176

Fourth terminal: Paktank Botlek		
Operation	Commodity	Quantity (mt)
Shore (D)	Ethanol	1,233
Board/b (L)	Ethyl acetate	500

Fifth terminal: Nieuwe Matex Botlek		
Operation	Commodity	Quantity (mt)
Shore (D)	Toluene	4,007
Shore (L)	Ethanol	1,921
Board/b (L)	Methyl ethyl ketone	502

sixth terminal: Buoys 61		
Operation	Commodity	Quantity (mt)
Board/b (D)	Ethanol	1,050
Board/b (L)	Acetic acid	900
	Formic acid	505
	Propionic acid	300
	Iso propyl acetate	239

Seventh terminal: Nieuwe Matex Europoort		
Operation	Commodity	Quantity (mt)
Shore (L)	Jet fuel	9,699
Board/b (L)	Creosote oil	2,101

Part I: Port Time Analysis of chemical tankers in the port of Rotterdam

With the port time program the theoretical terminal times are calculated with the use of this information.

The actual terminal times differ significantly from the theoretical terminal times as can be seen in the **Table I**.

Terminal		Theoretical time (hours)	Actual time (hours)	Difference (hours)
1.	TTR	8.1	17	8.9
2.	DOW	16.7	26	9.3
3.	POP	20.3	31	10.7
4.	PTB	8.9	16	7.1
5.	NMB	16.7	25	8.3
6.	BOY	9.5	44	34.5
7.	NME	20.9	47	26.1
Total		101.1	218	116.9

Table I: Overview terminal times

The actual port time is 115 percent higher than the theoretical port time (**Figure 31**).

Figure 32 shows that at the first five terminals the lost time per terminal was almost equal (about nine hours). At the last two terminals a lot of time was lost. The reason for this might be that the problems accumulate during the port call resulting in extra time losses at the last terminals. Other reasons for this could be that the crew gets tired after a few days in port resulting in extra time losses.

By closer investigation of the port report of this port call it was found that 59 hours of the 116.9 lost hours could be accounted for. That leaves 57.9 hours of lost time for which no specific reason could be found. These hours must then be the result of slow shore pumping, slow ship pumping and influence of viscosity on pumprate etc..

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

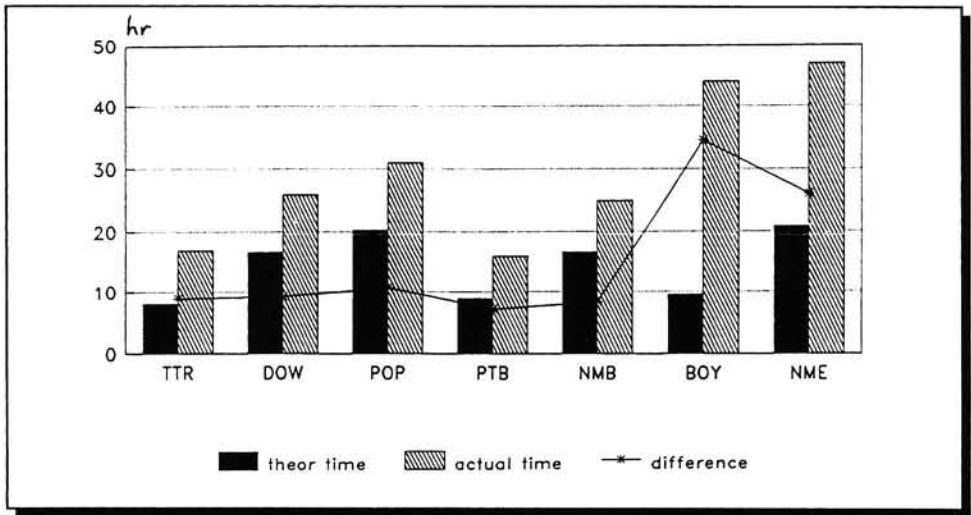


Figure 31: Time loss per terminal, 40,000 dwt ship

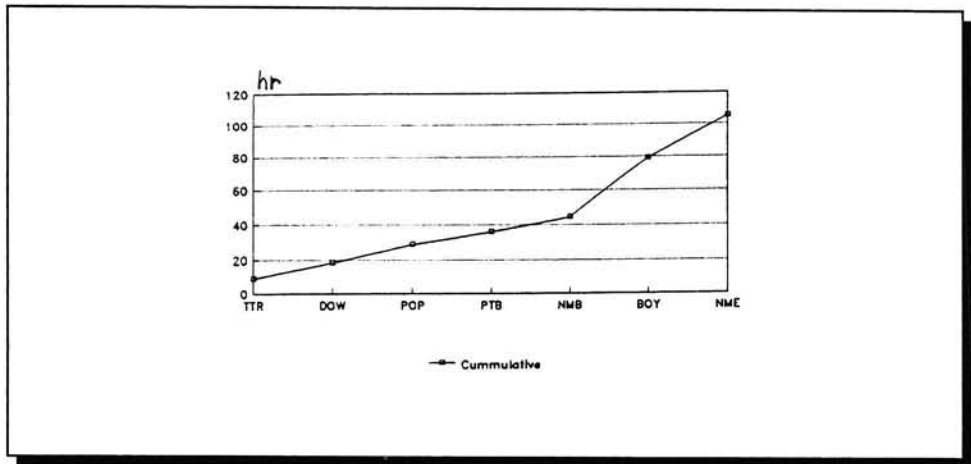


Figure 32: Cumulative time loss per terminal, 40,000 dwt ship

The second port call of the 40,000 dwt ship

The ship visited three terminals, handled 10 barges/coasters and 11 parcels. The ship discharged 200 metric tonnes and loaded 11,343 metric tonnes.

First terminal: Buoy 61		
Operation	Commodity	Quantity (mt)
Board/b (L)	Furfuryl alcohol	529
	Furfural alcohol	563
	Creosote oil	3,400
	Creosote oil	2,100

Second terminal: Panocean Pernis		
Operation	Commodity	Quantity (mt)
Board/b (D)	Molasses	200
Board/b (L)	Acetic acid	999
	Palmkernel stearine	502
	Methyl acrylate	501
	CTC	499

Third terminal: Nieuwe Matex Botlek		
Operation	Commodity	Quantity (mt)
Shore (L)	Ethanol	1,500
Board/b (L)	Butanediol	750

With the port time program the theoretical terminal times are calculated using this information. As can be seen in **Table II**, the theoretical and actual terminal times are very different. The actual port time is 36.6 percent higher than the theoretical port time.

Terminals 2 and 3 both have a lost time of about 12 hours (**Figure 33**), which looks similar to the losses of the first five terminals in the first port call.

The first terminal is a special case. At this terminal four barges had to pump cargo into the ship. The program has a limitation of two parcels handled simultaneously from barges into the ship. In this case however there were more parcels handled simultaneously resulting in a faster terminaltime.

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

Terminal		Theoretical time (hours)	Actual time (hours)	Difference (hours)
1.	BOY	9.0	18.8	9.8
2.	POP	8.0	10.0	12.0
3.	NMB	5.0	17.0	12
Total		22.0	55.8	33.8

Table II: Overview terminal times

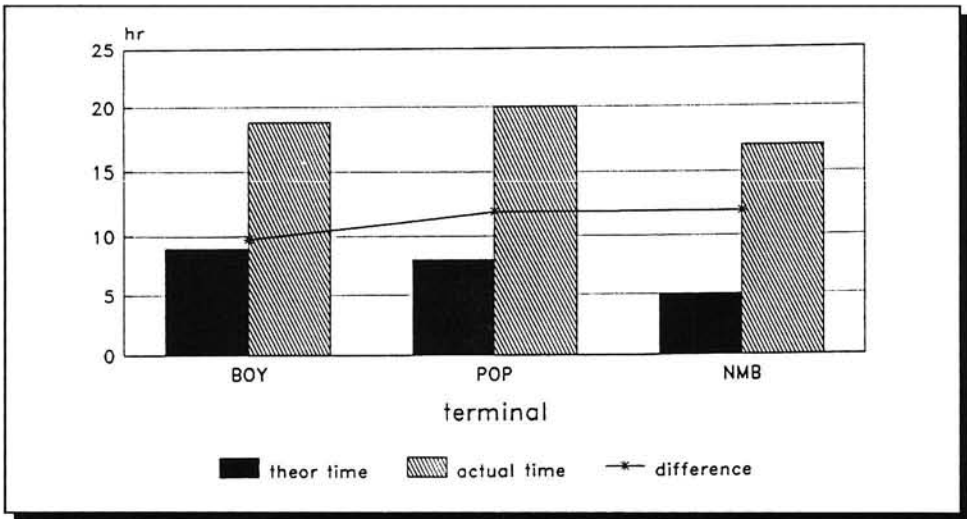


Figure 33: Time loss per terminal, 40,000 dwt ship

However the end result is still very obvious. A lot of time is being lost. Closer examination of the port report showed that waiting for barges was the main cause for these time losses.

Part I: Port Time Analysis of chemical tankers in the port of Rotterdam

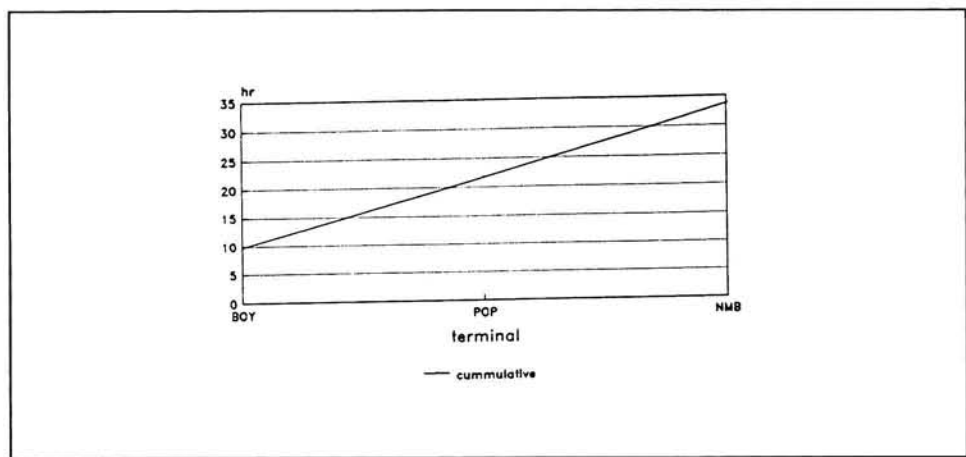


Figure 34: Cumulative time loss per terminal, 40,000 dwt ship

THE 12,000 DWT SHIP

The first port call

The ship visited seven terminals handled nine barges/coasters, one truck and 20 parcels. The ship discharged 7324 metric tonnes and loaded 9125 metric tonnes. In the following overview (D) means discharged and (L) means loaded

First terminal: TTR Botlek		
Operation	Commodity	Quantity (mt)
Shore (D)	MBTE	7,324
Board/b (L)	MMA	194

Second terminal: Panocean Botlek		
Operation	Commodity	Quantity (mt)
Board/b (L)	Glycerine	200
Shore (L)	Parafine	250

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

Third terminal: Panocean Rozenburg		
Operation	Commodity	Quantity (mt)
Shore (L)	Reofoss	500

Fourth terminal: Paktank Botlek		
Operation	Commodity	Quantity (mt)
Shore (L)	Heptasol	962
Board/b (L)	Whiteoil	420
	Whiteoil	410

Fifth terminal: Shell Pernis		
Loaded	Commodity	Quantity (mt)
Shore (L)	Poly Ethylene Glycol	100
	IPA	123
	MEK	116
	ECH	96
	Butyl oxitol	246
	Tri oxitol	198
	SBP	100
	Shellsol T	200

Sixth terminal: Panocean Pernis		
Operation	Commodity	Quantity (mt)
Shore (L)	Rapeseedoil	3,000

Seventh terminal: DOW Botlek		
Operation	Commodity	Quantity (mt)
Shore (L)	MEC	315
	Chlorothene	259
Board/b (L)	Styrene monomer	1,136

With the port time program and this information the theoretical terminal times are calculated.

Part I: Port Time Analysis of chemical tankers in the port of Rotterdam

Table III, Table IV shows a big difference between the actual and the theoretical terminal times.

Terminal		Theoretical time (hours)	Actual time (hours)	Difference (hours)
1.	TTR	20.0	45.0	26.0
2.	POB	2.5	9.0	6.5
3.	POR	2.5	7.3	4.8
4.	PTB	3.4	14.0	10.6
5.	SHE	3.8	16.0	12.2
6.	POP	7.5	16.1	8.6
7.	DOW	3.6	23.5	19.9
Total		40.8	132.4	91.6

Table III: Overview terminal times

The terminals with the most lost time are terminal 1 and 7 (**Figure 35, Figure 37**). The reason for terminal one might be that almost the whole ship had to be discharged at this terminal, usually that can be done through four shore connections but in this case, after reading the port reports, it is not certain if that was allowed the whole time.

The reason for the big time loss in terminal seven is the long waiting times for barges/coasters. Closer investigation showed that waiting for barges/coasters and waiting for ready berths were the main reasons of the time losses.

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

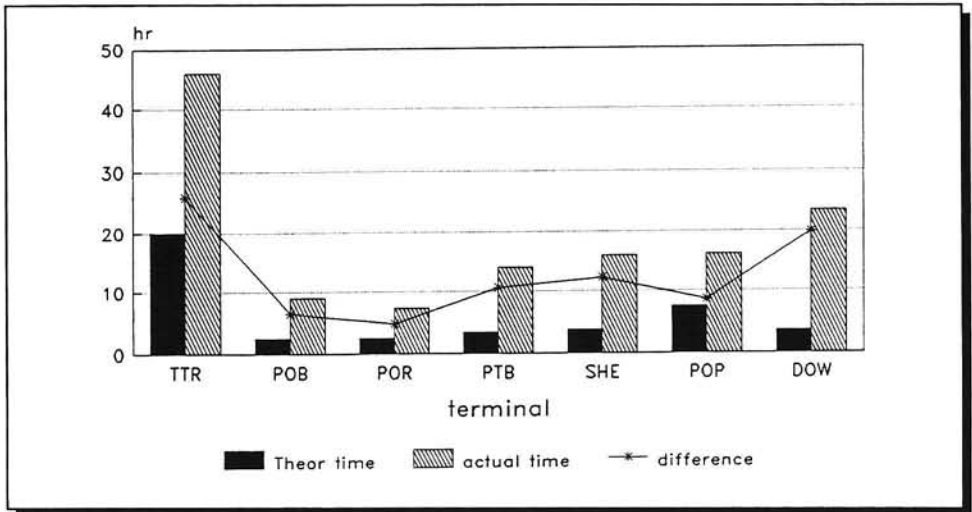


Figure 35: Time loss per terminal, 12,000 dwt ship

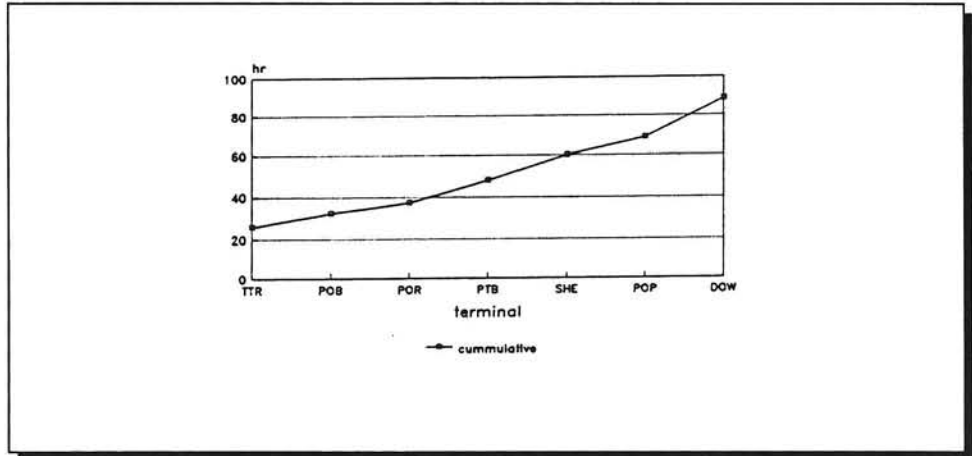


Figure 36: Cumulative time loss per terminal, 12,000 dwt ship

The second port call of the 12,000 dwt ship

In this port call the ship visited four terminals and handled six barges and 13 parcels. The ship discharged 4307 metric tonnes and loaded 8495 metric tonnes.

Part I: Port Time Analysis of chemical tankers in the port of Rotterdam

First terminal: Panocean Pernis		
Operation	Commodity	Quantity (mt)
Shore (D)	MTBE	3,789
Board/d (D)	Groundnutoil	518
Board/b (L)	White oil	500

Second terminal: Shell Pernis		
Operation	Commodity	Quantity (mt)
Shore (L)	Aviation gas	4,000
	Aviation gas	700
	B oxytol	100
	Caradol	300
Board/b (L)	Dobane	150
	Sap1163	100
	Sap2064	200

Third terminal: Nieuwe Matex Botlek		
Operation	Commodity	Quantity (mt)
Shore (L)	Paranox	272

Fourth terminal: TTR Botlek		
Operation	Commodity	Quantity (mt)
Shore (L)	Mono propylene glycol	523
Board (L)	Lub add	300

With this information and the port time program the theoretical port time has been calculated.

As can be seen in **Figure 37**, there is again a lot of difference between the theoretical terminal times and the actual terminal times.

The actual port time is 108 percent higher than the theoretical port time.

Terminal one has a lot of time loss, which may be induced by the number of available shore connections and long waiting times for barges/coasters.

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

Terminal		Theoretical time (hours)	Actual time (hours)	Difference (hours)
1.	POP	18.1	36.0	17.9
2.	SHE	18.0	29.2	11.2
3.	NMB	2.0	12.0	10.0
4.	TTR	2.8	8.0	5.3
Total		40.9	85.2	44.4

Tabel XXVI: Overview terminal times

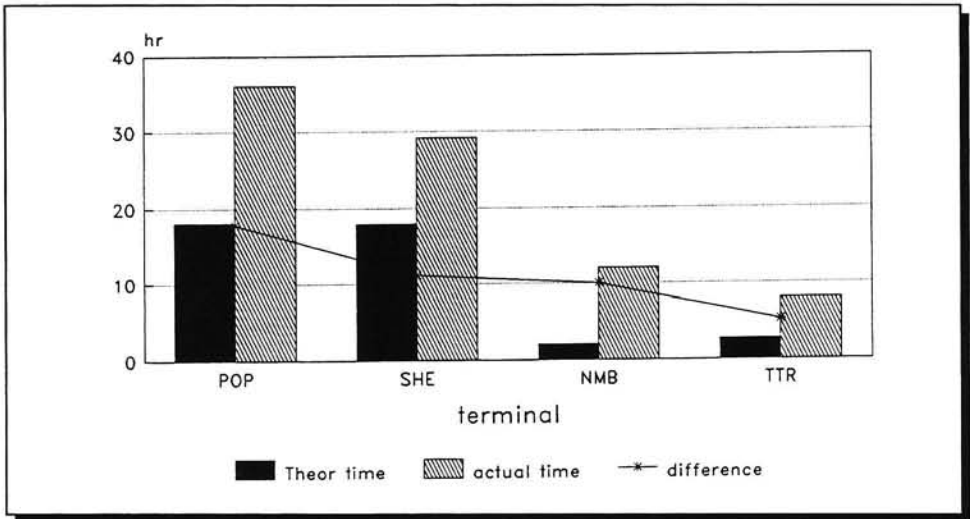


Figure 37: Time loss per terminal, 12,000 dwt ship

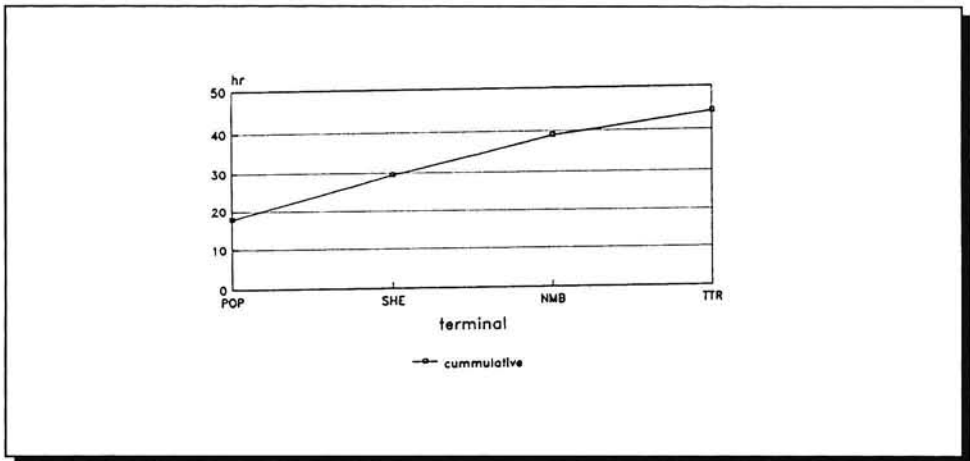


Figure 38: Cummulative time loss per terminal, 12,000 dwt ship

CHAPTER 7: RECOMMENDATIONS AND CONCLUSIONS.

TECHNICAL RECOMMENDATIONS

One of the main reasons for too long port stays is excessive analysis, which is caused by the difficulty of cleaning some of the tanks.

The ability to clean cargo tanks fast and thoroughly will have a big impact on the time lost due to these excessive analysis.

the first step in the cleaning process of a cargo tank is the stripping. When liquid bulk cargo is unloaded, part of it remains in the tanks, pumps and piping.

These residues occur because:

- * They stick to the tankwalls;
- * The tanks are insufficiently emptied.

These residues are undesirable because:

- * They represent a financial loss to the owner;
- * They cause environmental pollution when discharged into the sea;
- * During the subsequent washing process the quantity of washing water needed will be very large, resulting in long washing times.

There are two systems that have been developed to reduce the amount of residue even further:

- * The Allweiler Houttuin system;
- * The Marflex system (Figure 39).

At present there is scarcely any market for these second generation efficient stripping systems. However, these systems, when installed, will have a positive effect on the time lost due to excessive analyses.

The second step and usually the last in the cleaning process of a cargo tank is the tank washing. There are two specific terms which define the cleanliness of the tank, 'Product Clean' and 'Environmentally Clean'. 'Product Clean' means that the tank is cleaned to the extent that it complies with the high standards imposed by the cargo owner in relation to cargo contamination. 'Environmentally Clean' means that the tanks are sufficiently clean to allow the washing water to be discharged at sea.

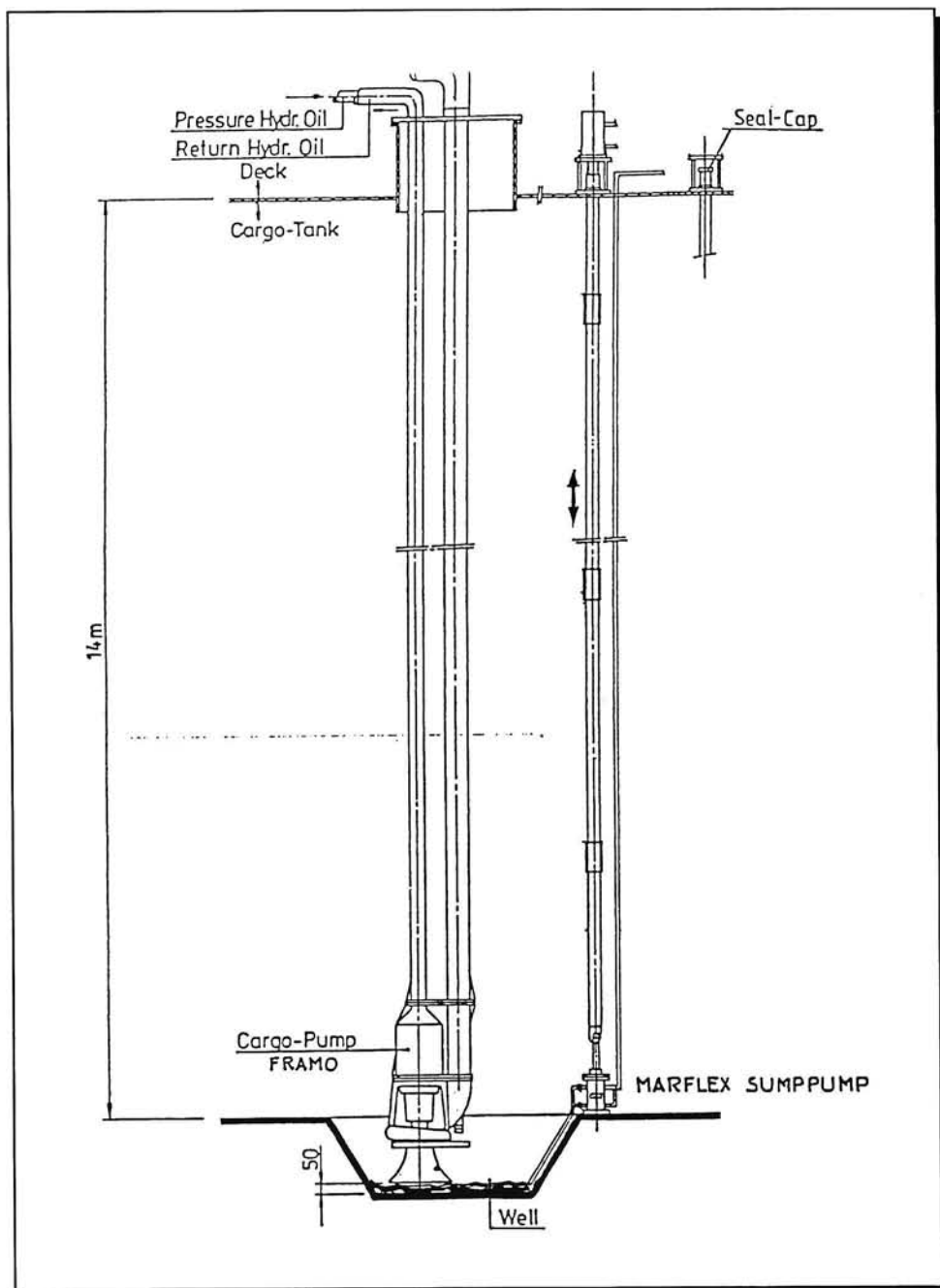


Figure 39: Marflex system

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

The washing time is prescribed by referring to the concentrations of product residues in the prewashing water. This procedure has the following drawbacks:

- * The concentration has to be determined by means of an analysis carried out in a laboratory, which is time consuming and thus causes delay; for this reason a standard prewashing is often allowed.
- * The concentration is no guarantee for the cleanliness of the cargo tank, since sticky deposits may still be present.
- * Furthermore, the inspection results of the surveyor who has to approve the tank are not always consistent; since a supplementary main washing is often prescribed, the crew often uses an excessive amount of washing water in an effort to prevent this.

In recent years there have been no major developments as regards the washing procedure used in practice. There are however some interesting research projects involving washing procedures. One project achieved a reduction of washing water of 40 percent.

The manufacturers of washing equipment are continually making alterations and adjustments to their machines. These developments, which are made within the constraints of the 'old' concept of the existing washing machine include:

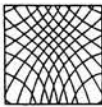
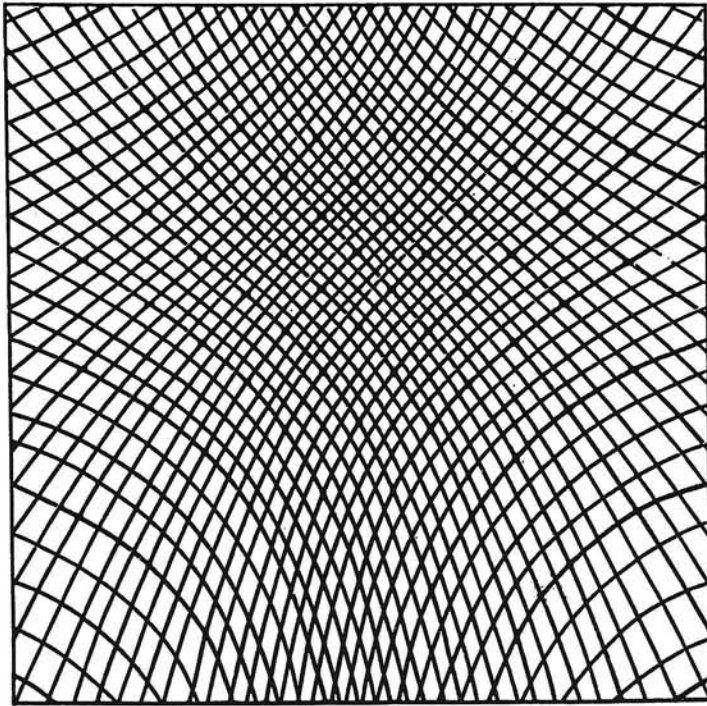
- * Application of corrosion resistant materials;
- * Optimisation of the nozzles in order to maximize the impact of the water on the wall;
- * Improvement of the cleaning pattern (**Figure 40**).

Ways to reduce excessive analysis:

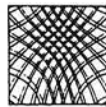
- * Adjustment of tank washing equipment to meet the requirements of the product;
- * Paying more attention to the proper selection of nozzles, rotors and toothed wheels for existing washing machines with specific cleaning problems.

EVALUATION OF WASHING RESULTS

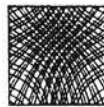
- * Formulation of a pragmatic definition of the term washing result should be made;
- * Formulation of a definition withing a MARPOL product category or groups of products which have comparable washing characteristics;
- * Establishment of a standardised testing procedure linked to MARPOL.



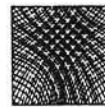
1/4 Cycle Time



1/2 Cycle Time



3/4 Cycle Time



1 Cycle Time



Figure 40: Cleaning pattern

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

MEASUREMENT OF TANK CLEANLINESS

The completion of the washing process is at present determined by the concentration of the substance to be removed in the washing water (the 'Environmentally Clean' criterion). In addition, the surveyor decides whether the tank is 'Product Clean', often by means of chemical analysis.

Both methods have their drawbacks:

- * The Environmentally Clean test is an indirect method; it provides no guarantee that the tank is actually clean;
- * The Product Clean test is often time consuming and expensive.

The development of methods/equipment which can measure the pollutions on the tank wall is regarded as very desirable. It is expected that robotics will be able to play a role here. One possibility would be a surveillance robot, which could scan the tank wall. The parts off the wall identified by the robot as still being dirty could then be cleaned by the the tank washing machine. It might also be possible for the washing machine to be controlled by the robot.

With improvements on measuring techniques the number of washing cycli could be reduced, leading to shorter port times. The lack of practical and reliable measuring equipment results in the fact that improved washing techniques do not directly lead to a reduction of the quantity of wash water.

A higher washing water temperature can in principle lead to less slops per cargotank. A reduction of the amount of wash water can be attained by using smaller tank washing machines. Many shipowners already employ machines with 8 mm nozzles instead of 11 mm. What has to be aimed at in developing smaller nozzles is to obtain a water jet range which remains the same or which is adequate, but needs less water

Coating materials with better properties have to be developed as well.

SHIP/TANK DESIGN AND CONSTRUCTION

The final effect of these measures will pay off only in the medium long term, when ships have been adapted or built accordingly to the latest views. In recent decades the shipbuilders and shipowners have been creative in seeking new ways of complying with the increasingly stringent regulations and specifications.

The amount of time spent washing is extremely dependant on the design and construction of the cargo tank. In recent years, there has been a trend toward tanks that are free of internals, such as structural parts and heating coils. Internal free tanks can be stripped and cleaned more effectively with a centrally

Part I: Port Time Analysis of chemical tankers in the port of Rotterdam

placed washing machine. New regulations on double skins can also have a big impact on the subject.

In general the better the washing and measuring techniques, the faster a tank can be cleaned and inspected. Also the number of times a tank is rejected will diminish.

In the case of newbuildings the installation of deck mounted self cleaning tank-wash equipment could lead to better cleaning results. The reason that most of the chemical tankers use the portable equipment is its flexibility. The costs of a portable tankcleaning system is about NLG 225,000, the costs of a deckmounted system is about NLG 1,000,000. The advantages of the deck mounted system are however its higher wash effectivity, therefore its cleaning time is shorter, compared to a portable system. This may result in a portable cleaning time which is two times as high as the cleaning time with a deck mounted system.

The manpower needed with a portable system is higher than with a deck mounted system.

If there is a lot of rain it is very difficult to dry the cargo tanks on the big ships. In order to improve this, better drying equipment could be installed.

THE MANIFOLD

The overall layout of the manifold is practical, however some small adjustments might be of help with the hose connecting and disconnecting handlings.

The shape of the flanges is made in such a way that 12 bolts are needed to fasten them; these bolts have nuts on both sides which require both hands to fasten. If there could be a way to construct these flanges differently so one needs only one hand to fasten them and with lesser bolts and still fullfil strength and universal requirements, this could be a way to shorten the connecting time of the hoses and to lower the working pressure on the crew.

A standardization of equipment on all ship types could also be helpful to reduce lost time in casses of equipment failure.

OPERATIONAL RECOMMENDATIONS

Because of the high work pressure on the crew it might be interesting to look at different ways of manning a ship. If it would be possible to divide the crew of a chemical tanker into a sailing, maintenance crew and a port crew maybe considerable gains can be achieved in the port times.

At the moment there is a port coordinator assisting some of the port calls. This is felt by the crew and others as an increase of the ship's productivity in port.

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

The sailing, maintenance crew should have a basic knowledge and some experience on discharging and loading cargoes. They should be able to clean tanks during a trip.

The port crew will come onboard the ship at the main loading/discharging regions (Rotterdam, Houston) and will handle all the cargo-handlings and cleaning operations.

This is maybe a too big financial burden for one shipowner alone, so a port crew pool might be established with other ship owners.

A reduction of the amount of activities which take place in Rotterdam can also lead to better performance of the ship. Never change crews or part of the crew (chief officer) at the start or during the port stay in Rotterdam. The crew which loads a particular cargo has a lot of information about that cargo, which is not always written down, so by changing the crew before discharging this can lead to unforeseen problems.

A small laboratory which can be moved from one berth to another (on a truck), which can be used by the surveyors to perform their analyses, could lead to less time losses and might speed up the time used for analyses.

A reduction of the number of berths visited in one port call will also reduce the time lost in port. This is of course difficult to achieve in the chemical trade. It might be interesting to give the chartering department a tool in which they can see what the influence of an extra berth on the port costs and the ship's performance are. Cargoes with a bad cleaning reputation should also be avoided as much as possible. The negative effects on the cleanliness of the cargo tank can have a big influence on the ship's performance in consecutive after that particular cargo was carried.

Sometimes cargo tanks are used to collect slops. When a cargo tank has been filled with a lot of different slops it is very difficult to clean such a tank. Maybe other ways of collecting slops (decktanks) might lead to better results.

The difficulty about this subject is that all the information which needed to see whether certain changes have an influence on the port time are not easily available. All the time measurements which are relevant (e.g. pump time, connect time, discharging time, analysis time, cleaning time, etc.) are recorded by the ship, the agents and the surveyors, but they disappear in a file and are hardly ever used.

Why not connect a time measuring machine to the ship's loadmaster which records and prints all the activities and their times. This reduces the enormous amount of paperwork and the information which is stored on a disk is immediately

Part I: Port Time Analysis of chemical tankers in the port of Rotterdam

ly available for planning and analysis. This system could even be connected to the shipping system which is now used by the shipowner.

CONCLUSIONS

From the analysis there are several conclusions that can be drawn on the subject of long port times.

The main reasons for time losses in the port of Rotterdam are excessive analysis, non available berths, delayed barges, slow shore and low hydraulic pressure.

The excessive analysis are a result of insufficient cleaning of the cargo tanks by the crew, cargoes that are polluted, traffic jams, tough surveyors etc..

The bad cleaning of the tanks can have various reasons like a very tough to clean product that was previously in that tank, a crew that is very busy, bad working cleaning equipment and weather influences (When there is a lot of rain it is very hard to dry the cargotanks).

Non available berths can be the consequence of poor planning, time losses at the beginning of the port call, other vessels occupying the berth etc.

There is a clear difference between the pumprates from the ship into a terminal and from the ship into a barge. The reason for this is not very clear but has to be the result of long lines at the terminal, clogged lines at the terminal, terminal restrictions on pumprate, the siphon effect and sometimes discharging against production.

Due to all these causes of delay the 40,000 dwt ship type loses a total of 26.4 percent of its port time in Rotterdam and the 12,000 dwt ship type, 20 percent.

That is equal to about 3,500 USD lost per day in the port of Rotterdam by a 40,000 ship type and about 1,000 USD per day for a 12,000 dwt ship type and those are only the expenses because of the port stay, the running and capital costs are not incorporated.

On a yearly basis and extrapolated over all the port calls, this means a loss of 500,000 USD (30 percent of the total port expenses) per year for a 40,000 ship type and 140,000 USD (20 percent of the total port expenses) per year for a 12,000 dwt ship type (these are estimates based on the port costs of Rotterdam).

Per year and extrapolated over all the ships in the chemical tanker fleet and based on the port of Rotterdam, the fleet loses 20,500 USD every hour it stays

Part I: Port Time Analysis of Chemical Tankers in the Port of Rotterdam

too long in port. On a yearly basis and an average loss of 23 percent, this amounts to 40,000,000 USD lost per year.

If the lost income is added, the amount of money lost for a 40,000 ship rises to 23,500 USD and for a 12,000 dwt ship to 13,000 USD. That means that every hour a big ship stays longer in port, it loses 1,000 USD and a 12,000 dwt ship 500 USD.

The conclusions that can be drawn from the port time program results in **Chapter 6** are the following:

- * They confirm the previous analysis of the actual port times and even give an indication that there is even more time lost in port than previous analysis suggested.
- * They indicate that due to an accumulation of delays and a rising pressure on the crew and the shore, the biggest delays arise in the last few terminals.
- * The average theoretical time lost per terminal for the 40,000 ship types is 14 hours and if we delete the extreme ones the average is 9.75 hours for the 40,000 ship type. For the 12,000 dwt ship types these figures are 12 hours and 8.6 hours respectively.
- * In practice and compared with theoretical values the 40,000 ship type loses more time and money in the port of Rotterdam than the 12,000 dwt ship type.
- * Overall one can say that there is still a lot that can be done in order to reduce this lost time and by doing that, the costs and the time will not only be reduced but the working pressure on the crew will also be lowered

**PART II - PORT TIME ANALYSIS OF CHEMICAL
TANKERS IN THE PORT OF HOUSTON**

Table of Contents

CHAPTER 1:	INTRODUCTION	70
CHAPTER 2:	PORT CALL OF A CHEMICAL TANKER	73
CHAPTER 3:	DISTURBANCE ANALYSIS	79
CHAPTER 4:	PORT COSTS	95
CHAPTER 5:	MODELING THE ACTIVITIES IN PORT	100
CHAPTER 6:	ARRANGEMENT OF THE INPUT DATA	116
CHAPTER 7:	THE COMPUTER PROGRAM	129
CHAPTER 8:	THE USERS GUIDE	142
CHAPTER 9:	TESTING AND USING THE ROUTE SIMULATION SOFTWARE	153
CHAPTER 10:	CONCLUSIONS AND RECOMMENDATIONS	181

PART II - PORT TIME ANALYSIS OF CHEMICAL TANKERS IN THE PORT OF HOUSTON

CHAPTER 1: INTRODUCTION

THE ASSIGNMENT

This study is the result of a joint project of the departments Logistics headed by Prof.dr.ir. J.J.M. Evers and the department Maritime Business Studies headed by Prof.dr.ir. N.Wijnolst. Both departments are part of the Faculty of Mechanical Engineering and Marine Technology of Delft University of Technology. This assignment is carried out under the authority of a shipping company managing several chemical tankers out of Houston. During this study the client will be referred to as 'the shipping company studied', 'the shipping company investigated' or the company will be mentioned under the pseudonym 'ABC shipping company'.

The main objective of this study is to analyze the port calls of chemical tankers in the port of Houston¹ and successfully implement a tool which can help the operational department of ABC shipping company to limit the time spent in port.

THE BACKGROUND OF THE STUDY

The operational and commercial department of ABC shipping company recognized that their vessels spent a lot of time in port compared to their time at sea. The time the vessels spent in port is considered non-productive. That is why ABC shipping company is interested in a study on the minimization of their port costs. ABC shipping company is especially interested in analyzing the situation in the port of Houston¹ because their vessels are spending most of their time in this particular port.

When a chemical ship, managed by ABC shipping company, visits the port of Houston¹, the vessel will generally load or discharge at about six different terminals. In total there are about 20 different terminals in Houston which handle chemicals for vessels operated by ABC shipping company. Some of the problems are:

1. ABC shipping company can not quantify how much time is lost and what the causes of the delays are². This makes it difficult to find adequate solutions to reduce the time the vessels spend in port.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

2. The chemical tankers often have to wait because a terminal is occupied. If this is the case, the first six hours will be for the account³ of the shipping company investigated.

3. There is no accurate information available about the performance of the different terminals which are visited. This makes the planning of the rotation of the vessels in port difficult⁴.

The situation described above can be different for each terminal. Other factors, such as the possibility to bunker, repair and take in supplies and spare parts are also influencing the time spent in port.

The objective of this study is to make a user friendly operational port call planning model. The model should be able to:

- a. Conduct a pre-planning;
- b. Adjust the planning during the port call;
- c. Make an evaluation of the planning performance;

The information on which the decisions in this model are based, should be quantified in such a way that the simulation matches the real situation as good as possible.

THE APPROACH OF THIS PROJECT

The project is divided into three parts:

1. First the actual situation has to be studied and the causes of delays should be detected and quantified. Based on this information sufficient solutions can be suggested to minimize the port time. Then the required data to implement the chosen solution can be collected;
2. A sufficient user friendly model/tool has to be developed to deal with the problems detected in the first phase of the study;
3. Installation and testing of the simulation model and introducing the software to the users.

The project was conducted during a 6 month period in 1993/1994.

THE CONTENT OF THIS REPORT

This report starts with a brief introduction explaining what happens during a port call of a chemical tanker and which tasks the port agent has to fulfill during the port call (**Chapter 2**). This is concluded with a brief description of the port of Houston¹.

After the two introductory chapters, **Chapter 3** contains the disturbance analysis. This chapter explains why chemical tankers are delayed during port

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

calls. **Chapter 4** explains the economic impact of port delays to the owner/operator of chemical tankers.

Based on the results from the disturbance analysis a scheduling tool is developed for chemical tankers in the port of Houston¹ ('Route Simulation Software'). First in **Chapter 5** the objective of the port planning model is accurately defined and the available input data is studied. Based on the available input information and the objective of the simulation model a modeling approach is suggested. The proposed model is described with the assistance of flow chart techniques and the most important parts of the simulation tool are described in more detail with the process description method [4](**Chapter 5**).

Chapter 6 explains how the input data, gathered in the previous chapter, is transformed into statistics in the 'Route Simulation Software'. The influence of barge traffic in the port of Houston¹ and the flexibility of some terminals concerning cargo handling (flexible terminal layout) is also studied.

Based on the framework of the port simulation model developed in **Chapter 5** and the available statistics (**Chapter 6**), the 'Route Simulation Software' could be developed. **Chapter 7** contains a description of the software. Both the general context of the program and some interesting programming details are described.

Chapter 8 contains the users guide of the 'Route Simulation Software' and **Chapter 9** contains a description of the testing and implementation of the software. Finally, in **Chapter 10** the conclusions are presented. In this chapter the situation in the port Houston¹ is also viewed from a broader perspective resulting in a proposition of how cooperation between the parties involved can reduce port times and consequently make the Port of Houston more cost-efficient and competitive.

Notes

1. Including Texas City and Freeport.
2. Of course the management of the shipping company investigated had a global impression of what reasons of delays existed but management did not have hard facts about this subject available.
3. The charter hire of the vessels managed by ABC shipping company is about US\$9000 a day. Paying for the first six hours results in additional costs of $6/24 \times \text{US\$ } 9000 = \text{US\$ } 2250$.
4. The planning is difficult because there are almost no facts available on which planning decisions can be based.

CHAPTER 2: PORT CALL OF A CHEMICAL TANKER

INTRODUCTION

When analyzing port times of chemical tankers, detailed knowledge of the activities of chemical tankers in port is required. This chapter discusses the different activities of chemical tankers in port and the role of the port agent will be explained. As the activities in the port of Houston¹ are the subject of study in this project, this chapter is concluded with a short description of the port area in Houston¹.

THE ACTIVITIES OF CHEMICAL TANKERS IN PORT

In **Figure 1** the different aspects of a port call are summarized. The block 'customs' has a different pattern because boarding by customs and immigration is just needed at the first terminal visited in the U.S.A. The block 'sea leg' has a different pattern because it is not part of a port call.

When the vessel enters the port a pilot will board the ship in order to guide the vessel safely to a berth. At the same time a Notice Of Readiness (NOR) will be sent to the terminal which the ship is planning to dock. At the berth the vessel often needs the assistance of tugboats for docking safely. After docking the pilot will leave the ship. If the terminal visited is the first terminal visited in the USA, the following government departments will board the ship:

- a. Customs/immigration will board the ship to check if the information in their administration is correct. When they board the ship a representative from the port agent will accompany them and provide them with the necessary documents. The clearance of the ship by customs should be done within an hour.
- b. The US Department of Agriculture (USDA) will board the ship to seal food that is bought outside the USA and inspect the garbage.
- c. The US Coast Guard can board the ship to check if all licenses are up to date and carry out technical and safety inspections. The US Coast Guard doesn't necessarily have to board the ship at the first terminal visited but they often do that for the convenience of the shipping company.
- d. Sometimes the Drug Enforcement Agency (DEA) will board the ship to look for drugs. The DEA can board the ship anytime they want.

When customs has cleared the ship, the dock master and the cargo surveyor will board the ship. Both the dock master and the cargo surveyor will check if their information about the cargo is correct. The cargo surveyor represents the receiver or shipper of the cargo depending on the contract of affreightment. It is

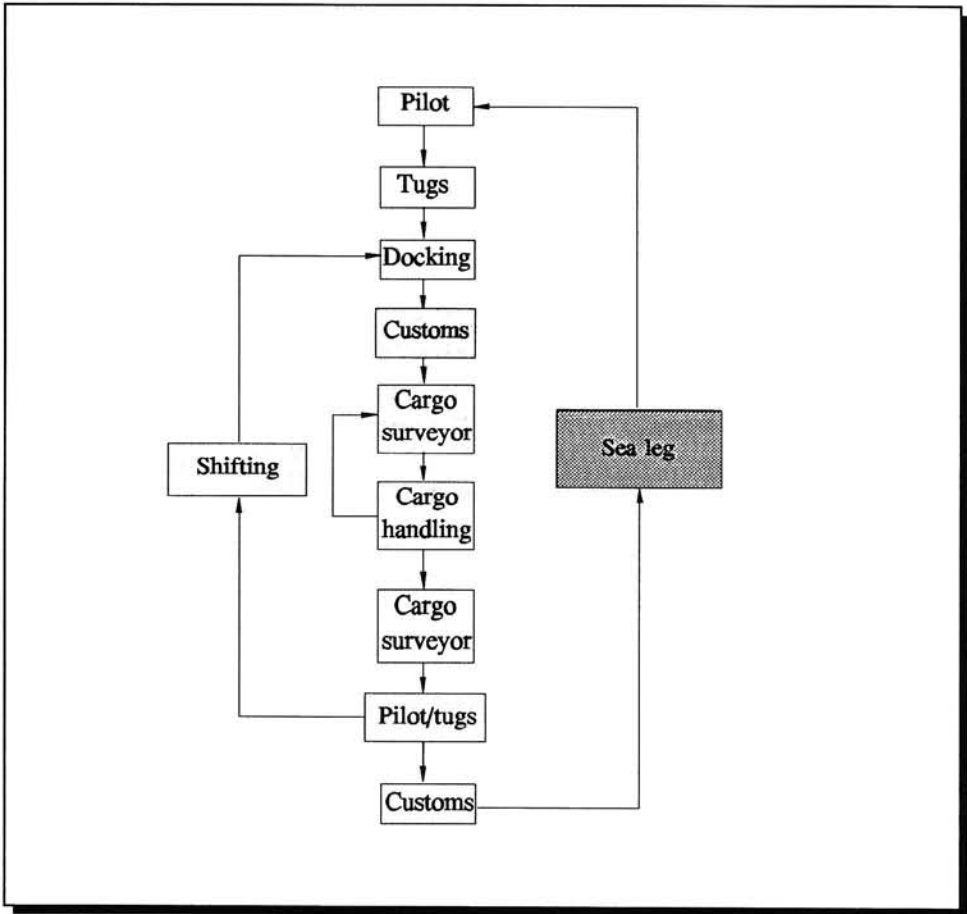


Figure 1: Diagram of a port call

the surveyors task to look after the cargo according to their clients instructions. When a ship wants to load cargo, the surveyor will carry out the following inspections:

- * The surveyor will always visually inspect the cargo tanks. If their client requires a physical inspection, a wall wash is carried out. The samples are sent to a laboratory for analysis. The surveyors try to carry out the wall washes before the ship docks the terminal where the tank actually is going to be used. This is done to prevent large time losses due to this analysis. A visual inspection of the tank is always required at the berth of loading, even when the tank has been wall washed at a previous terminal.
- * A visual inspection of the lines used in the cargo operations will always be carried out by the surveyor. If the client requires it, samples will be

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

taken of the line for analysis in a laboratory. The samples of the line will be taken at the end of the line at the part that is going to be connected to the manifold of the vessel.

- * Sometimes the surveyor has to take foot samples of the cargo. This means that a sample is taken of the cargo when one foot of the cargo is pumped into the cargo tank. If the foot sample doesn't meet the required standard, it could be necessary to pump the cargo back to shore and then again re-load the tank with another foot sample.
- * After loading of the cargo is completed, a sample will be taken of the cargo and this is again sent to a laboratory for approval. Most of the time a vessel will start sailing before the final samples are analyzed.
- * The quantity of the cargo is measured (sounding).

When discharging cargo a different procedure will be followed by the cargo surveyor:

- * The surveyor will take samples of the cargo and sent them to a lab for analysis;
- * The lines are inspected visually and if necessary physically;
- * The quantity of the cargo is measured (sounding).

Cargo handling of the chemicals can proceed after the cargo lines are connected to the manifold of the ship and the surveyor has approved the tanks, lines and the cargo. The manifold is the pivot of all cargo lines at the ship (**Figure 2**). The hoses are connected to the manifold by fastening the flange of the cargo line at the manifold together with the flange of the cargo hose.

After cargo handling operations is completed, the vessel is ready for shifting to the next terminal. The pilot will again board the ship and often the assistance of tugs is required. When starting shifting a Notice Of Readiness (NOR) is sent to the next terminal in the port. Of course, if the vessel is going to shift to another port the NOR will not be sent to the terminal when arriving at the pilot station.

THE PORT AGENT

The port agent plays an important role when a ship is in port. The main task of the port agent is to coordinate all activities of the ship in port:

- a. Scheduling the vessel to the different terminals in port. When scheduling the ship through the port the following points are taken into consideration:
 1. The stowage plan of the vessel. Sometimes it is not possible to load a certain cargo before another cargo;
 2. The availability of a berth and the cargo.;
 3. The overall shift time between the different terminals.

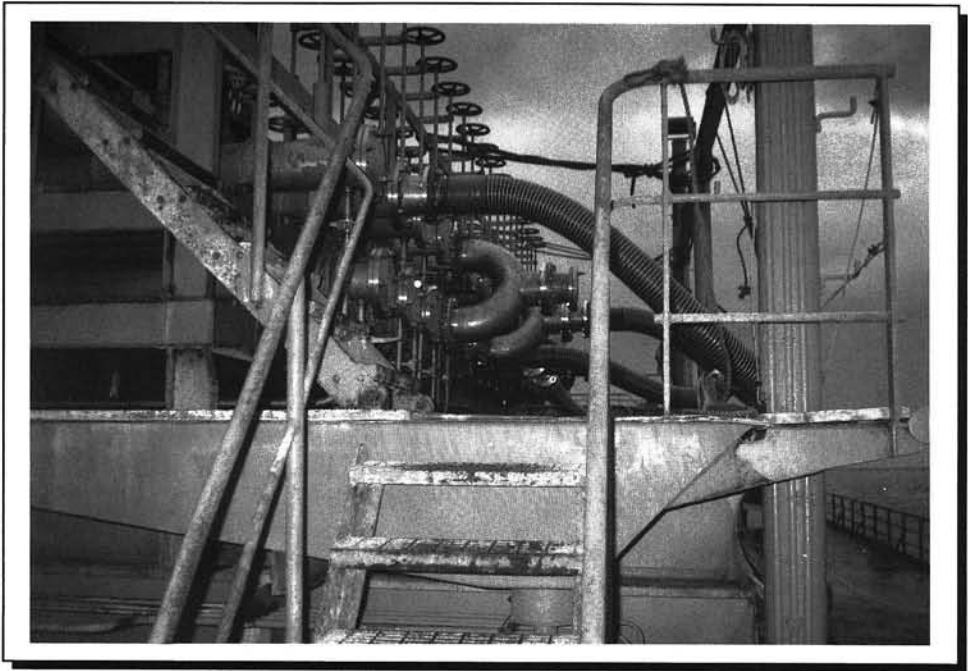


Figure 2: Manifold of a chemical tanker

- b. The port agent schedules the pilots, tugs and line men. When changes in the time table of the vessel occur, rescheduling of the pilot, tugs and line men may be required;
- c. Transportation of crew members to the airport or to medical services and crew changes are arranged;
- d. The port agent prepares the documents for customs and immigration;
- e. The port agent has intensive contact with the vessel when it is visiting Houston. The agency tries to visit a vessel in port at least once a day. He will also take care of the mail and do other small favours for the crew;
- f. Arranging the bunkering of the ship. The bunkers are purchased by the operations department of the shipping company.

In the context of this study, especially the scheduling tasks of the port agent are of importance.

THE PORT OF HOUSTON¹

The port of Houston contains all terminals located around the Houston Ship Channel and the terminals in Bayport. Both Texas City and Freeport² area considered as being different ports because they are each part of a different customs district. The map of the port area around Houston shows how the relevant

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

terminals for the shipping company studied are located in relation to each other (Figure 3).

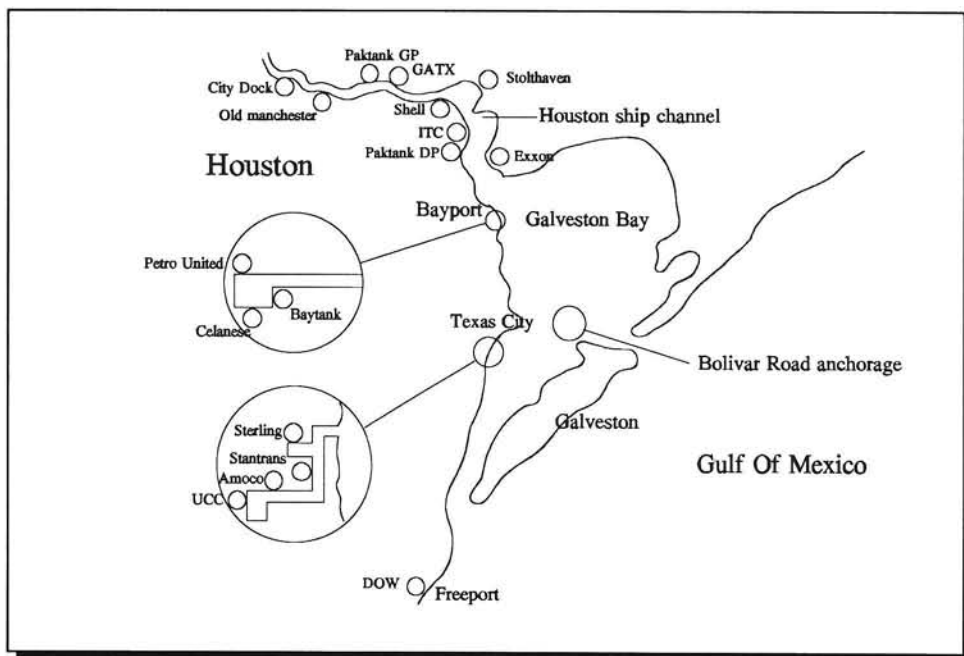


Figure 3: Port of Houston

For various reasons a vessel has to wait for a certain dock because the dock is occupied. The problems arising when a vessel has to wait for a berth can partly be explained by the geography of the port. If a vessel for instance has to wait for GATX (Galena Park) located far up in the Houston Ship Channel, there are two options: (1) docking at a layby berth and (2) anchorage at the anchorage place. Both these possibilities have specific drawbacks:

1. When docking at a layby berth additional costs are involved because lines men have to be arranged and often a tug is needed³. These costs come in addition to the docking fee of the specific layby berth and costs of shifting the vessel to this berth.
2. The anchorage option has as main drawback that the vessels have to be anchored at Bolivar Road which is located in the beginning of the Houston Ship Channel. This results in high shifting costs and a lot of lost time.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

Notes

1. The port of Houston is defined in such a way that the port of Texas City and Freeport are included.
2. Freeport is about a one hours drive from Houston.
3. All vessels docking at a berth in Houston are required to hire a mooring company even if the crew of the vessel can take care of the lines themselves. This is the result of the strong presence of the labour unions.

CHAPTER 3: DISTURBANCE ANALYSIS

INTRODUCTION

In order to create insight into the causes of delays of chemical tankers in port a statistical analysis of the delays is required. Two vessels were studied intensively during totally 31 port calls to Houston.

The information used when making the statistical analysis of the port times is based on the administrative files. In this context it is necessary to know how the administration is organized and in which way the different files are processed. The paragraph 'Structure of the administration' will explain the different files available in the administration concerning the operations of the vessels. Next, will be explained which particular information is required for the statistical analysis of the delays in port and how this relates to the information available in the administration (paragraph 'Disturbance analysis'). Finally, the results of the statistical analysis are presented.

STRUCTURE OF THE ADMINISTRATION

In the administration of the shipping company investigated there are four important types of administrative sheets which contain information of the day to day operations of the vessels available. All of the information is filed separately for each ship and voyage. A voyage is in this case defined as a roundtrip which starts at the first loading port and ends at the last port of discharge.

Daily vessel report

The Daily Vessel Report contains information about the current and future positions of the vessels. The service coordinator writes the Daily Vessel Report in supervision of the operational manager.

The information in the Daily Vessel Report is based on information received from the master of the ships and the port agents. The estimates for the future position of the vessel are made by the port agents, brokers and the operational manager.

Each day all employees in the head office in Houston receive a Daily Vessel Report. They use the report to plan their activities. For example, the executive assistant responsible for crewing, uses the report to coordinate crew changes. Technical management uses the Daily Vessel Report for the planning of repair and maintenance of the vessels.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

The Leg Report

The Leg Report is produced by the commercial manager. The Leg Report contains a voyage schedule of the different vessels. The report is produced in a special computer program available on the computer network of the company. The program contains all the distances between the different ports and information about the speed of the ships (nautical miles per day). In this way the program is able to calculate the time necessary for each leg. The time required for cargo handling at each terminal is produced by an educated guess of the commercial manager.

The program also contains a feature that makes it possible to update the Leg Report with information available on the Daily Vessel Report. When certain data changes (for instance because of a delay) all other data is corrected automatically.

The Leg Report is produced every two days and distributed to all employees in the head office, port agents and important clients.

Statement Of Facts

The Statement Of Facts gives information about the activities of a ship at a particular terminal. The information in the Statement Of Facts is recorded from the moment the ship tenders notice of readiness (NOR) until the ship has disconnected the hose after finishing loading and/or discharging at a terminal. The Statement Of Facts both records some key data concerning the cargo handling and some figures concerning the ship. On the bottom of the form is space for remarks. After the form is filled out by the chief mate (direct responsible for cargo handling), both the master of the vessel and the agent should check The Statement Of Facts on its correctness.

The Statement Of Facts is sent to the operations department in the head office. The operational manager uses the Statement Of Facts to see whether there have occurred delays which were not agreed in the freight contract. The demurrage calculations are based on information available through the Statement Of Facts and the freight contracts. The operational manager passes the demurrage calculation on to commercial management. Commercial management decides if the company is going to collect the demurrage. The commercial manager also evaluates the freight rates given to a certain client for a certain commodity transported between two specific terminals².

Summary of the Statement Of Facts

During a voyage a Statement Of Facts is produced each time the ship visits a terminal. For the convenience of management the key-figures of these Statements Of Facts are summarized on one page (A4). For each voyage two summaries are made, one for the load ports and one for the discharge ports.

DISTURBANCE ANALYSIS

During port calls of a ship there are various causes for delays. First, the most important reasons for delays are explained (paragraph 'Delays in port'). When making an overall disturbance analysis it is desirable to create categories corresponding to the various reasons for delays. To achieve this, the necessary information should be available. The way the administration is organized made it necessary to choose another classification of the delays (paragraph 'Grouping of delays'). Finally it is explained in detail how the information available in the administration is put into a spreadsheet to make the overall disturbance analysis.

Delays in port

From studying literature [1] and through interviews with the operational manager the following reasons for delays were found:

- a. Excessive analysis: This is defined as additional analysis required by either clients or terminal;
- b. Low hydraulic pressure: This appears when the vessels pumps are not working well (slow loading/discharging rate);
- c. Slow shore: The shore can for instance cause delays because of mechanical breakdowns of their equipment, administrative procedures, non availability of the cargo or the non availability of clean hoses;
- d. Pilot late: Sometimes the pilots are not in time to board the ship at the pilot station or at the berth;
- e. Surveyor late: When the ship is docked the cargo surveyor should board the ship right away because the cargo handling can only start when the surveyor has finished his job;
- f. Cleaning: Normally the tanks are cleaned when the ship is sailing and there should not be any delays in port because of cleaning. Though if the surveyor doesn't give the clean tank a certificate, an additional cleaning operation could be necessary;
- g. Weather: This could for instance be fog, storms or hurricanes;
- h. Poor planning;
- i. Equipment breakdown: Some of the ships operated by the shipping company studied have sometimes problems with their ballast pumps;
- j. Shifting delays: Delays in the transit time between the terminals;
- k. Occupied berth: It happens that the berth which a vessel wants to visit is occupied. In this case the ship has to wait.

When studying the administrative files at the shipping company headquarters it seemed difficult to determine delays and attribute them to one of the categories mentioned above. This problem exists because of several reasons:

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

1. When looking at the Statement Of Facts it appears that if delays occur, the reasons for the delays should be mentioned at the remarks. Unfortunately the chief mates of the ships, writing the Statement Of Facts, do not write detailed explanations when delays occur.
2. It is clear that not everybody has the same definition of ship's delay and the accuracy of the measurement of delays differs a lot from one chief mate to another.
3. In order to detect the delays as grouped in the beginning of this paragraph a detailed description of the entire port stay of the ship and a detailed description of cargo handling operations is needed. These documents do most often not exist in the administration of a shipping company.

Because of the problems mentioned above, it was necessary to rearrange the of different delay categories. The way of grouping delays and how this is compatible with the administrative files available is explained in the following paragraph.

Grouping of delays

For the statistical analysis of the delays three types of administrative files seemed useful: the Daily Vessel Report, the Statement Of Facts and the summary of the Statement Of Facts. The Leg Report seemed in this context to be less useful because of its planning character.

When making the statistical analysis, the following basic assumptions were made:

1. No double notation of delays are made. For example, if two products are loaded at the same time and in both cargo operations delays occur, only the cargo operation which created an overall delay will be noted as being delayed. This way of notation is chosen because if all delays are written down, the picture of the delay time compared to time used for terminal operations would be unrealistic.
2. When cargo handling operations could have proceeded faster than they did, there must be some kind of a delay.
3. Time lost because of a ship docking at a layby berth because of maintenance and repairs are excluded (offhire).

The delays occurring during port calls are grouped as follows:

- a. **Not available berth** (NA berth): When a ship is delayed because of an occupied berth the ship can either anchor or dock at a layby berth. When the ship is anchored the reason for anchoring should be mentioned in the Statement Of Facts at the appropriate place. When the ship is docked at a layby berth because of an occupied berth, this is most of the time

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

mentioned in the Daily Vessel Report. For example, 'Docked Dow A4/OCC'.

There are different reasons for the berth being not available:

- * Another ship is docked at the berth;
- * Technical problems at the terminal;
- * Administrative forms of ship and terminal do not match;
- * The cargo is not available at the terminal.

- b. **Excessive analysis** (Exc.An.): The excessive analysis occurs most of the time when the loading of cargo is stopped and then later on resumed (foot sample). At the Statement Of Fact form there is an appropriate blank for both stopping cargo operations (STOPPED) and resuming cargo operations (RESUMED). Sometimes there are remarks placed on the bottom of the form concerning this matter.

In general, there are two main reasons for the excessive analysis (foot sample):

- * The analysis is required by the shipper;
- * The analysis is required by the terminal due to security.

- c. **Low pressure** (Slow loading/discharging rate): Most of the times the crew doesn't mention low pressure as being a factor of delay. To see whether the speed of pumping is sufficient, it is necessary to compare the pumping performance with a minimum required pumping rate. The actual pumping rate can be calculated with numbers available on the Statement Of Facts. First the quantity of the product is needed. The Statement Of Fact contains two numbers concerning this matter, 'SHIP FIGURES' and 'SHORE FIGURES'. 'SHIP FIGURES' gives the quantity of cargo loaded according to ship measurement equipment and 'SHORE FIGURES' gives the quantity of cargo loaded according to the shore measurement installation. The average of these two numbers are used for the calculation of the pump rate. The time used for pumping is available by subtracting the time when loading commenced from the time when loading IS completed. When cargo operations are stopped due to excessive analysis, the time lost will be subtracted from the loading time.

To judge whether a pumping performance is sufficient, the performance should be compared with pumping rates of the same product in the past. These numbers were not available in the office in Houston. Therefore a list of minimum required pumping rates for the different commodities was constructed in co-operation with the operational manager. The numbers are based on his experience.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

If the performed pump rate is slower than the minimum required pumping rate, the time difference will be attributed to the low pressure category.

The reasons for slow pump rates could be:

- * Leakage of pump or hoses;
- * Problems with the hydraulic system;
- * Loading/discharging out of trucks or railcars;
- * High back pressure.

- d. **Slow shore I:** When a ship docks at the terminal it should, according to the operational manager, be able to start loading within two hours. If the loading operations commenced more than two hours after docking, the time lost will be ascribed to the category "slow shore I". If time is lost because of that the surveyor is late, this is taken into consideration when calculating the time lost. For example, if the ship docks at 0400, the surveyor is on board at 0420 and cargo operation is commenced at 0700 the following delays will be calculated: 0.33 hours will be attributed to the surveyor category and $7 - 4 - 2 - 0.33 = 0.67$ hours will be ascribed to the "slow shore I" category.

There are different reasons why the cargo handling operation starts later than two hours after docking:

- * Slow analysis;
 - * Technical problems at the terminal;
 - * The cargo is not available;
 - * Administrative forms of ship and terminal do not match.
- e. **Slow shore II:** When a ship completes loading it should be able to start shifting within two hours (according to the operational manager). If the time exceeds two hours the time lost will be ascribed to the category "slow shore II". The time of completion of cargo handling operations is written down in the Statements Of Facts (COMPLETED). The time when the ship starts shifting is written down in the Statement Of Facts of the next terminal in the rotation (STARTED SHIFTING). The time when a ship starts shifting is also available through the Daily Vessel Report.

Reasons for delays after cargo handling operations are completed could be:

- * Administrative procedures;
- * Pilot not ready;
- * Analysis not complete.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

- f. **Slow shore III:** At one terminal a ship can load various kinds of products. Ships managed by the shipping company studied will load from 1 to 6 different products at a terminal. The stowage plan of the ship is almost always arranged in such a way that loading of all products at the same time is possible. Though it happens often that the terminals load some of the products after each other. Delays occurring because of this are ascribed to the category Slow shore III.

Reasons for not loading all the products at the same time could be:

- * Not enough manpower available at the terminal;
- * Not enough hoses or lines available.

- g. **Surveyor late:** When the surveyor is not available right after docking, cargo handling operation cannot commence in time because the inspection by a surveyor has to be done first. The arrival time of the surveyor is written down in the Statement Of Facts.

Reasons for delayed boarding of the surveyor could be:

- * Laxity of the surveyor;
- * Traffic;
- * The surveyor is delayed on the terminal.

- h. **Shifting:** To discover delays in the shifting time there must be numbers available about the average shifting time. At the head office in Houston these numbers were not available but the master of one of the vessels had a form with all the distances and shifting times between terminals in the Houston area. According to the master of this vessel a deviation of 20 minutes in the shifting times is acceptable. Therefore we can speak of a delay in the shifting time if the performed shifting time exceeds the shifting time mentioned on captain Ocanola's form plus 20 minutes. The performed shifting time is available on the Statement Of Facts by subtracting 'START SHIFTING' from 'SAFELY MOORED AT DOCK'.

Reasons for delays in shifting time could be:

- * Weather;
- * Heavy traffic in the shipping channel;
- * Mechanical problems with the ship.

- i. **Miscellaneous:** Delays due to weather will be mentioned in the remarks of the Statement Of Facts and sometimes there will be a remark at the Daily Vessel Report as well. On the Daily Vessel Report there would for instance appear a remark like 'SAILED DOW A4/FOG'.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

Statistical analysis of port delays

When making the statistical analysis, data concerning both the two vessels were studied (Vessel 1 and Vessel 2).

Vessel 1 was chosen for this study because this ship has the largest earning capacity of the shipping company studied. The statistical analysis will be most useful for the vessels with the largest earning capacity because possible time savings in port will generate most money. Voyages of the last 2.5 years were studied.

Vessel 2 was studied because this ship makes more than twice as many voyages a year than Vessel 1 (16 a year versus 7 a year) and because it operates in another trade than Vessel 1. In this way it is possible to get a better general picture of the port of Houston². The data of 1992 concerning Vessel 2 was entered into a spreadsheet (15 voyages). In total 31 voyages were studied (Vessel 1 and Vessel 2).

Information about delays in the port of Houston² available in the administration of the shipping company was entered into spreadsheets and organised in categories as explained in the previous paragraph. At the head office, administrative files were readily available for the last 2.5 years. When entering the information into the spreadsheet the problem occurred that there were not always explanations in the administration available for certain delays. In these cases common sense was used to figure out what kind of delay occurred³.

After making the statistical analysis of the different causes of delays, the data was re-arranged in such a way that the performance of the different terminals could be investigated. For each visit to the terminal the total time delay caused by the terminal was entered into a spreadsheet. The same was done for delays just caused by an occupied berth. Also the delay time excluding time lost because of an occupied berth is calculated. In this way it was possible to get an insight of *terminal operation performance*.

RESULTS

The results of the statistical analysis are discussed in this paragraph. First the results concerning the causes of delays will be discussed and finally the results of the analysis concerning the terminal performance are presented.

Causes of delays

The results concerning delays of both Vessel 1 and Vessel 2 are summarized in two pie charts (Figure 4). The categories 'Pilot late', 'Cleaning' and 'Bad equipment' are not incorporated in the pie concerning Vessel 1 because their share of the total delay time is negligible (0.25%, 0.39% and 0.18% respecti

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

vely). For the same reason the categories 'Pilot late' and 'Miscellaneous' are excluded from the pie concerning Vessel 2 (0.07% and 0.02% respectively).

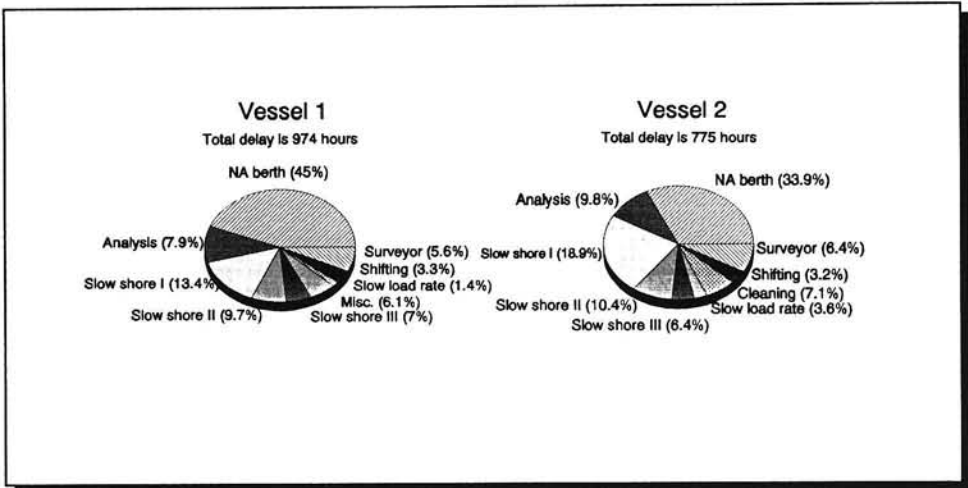


Figure 4: Vessel delays

When comparing the charts of the two vessels it appears that the largest difference is found in the category miscellaneous. This category contains delays due to weather. Serious delays due to for instance hurricanes do not occur very often, but when they occur it often results in large delays. In 1992 vessel 1 was for instance delayed for more than 36 hours because of the hurricane Hugo.

Combining the data of both Vessel 1 and Vessel 2 results in Figure 5. From this figure it appears that the category 'NA berth' is a major cause of delay in the rotation of the ship through the port of Houston, Texas City and Freeport. Delays due to slow shore operations have a share of 32.5 % of the total delay time.

It is of course also interesting to compare the total delay time with the total time spent in port during the same period. The total time spent in the port of Houston during the 31 voyages which were analyzed can be calculated from the Daily Vessel Reports. In total 4030 hours were spent in port during the 31 voyages. With a total delay of 1749 hours during the same period, it is clear that **43% of the time spent in port is lost because of delays**⁴. Delays due to occupied berth resulted in a loss of 17.4% of the total port time⁵.

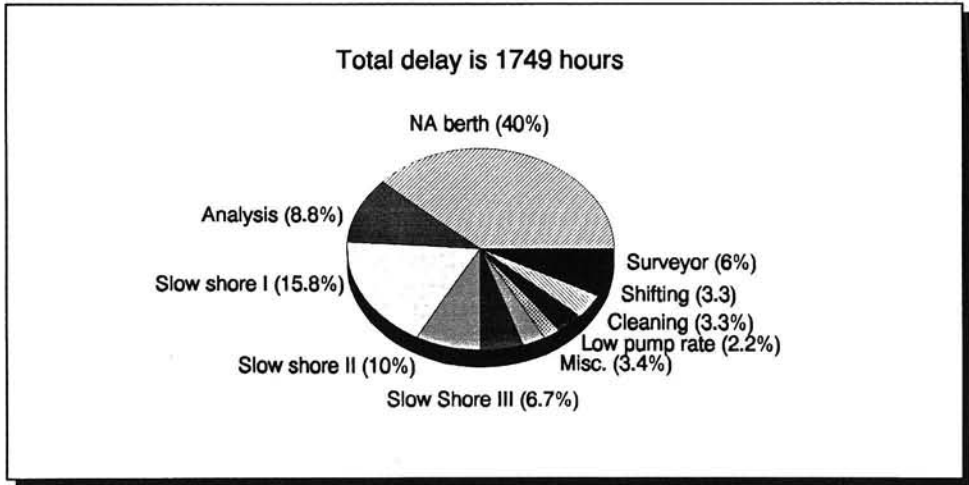


Figure 5: Port delays

Terminal Analysis

When reading the results on the following pages, it is important to keep in mind that the call frequency of the different terminals differ a lot from one terminal to another. The call frequency for the two vessels which were studied during a period of time is printed in **Figure 6**.

It is clear that Paktank Deer Park was the terminal most visited by Vessel 1 and Vessel 2. Also the DOW terminal in Freeport is visited very often.

Making statistics based on just a few calls can be misleading. That is why prudence is required when interpreting the results concerning the terminals Old manchester, Fertifex, Shell, Sterling and Paktank Galena Park.

When the total delay time caused by the terminal is calculated and arranged per terminal, the results can be summarized in **Figure 7**⁶.

The diagram in **Figure 7** above doesn't relate the number of terminal visits to the total time lost. It could for instance happen that the DOW terminal is visited 10 times more often than the Stantrans terminal which means that the Stantrans terminal actually performs worse than the DOW terminal. To get an insight in the performance of the terminal, the average delay is calculated by dividing the total time lost at a terminal by the number of visits to the terminal (**Figure 8**).

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

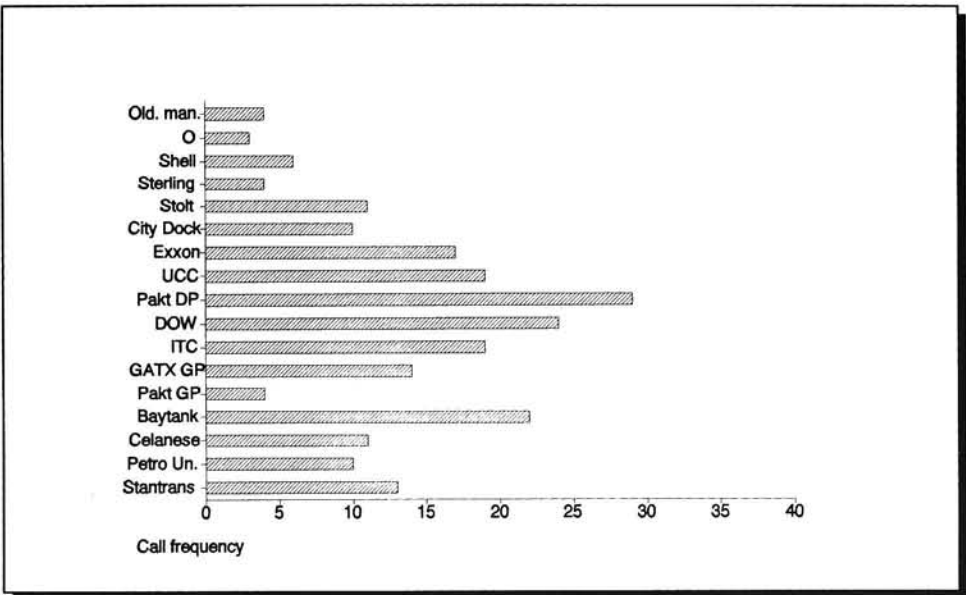


Figure 6: Call frequency of the terminals

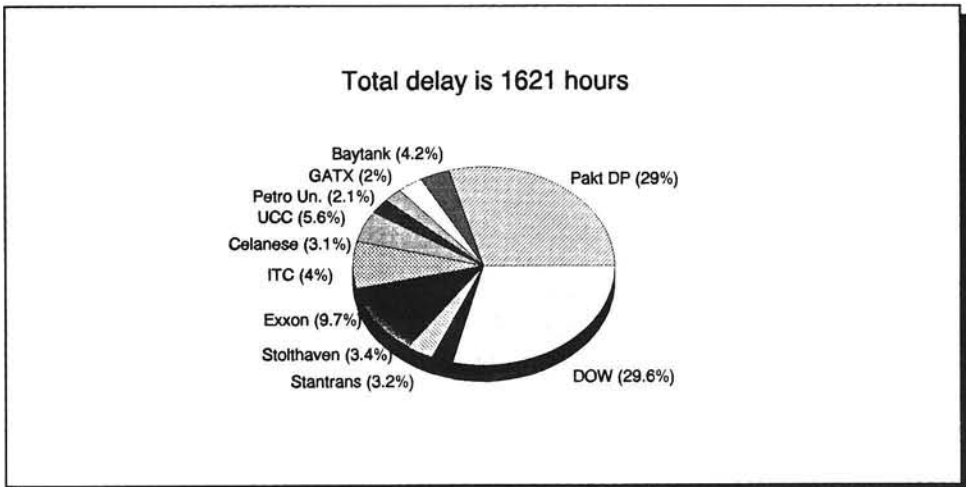


Figure 7: Total delay per terminal

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

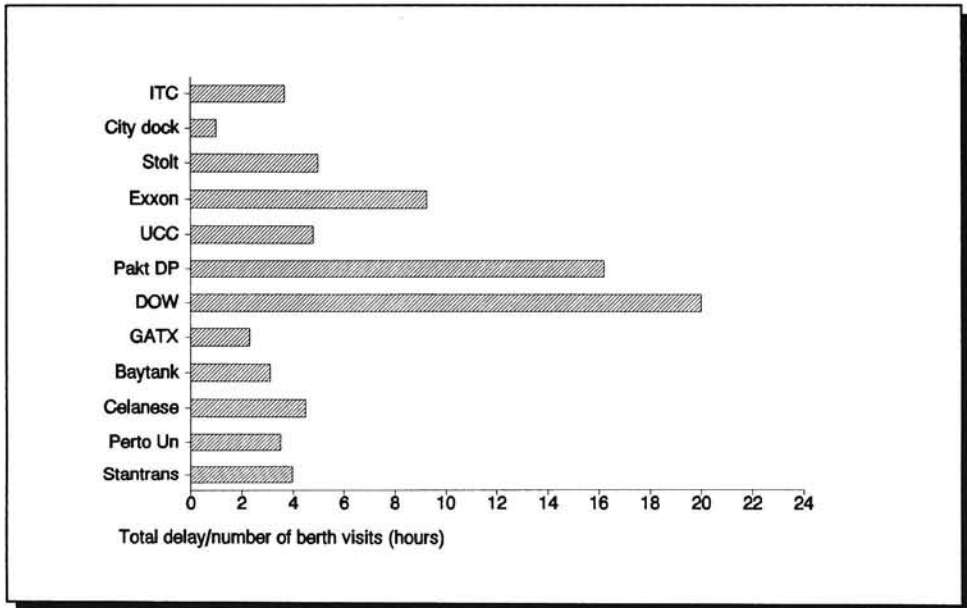


Figure 8: Terminal performance

From the bar diagram it appears that in average 20 hours are lost for each visit to the DOW terminal and 16 hours are lost when visiting the Paktank Deer Park terminal. City Dock appears to be the best performing terminal of the terminals listed above. Terminals which were visited less than 10 times during the investigation period are excluded from the diagram.

In the former paragraph was concluded that the category 'NA berth' was a major cause of delay. Therefore it would be interesting to see which terminals are major contributors to this category of delay (Figure 9 and Figure 10).

Figure 10 shows that the vessels visiting the DOW and Paktank Deer Park terminals had to wait in average more than 10 hours before docking. Surprising is that the waiting time for a berth at the Exxon terminal is as low as 0.5 hour in average. The Exxon terminal is known as a terminal where many delays occur.

When comparing the delays in port caused by an occupied berth it is important to notice that the DOW terminal is located in Freeport. The DOW terminal is the only terminal in Freeport. This means that if a ship has arrived in Freeport, it has to sail for DOW. If their docks are occupied, the vessel cannot be rescheduled to another terminal. The Paktank Deer Park terminal in Houston doesn't have the same problem because many other terminals are located near the terminal, which makes it possible to reschedule the vessel.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

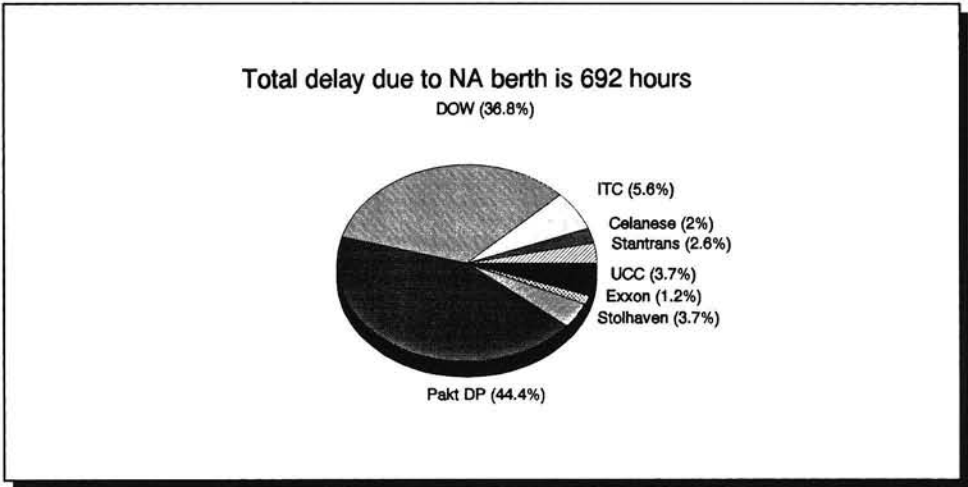


Figure 9: NA berth per terminal

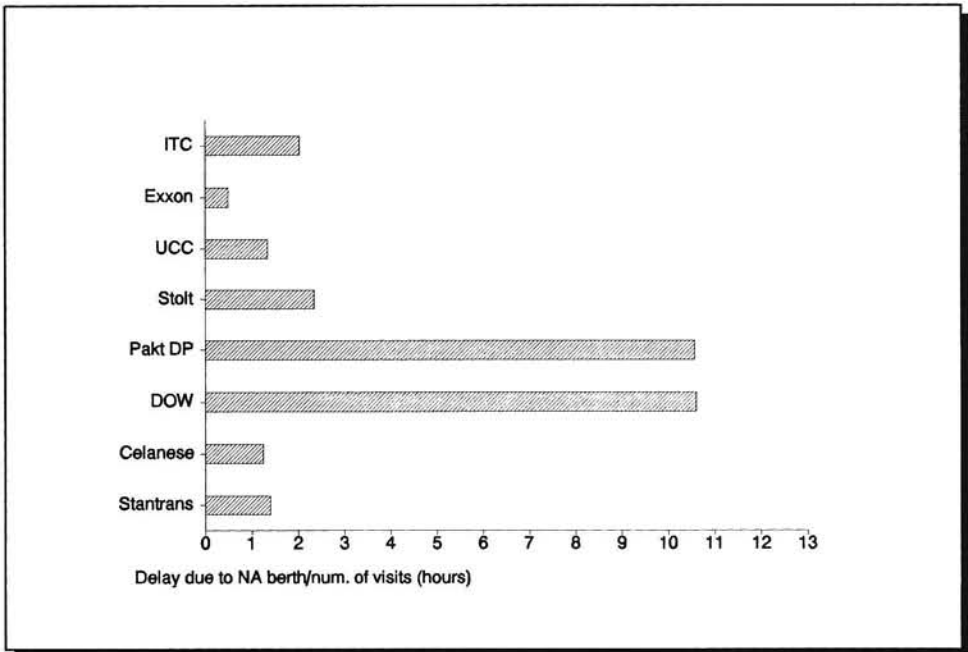


Figure 10: Terminal performance

When dividing the number of times 'NA berth' occurred at a terminal through the total number of visits to that specific terminal Figure 11 is produced.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

Of course the numbers in **Figure 11** do not give an actual picture of the occupancy rate of the terminal. The data available at one specific shipping company is influenced by the possibilities to reschedule the vessels.

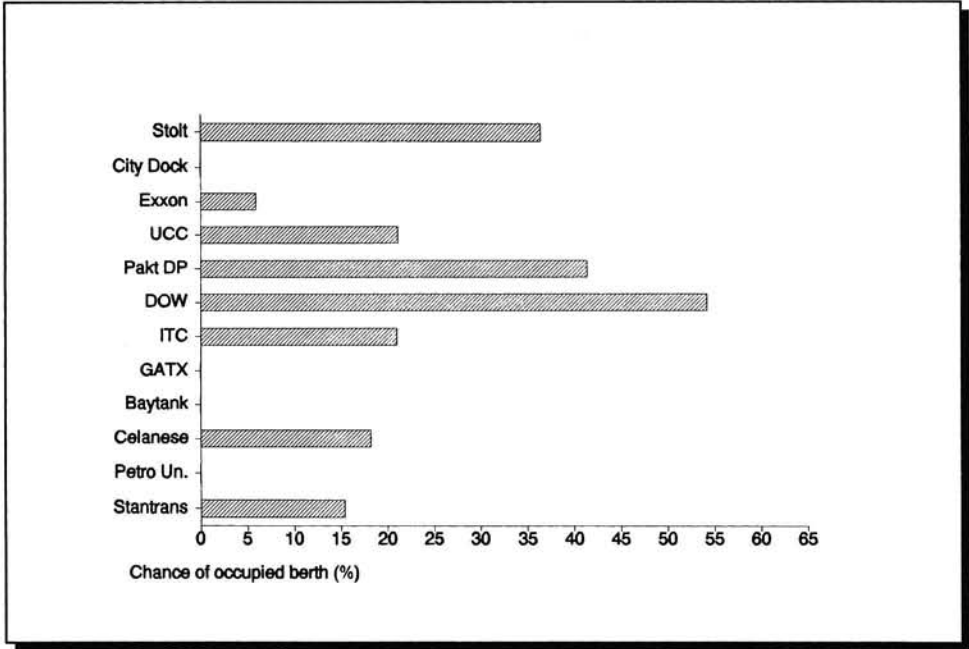


Figure 11

It would also be interesting to take notice of the performance of the terminal when the category 'NA berth' is excluded. In this way the delays due to other causes of delay can be calculated (**Figure 12** and **Figure 13**).

From the figures it is clear that both DOW and Exxon are the worse performers concerning shore operations⁷. This is the reason why Exxon in the overall delay performance diagram performs bad though it is one of the best performing terminals concerning berth availability. Interesting is also that Pak-tank's shore operations causes in average 40% less time lost than the shore operations of the DOW terminal.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

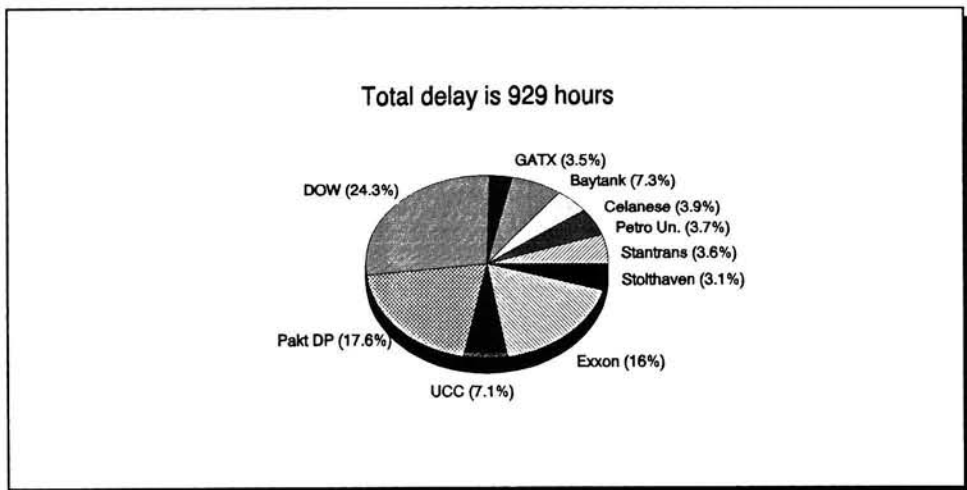


Figure 12: Delays per terminal excl. NA berth

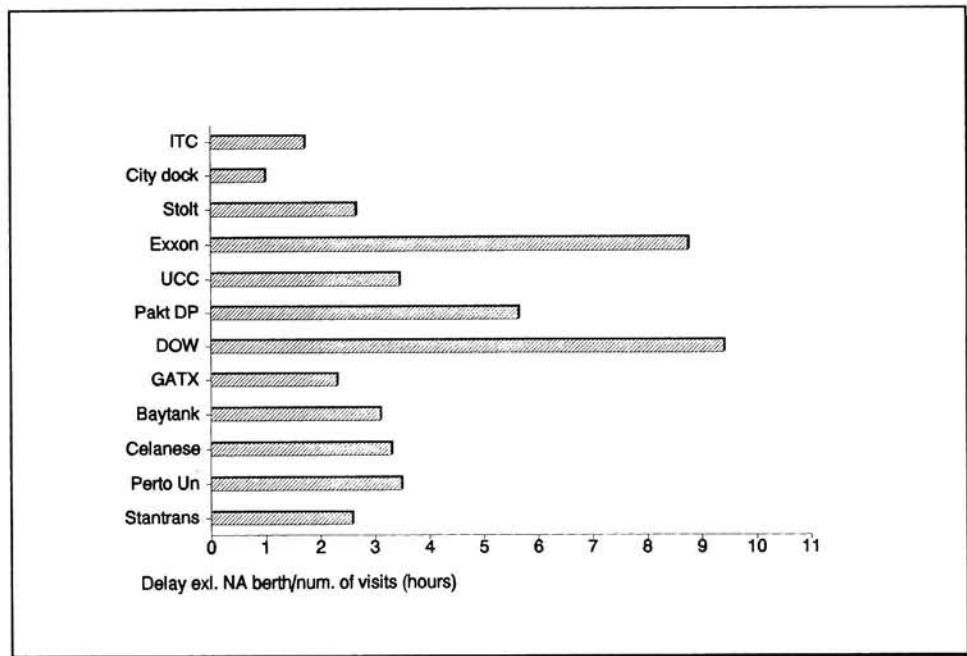


Figure 13: Terminal performance

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

Notes

1. Some terminals always refuse to pay for demurrage bills passed on from the cargo owner. When evaluating freight rates these potential extra costs for the shipping company have to be taken into consideration.
2. Port of Houston including Texas City and Freeport
3. From experience the operational manager could most often find a reason for a particular delay.
4. It is important to notice that part of the time lost due to delays was compensated through demurrage claims.
5. When a berth is occupied the first six hours are for the shipping companies account. Economical loss because of longer waiting times can be compensated through demurrage claims.
6. Terminals with a share less than 1 percent of the total delay are not included in the pie.
7. Other causes of delay than shore operations are also included though their share is small compared to shore delays.

CHAPTER 4: PORT COSTS

INTRODUCTION

In maritime transportation the ships are a certain time of the year in port. The time spent in port is considered as being non-productive because cash flow is generated only by transporting products from origin to destination, not by moving them around in port. Therefore shipowners try to limit the time their vessels spent in port.

For the chemical shipping companies the time spent in port is considerable. The amount of time spent in port depends on the size of the ships, the route of the vessel¹, the commodities transported and the port facilities available. It is quite obvious that there are large amounts of money involved in these port stays. In the context of the port time analysis, it would of course be interesting to figure out how much money actually is spend in port. Therefore, first is explained how both the total time spent in port of the vessels and the costs involved are calculated and finally the result of this analysis is presented.

TIME AND COST CALCULATION

The calculation of the total time and money spent in port is based on two kinds of administrative sheets available at the shipping company investigated, the Final Estimate Report and the Voyage Summary.

Final Estimate Report

The Final Estimate Report is made by commercial management and contains the arrival date to a port, port name, sailing time, port time, port costs, the commodities transported, client's name, quantity, freight rate and bunker surcharge. The gross and net income as well as costs for each cargo and for the total voyage is calculated.

The same form also contains an estimate of the costs of tank cleaning, cleaning chemicals, persistent oil and representation. The estimated costs for tank cleaning contain the extra bonuses for the crew. Cleaning the tanks is not a very pleasant job. The category persistent oil contains costs made for extra insurance premiums when transporting oils which do not disperse when spilled. The money spent on representation contains dues paid in port.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

Voyage summary

The voyage summary is produced by the accounting department of the shipping company. It gives a summary of the costs and income involved for each voyage of the ships in a specific year. For each voyage the following data are presented:

- * Net revenues. The net revenue is calculated by multiplying the quantity of products transported by the matching freight rates;
- * Charter hire. The charter hire contains the hire of the ships, manning costs and provisions;
- * Fuel;
- * Port costs. The port costs are defined as the out-of-pocket costs like pilot, tug as well as canal fees and includes the costs for tank cleaning, cleaning chemicals, persistent oil and representation costs;
- * Demurrage;
- * Total costs;
- * Gross results.

The Voyage Summary is made for general management and the auditors.

The calculation

The calculation of time and money spent in port is based on the financial year of 1992. The following assumptions are made:

- * The port costs are defined as the total costs of having a ship in port. This includes both out-of-pocket costs² and the charter hire of the ship during the period it stays in port. Therefore it is necessary to calculate the total time the ships spent in port. Excluded from the port costs are the costs for tank cleaning, cleaning chemicals, persistent oil and representation.
- * The calculation is based on the 6 vessels operated by the shipping company investigated. Vessels which are chartered for a limited period of time are excluded.
- * The ports of Freeport, Texas City and Houston are considered as one port.
- * The assumption above implies that the shifting time between the different ports (now considered as one) should be included in the port time. For practical reasons these shift times are excluded from the port time. The difference in the total port time will not be influenced substantially because of this simplification³.

In order to calculate the desirable data, relevant data is entered into a spreadsheet. For each voyage the costs of tank cleaning, cleaning chemicals, persist oils (including representation), total port days and port days in Houston (inclu-

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

ding Texas City and Freeport) are entered into the spreadsheet. This information can be obtained from the Final Estimate Reports.

With information from the spreadsheet the total port costs can be calculated. First, the part of the charter hire which should be contributed to the port costs is calculated (total charter hire at the Voyage Summary x total port days / total days in 1992). The desirable port costs are calculated as follows:

$$\begin{array}{r} (+) \text{ Total port costs according to Voyage Summary} \\ (-) \text{ Tank cleaning costs, cleaning chemicals etc.} \\ (+) \text{ Share of charter hire} \\ \hline \text{Result : Total port costs (including charterhire)} \end{array}$$

The results are presented in the following paragraph.

RESULTS

From the calculations in the spreadsheet it seems that the total port time is about one third of the total time available⁴. About 35% of the time spent in port is spent in the port of Houston⁵ (Figure 14). In this context it is important to notice that one of the vessels of the shipping company studied never visits Houston. Therefore the share of the port time in Houston for the other five ships is even larger (39.5%).

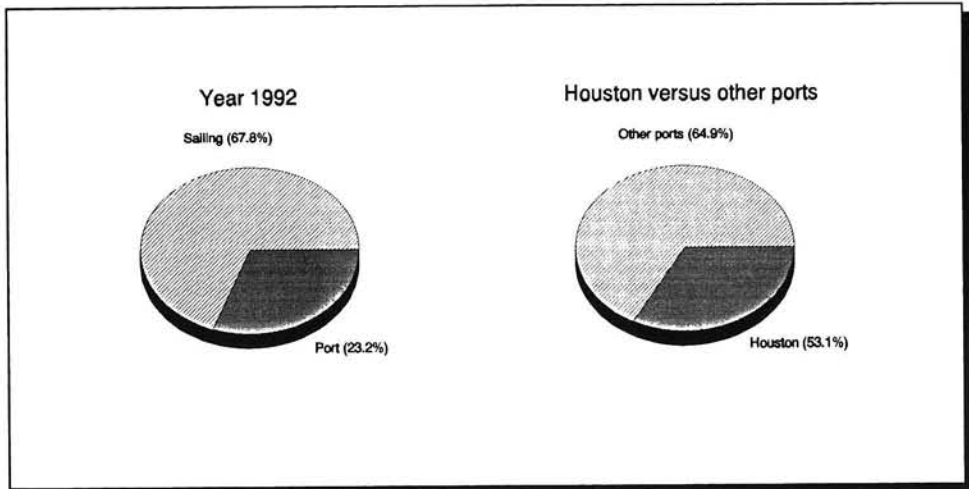


Figure 14: Time overview

The total costs a year was about US\$ 24.3 million⁶. About 44% of this amount is spent during port calls⁷. Of the money spent in port about 53% is spent on

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

out-of-pocket expenses and the remaining costs are costs due to charter hire⁸ (Figure 15).

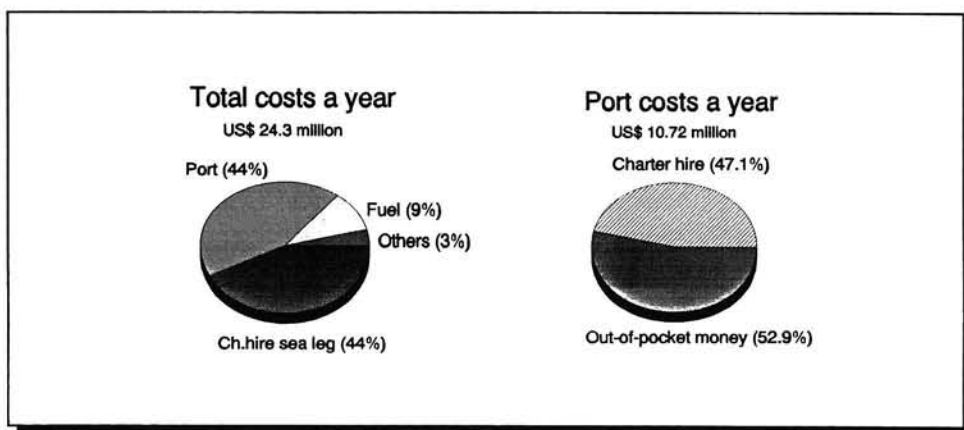


Figure 15: Costs

From the pie charts it is possible to calculate that US\$ 3.75 million was spent in the port of Houston⁵ in 1992⁹. When visiting the port of Houston a ship will on average visit 6 terminals. This means that during the 60 voyages the vessels of the shipping company studied made in 1992¹⁰, about 360 terminals were visited in Houston. The average costs of visiting a terminal is than about US\$10400.

Economic background for reducing time lost in port

It would of course be interesting to calculate what economic consequences the reduction of delays in port would have.

The study of the delays showed that 40% of the time lost in port is caused by an occupied berth. This is the reason why it seems desirable to make a model of the port of Houston where an optimal rotation of the vessels is calculated. According to commercial management US\$2500 additional profit per ship can be made for each day that is saved. The additional profit is large because the fixed costs are high (about 70%).

In the disturbance analysis it appeared that a vessel loses 43% of the time spent in port and that 40% of all time lost is caused by an occupied berth. In the calculation of the port costs it appeared that 32.2% of the available time is spent in port and that 35.1% of all time spent in port is spent in the port of Houston⁵. For each percent time savings in awaiting for a berth, additional annual earnings can be created (only for the port of Houston⁵):

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

$$[\text{Nett revenues/day}] * [\text{No. of ships}] * [\text{No. days/year}] * 0.322 * 0.351 * 0.43 * 0.40 * 0.01 =$$

$$US\$2500 * 6 * 365 * 0.322 * 0.351 * 0.43 * 0.40 * 0.01 = US\$1065$$

A 30% improvement through better scheduling of the vessels in the port of Houston⁵ will generate additional earnings of US\$ 32000 a year.

Notes

1. Short routes means that a relative high percentage of the time is spent in port.
2. Out-of-pocket costs contains costs made in port for tugs, mooring companies, pilots etc.
3. Because the relevant ports are more or less located next to each other.
4. The total time available: 6 vessels x 365 days = 2190 days. From the spreadsheet it appears that totally 704.43 days were spent in port in 1992. Conclusion: $100 \times 704.43 / 2190 = 32.2\%$.
5. Including Texas City and Freeport.
6. This is excluding the payed demurrage bills. Therefore in reality the costs would be slightly lower.
7. Total port costs (including charterhire) was US\$ 10.72 million in 1992.
8. The out-of-pocket costs is calculated by subtracting the cleaning costs, cleaning chemicals etc. from the total costs according to the Voyage Summary.
9. Share of port of Houston in total amount of port days (0.35) x total port costs (US\$ 10.72 million) = US\$ 3.75 million. Demurrage is excluded from this calculation.
10. Excluding that one vessel which never visits the port of Houston.

CHAPTER 5: MODELING THE ACTIVITIES IN PORT

INTRODUCTION

From the previous chapters it has become clear that optimizing the scheduling of a vessel visiting the port of Houston¹ makes financial sense. In order to achieve this a simulation model/tool has to be developed.

Making a model of the chemical shipping activities in port is a process which can be divided in several parts. First it is necessary to accurately define the objective of the port planning model (paragraph 'Objective of the simulation model') and to define the input data required. Successful implementation of a scheduling tool very much depends on the availability and the quality of the input data. Therefore the paragraph 'Available input data' will explain which input data is available for the simulation. Next, in the paragraph 'Simulation and programming approach' is explained in which way the real life situation in port can be translated into a computer model. **Chapter 5** is concluded by explaining the modeling approach in more detail with the assistance of flow chart techniques and the process description method (paragraph 'General description of the computer model').

OBJECTIVE OF THE SIMULATION MODEL

The objective of the simulation model is to make a tool for the port agent which helps him to schedule the vessels through the port of Houston¹. When a vessel visits the port of Houston¹, relevant information will be entered into the program and the time required for all the different combinations of the rotation through port will be calculated. The tool will point out the fastest route based on the input information and statistics concerning the performance of the different terminals. The port time will be used as a unit of measurement. The consequences of the following policies can for instance be evaluated:

1. At this time the Paktank Deerpark terminal is always visited right away when it is available. What is the influence of this policy on the total time spent in port? Could other terminals be eligible for such a policy? And what influence has the current position of the vessel?
2. The port agent tries to schedule the vessels to the terminal which is located furthest in the Ship Channel. What are the consequences of this policy?

Figure 16 contains a schematic outline of the model.

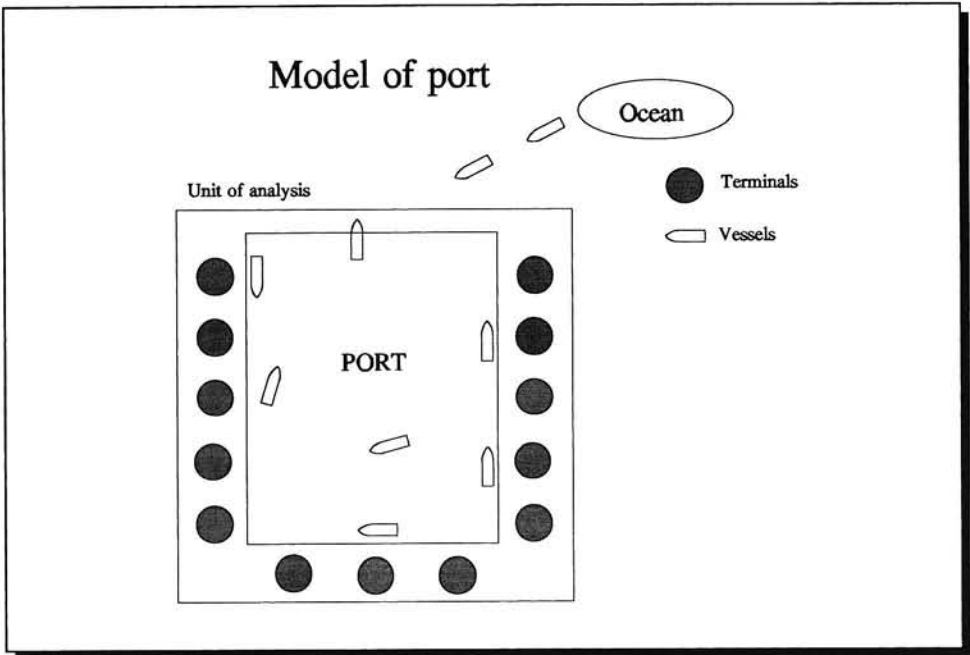


Figure 16

INPUT DATA REQUIRED

The movements of chemical ships in the port of Houston must be simulated in such a way that the occupancy rate of the terminals correspond with the actual situation. Therefore the quality of the input data is of great importance.

There are two ways of simulating the activities in port: (1) from the ship's point of view and (2) from the terminal point of view:

1. Each time a chemical ship enters the port, the terminals which are going to be visited are drawn from a certain distribution. This way of modeling requires the following input data:
 - * Number of chemical vessels entering the port;
 - * Which terminals are going to be visited;
 - * Laytime at the terminals;
 - * Routing strategy for each vessel;
 - * Shift times between the different terminals.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

2. For each terminal the interarrival time and the laytime is drawn from a valid distribution for a specific terminal. This way of modeling requires the following input data:
 - * Statistics of the intermediate arrival times for each specific terminal;
 - * Statistics of the laytimes of the vessels for each specific terminal;
 - * Shift times between the different terminals.

The choice of the modeling approach will be dependent on the information available. The following paragraph will explain which relevant sources are available and what input data can be generated.

AVAILABLE INPUT DATA

Sources for the data required for the simulation model

The model/tool will require certain basic information about the terminals. The information required for this study was not available in the administration of the shipping company studied. The following companies or institutions were visited in the search for relevant information:

- * A towing company;
- * The Houston Pilots;
- * The Port Authorities of Houston;
- * Marine Exchange of The West Gulf, Inc.;
- * US Coast Guard.

It was clear that the US Coast Guard had the most complete picture of the different terminals and the information was arranged in such a way that a statistical overview of docking times and interarrival times could be made. Another advantage of the USCG is that they are obliged to give information to other institutions or companies according to The Freedom of Information Act. The organisation of the administration at the USCG is explained in the following paragraph arranged.

Because both the docking times and the interarrival times could be derived from information available at the US Coast Guard the modeling approach from the terminal point of view was chosen (as explained in the previous paragraph). The interarrival time (IAT) is here defined as the time between departure of a ship from a terminal and docking of the next ship to the terminal.

The Marine Exchange had some general information about ship movements available. The Marine Exchange of The West Gulf is a non-profit membership organization which provides information on deepsea vessel arrivals at the port of Houston and other West Gulf ports. From a lookout station at Morgan's point, Marine exchange personal identify deepsea vessels as they enter the port of Houston. The information reported includes: name of vessel, flag of vessel, type

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

of vessel, passing time at Morgan's Point, first berth and agent or operator. Each month statistics are made concerning the number of arrivals of the different types of vessels (Figure 17).

Arrivals By Type - Port of Houston - Jul, 1993															
	DEC	NOV	OCT	SEP	AUG	JUL	JUN	MAY	APR	MAR	FEB	JAN	1993	JUL	1992
BB-Break Bulk						95	81	97	83	88	89	92	625	80	588
BC-Bulk Carrier						32	39	32	47	46	38	50	284	39	298
CL-Cable Layer						0	0	0	0	0	1	0	1	0	0
CP-Contr,part						13	20	11	14	11	13	20	102	18	98
CS-Contr, full						21	24	21	21	21	21	21	157	23	162
CT-Tanker,Chem.						69	82	75	75	71	68	73	513	75	548
LA-LASH						0	0	0	0	0	0	0	0	0	2
LN-LPG/LNG						31	24	21	26	36	31	33	202	45	260
N/C-Not Clsfd.						0	0	0	0	2*	0	1	3	0	1
NA-Navy,combat						0	0	0	0	0	0	0	0	0	1
OB-Ore/Bulk/Oil						15	5	8	9	12	7	8	64	9	61
RE-Research						0	0	0	0	2	0	0	2	1	1
RF-Reefer,full						0	0	1	2	1	0	1	5	0	1
RO-Roll on/off						16	13	14	12	14	13	11	93	13	106
TK-Tanker,oil						111	118	119	114	120	128	129	839	120	761
TL-Tug, Light+						0	0	0	1	0	0	0	1	0	0
TT-Tug/tow+						33	20	28	21	16	14	21	153	13	132
VC-Vehicle Carr.						11	6	7	5	6	4	7	46	11	66

+ = Offshore Tugs only
* = Special oil industry ship & hospital/mercy ship.

Figure 17: Information available from the Marine Exchange of The West Gulf

It appears that in 1993 in average 73 chemical ships visited the port each month.

The US Coast Guard

One of the departments of the US Coast Guard is the Vessel Traffic Control department (VTS). This department has as task to control the vessel movements in the port of Houston and Texas City. Their main goal is to avoid accidents. In order to operate successfully, the USCG needs accurate information about the positions of all ships in port. This information is obtained by:

1. The masters off the ships in port give voluntarily information about their position to the USCG when they pass certain points in the Ship Channel. This information is passed on to the USCG by radio.
2. At certain points in the ship channel cameras are installed. At the Vessel Traffic Control centre the traffic controllers can look into the Ship Channel with these cameras. It is possible to turn the cameras and to zoom in on different objects.
3. A radar is positioned near Galveston. On this radar it is possible to follow all ship movements in the Galveston Bay.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

Information about each movement of a vessel in port is written down in the vessel transit log. Each day a new vessel transit log is made. In average 365 vessel movements are made in the port of Houston and Texas City each day. In this number the movement of tugs and pleasure boats is excluded.

From the Vessel Transit log it is possible to get the data needed for the model although in the way the data currently is presented, this would be a lot of work. That is why the data base program was changed by the US Coast Guard for this study in such a way that all transits from a certain terminal during a three month period are selected and printed. The prints were made for each berth vessels of the shipping company studied visits except from the DOW terminal in Freeport. Freeport is not part of the same US Coast Guard district and therefore no information about this terminal was available at the Vessel Traffic Control centre in Houston. In total 29 docks were studied during the visits to the US Coast Guard. It took 22 hours to run the database program to select the desired information.

From the rearranged files, information about the docking times and the interarrival times of the different terminals was generated. The number of berth calls studied for each terminal was most of the time limited to about 20 calls (but at least one month was studied) due to the enormous amount of working hours involved. This means that it was just necessary to study the total 3 month period for terminals which are not visited very often. It is important to notice that the times mentioned in the Vessel Transit Logs are the entry times to the system of the US Coast Guard which means that they could differ slightly from the real transit times. The results of the study are presented in the following paragraph.

Docking times and IAT of the different terminals

The study is limited to the 29 docks which are most visited by the vessels of the shipping company investigated. For each dock the following information could be generated:

- * General information about the dock;
- * The period of which the transits were studied;
- * A bar diagram of the docking times;
- * Average docking time;
- * A bar diagram of the interarrival times (IAT);
- * Average interarrival times (IAT);
- * Average occupancy rate of the terminal.

In ? an example of the statistics made for a each dock is printed. The numbers on the horizontal axis are in hours and the numbers on the vertical axis show how many times a certain entry occurred.

It is important to notice that barge activities at the terminals are excluded from this study. In the port of Houston about 65% of all movements in port are barges. At most terminals ships will not be delayed because of barge activities because:

- * Barges are most of the time shifted away when a ship wants to dock a berth;
- * Many terminals have separated barge and ship docks;
- * Barges are much cheaper to operate than ships. The demurrage bill from a ship operator will therefore be larger than the demurrage bill from a barge operator.

At a few terminals vessels of the shipping company studied could be delayed because of barge activities. These terminals are:

- * GATX Galena Park;
- * Stantrans;
- * Petro United;
- * Paktank Deer Park;
- * Old Manchester;
- * DOW.

In **Chapter 6** it will be explained how the statistics concerning the terminals mentioned above are corrected for barge traffic.

SIMULATION AND PROGRAMMING APPROACH

Simulation approach

In the paragraph 'Input data required' was explained that there are two different ways of modeling the chemical shipping activities in port: (1) from the ship point of view and (2) from the terminal point of view. In the first modeling approach the **vessels** will have a process and in the second modeling approach the **terminals** have a process. Each of these modeling approaches require different input data. The choice of modeling approach depends on the available input data. For this reason the second modeling approach was chosen². The following input data is required:

- * Statistics of interarrival times of the vessels at a specific dock;
- * Statistics of the lay times at the dock;
- * Statistics of the waiting times of vessels when waiting for an occupied berth;
- * Shift times between the docks.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

It is important to notice that statistics are needed for each specific dock because it often happens that a vessel has to visit a specific dock at a terminal. This is caused by the fact that some docks have limited cargo handling capabilities³.

For terminals which have more than one dock that can conduct all kinds of cargo handling, statistics are needed for the combined operations of these docks because the performance of the terminals is influenced substantially by this flexible terminal layout. The average waiting time for an occupied dock will be reduced considerably. The Exxon terminal is a good example of this phenomena. Exxon has 2 berths which are both able to handle all kinds of chemicals. In the 'Disturbance Analysis' presented in **Chapter 3** it appeared that waiting for an occupied berth at Exxon happens very rarely, although the average occupancy rate of the terminal is 19%⁴. **Chapter 6** will explain how the statistics of separate docks are combined resulting in statistics for the overall terminal performance.

Programming approach

Translating the model into a computer program can be done in two ways⁵:

1. The real situation will be modelled as close as possible by introducing components with attributes. The terminals will work simultaneously, with each their own terminal process while the vessel of the shipping company studied will sail to each terminal according to the feasible route (the vessel of the shipping company studied also has its own process). Because the terminals are working simultaneously, this programming approach will be called the 'simultaneous programming approach'.
2. It is also possible to simulate reality with terminals working sequentially instead of simultaneously. When a vessel of the shipping company studied arrives at a specific terminal, the terminal will start simulating its own process (meaning arrivals and departures of vessels) from the pre-defined beginning point⁶ to the current time. After this simulation process it will be clear whether the terminal is occupied or not. This programming approach will be called the 'sequential programming approach'.

Both programming approaches described above have specific advantages and drawbacks. When using the 'simultaneous programming approach' the following points are of importance:

1. This approach corresponds very close with the actual situation in port, because in the real situation the terminals will also work simultaneously. This similarity between reality and the model makes communication with the users easier⁷.
2. It is possible to extend the model without complete changing the programming layout.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

3. The 'simultaneous programming approach' has one major drawback: The speed of the program. Because the terminals are running simultaneously some of the computer power is used for coordinating the activities. This is mainly done by introducing 'standby' procedures which means that certain parts of a running program will standby until a specific pre-defined condition occurs. Sometimes these 'standby' procedures will result in a loss of speed which is beyond the acceptable limits⁸.

The 'sequential programming approach' also has some advantages and drawbacks:

1. Explaining the way the model works to the users will be more difficult because it could be hard for the users to translate the real life situation of simultaneous working terminals to a model containing sequential working terminals.
2. When translating the model into source code according to the 'sequential programming approach' the resulting software will be designed for one specific situation and it will therefore be difficult to extend.
3. The coordination between the different modules in the program will not influence the speed of the program substantially. No 'standby' procedures will be required when programming according to the 'sequential programming approach'.

It is obvious that when the running speed of the program is of no importance, the 'simultaneous programming approach' will be chosen. But because the objective of this project is to design a planning tool which is going to be incorporated in day to day operations, there are some requirements concerning the running speed of the program. When the port agent has gathered all the required input information⁹ it must be possible to make the final decision about the first terminal call in the routing within a half an hour¹⁰.

In order to decide which programming approach will fit best for the 'Route Simulation Software' information about the difference in speed when running each of the programs should be available. It is very difficult to derive this information theoretically. Therefore two pilot programs were build, each based on a different programming approach, in order to compare the running speed of the programs.

After building and testing the two pilot programs it could be concluded that the program based on the 'sequential programming approach' was able to calculate the port time 3 to 4 times faster as the alternative program. This is the reason why the 'sequential programming approach' was preferred although there also are some disadvantages connected to this approach. The following paragraph contains a general description of the chosen modeling approach.

GENERAL DESCRIPTION OF THE COMPUTER MODEL

Introduction

The objective of the computer model is to calculate the optimal route for a vessel which visits different terminals in the Houston area. When a vessel arrives at the port of Houston (including Texas City and Freeport), the computer model requires the following input data:

- * The terminals (or berth's) which are going to be visited;
- * Restrictions in the order in which the vessel can visit the different terminals¹¹. The program will ask which berth has to be visited before another berth;
- * The position of the vessel;
- * For each terminal which is going to be visited the following information is required:
 - Whether the berth is occupied;
 - If the berth is occupied an estimate has to be made when the berth will be available. If the berth is available, the departure time of the last vessel leaving that specific berth has to be entered into the program. This information is available from the different terminals¹².

With the statistics of the interarrival times, docking times and waiting times at the different terminals and the matrix with sailing times between the different terminals (the 'shiftmatrix'), the movement of chemical ships in the port of Houston¹ can be simulated. Each individual terminal will, according to their input information, start to simulate arrivals and departures of vessels to their docks.

The program will first calculate all the different routing possibilities of the vessels (taking the limitations into consideration). The vessel will visit the terminals according to these feasible routes. For each route this process is repeated many times so that for instance the 90 percent quantile of the total time in port can be calculated. This means that 90% of all port visits according to that specific route will be within the calculated amount of hours. This process will be repeated for each different feasible route. The average port time and the 90 percent quantiles of the port time for each route will be compared with each other and the best routings will be printed on screen. Also the routing possibilities differing less than for instance 5 percent from the optimal solution will be printed. In this way good alternatives are available if the optimum solution is not acceptable for whatever reason.

The description of the model above will be further explained with the help of a flow chart technique introduced by Robert E. Shannon [3]. This approach is chosen because the visualization of models often makes it easier to understand them¹³. Four symbols are of importance (Figure 18).

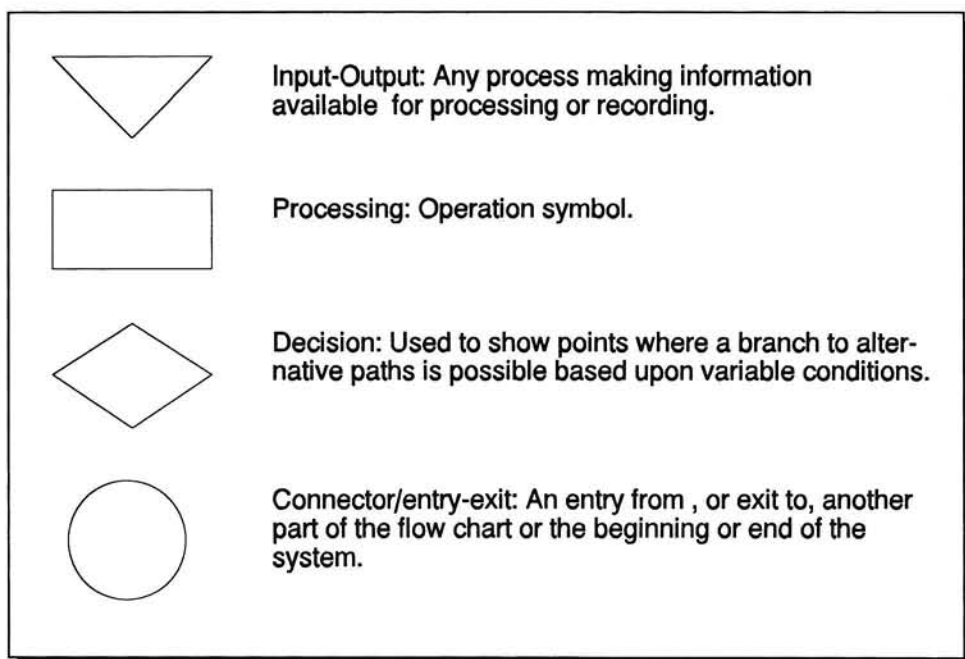


Figure 18: Symbols used in the flow charts

Flow charts for the 'sequential programming approach'

First a diagram of 'Main' will be shown (Figure 19). 'Main' is that part of the model which initiates the model variables and starts all the other parts of the model.

First the port planning model requires the input of relevant data. In the next unit, 'Make routing possibilities', all the different combinations of the rotation through port are calculated. Then the 'Control process' is started (Figure 20).

The 'Control process' acts as a central unit for the model. After finding a feasible route, the control unit will go to the 'Ship process'. In the 'Ship process' the total port time for the vessel will be calculated. This process is repeated until the accuracy of the simulated port time is satisfactory. The average port time and the 90 percent quantiles will be saved. If there are more feasible routes left, the process described above will be repeated. Otherwise the results will be printed on screen.

As explained before, the total port time of a vessel is calculated in the 'Ship process' procedure (Figure 21). This procedure starts with finding the next terminal that is going to be visited in the rotation through port. It will then wait the appropriate shift time. This is done by increasing the current port time with

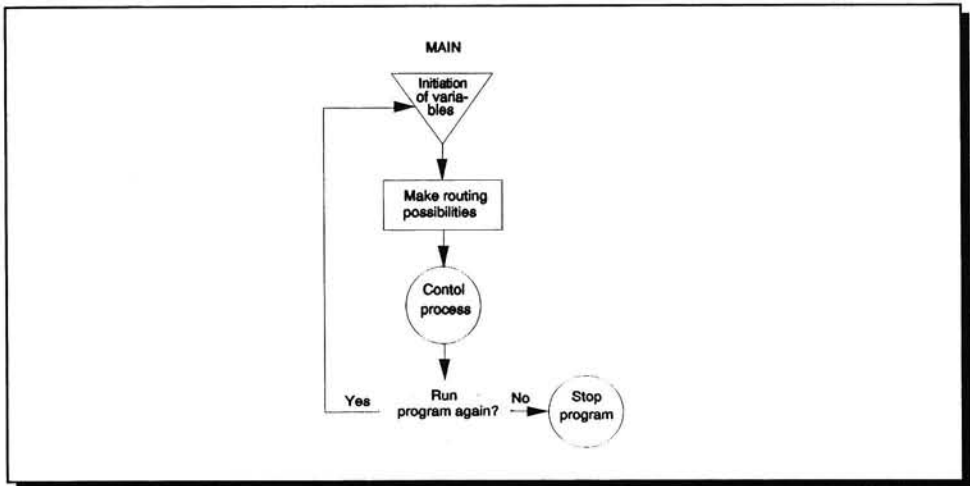


Figure 19

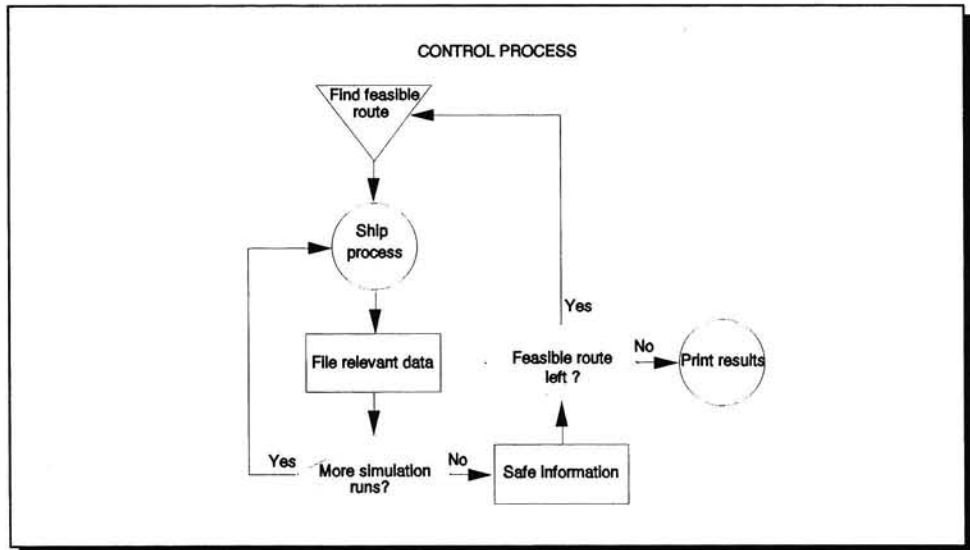


Figure 20

the shift time. Next, the 'Terminal process' will be called (Figure 22). In the 'Terminal process' the current port time will be increased with the docking time at that terminal. If that terminal was occupied when the vessel arrived, the appropriate waiting time will also be added to the port time. This process will be repeated for each terminal in the routing of the vessel. Finally, the shift time from the last terminal to the port exit will be added to the port time, resulting in the total port time.

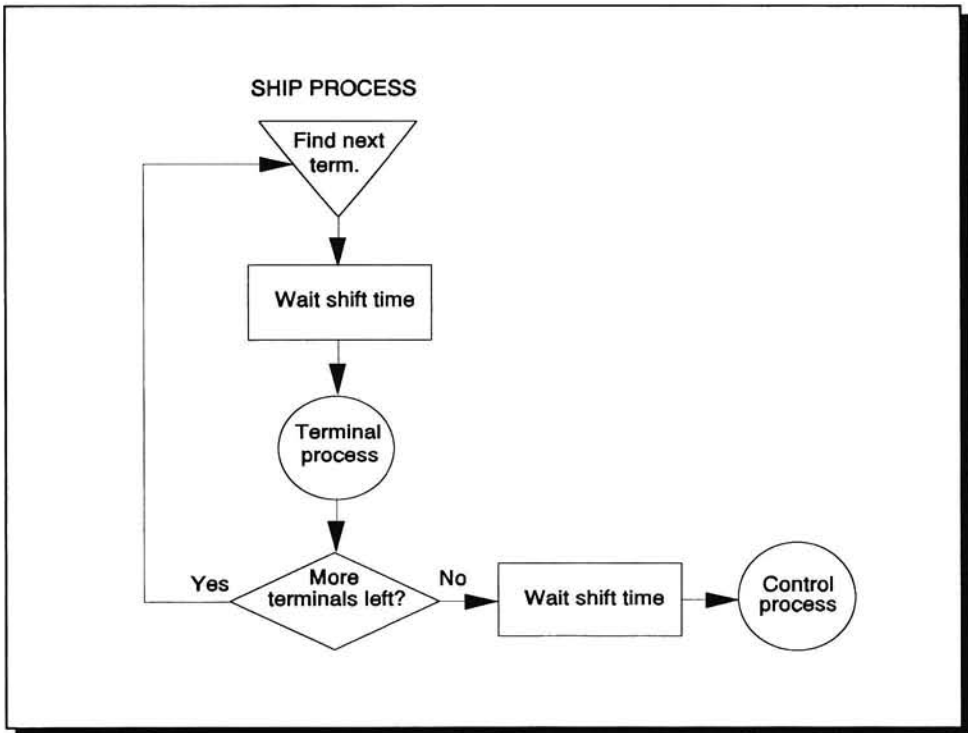


Figure 21

The 'Terminal process' starts with initiating the relevant variables for this particular terminal. Then the interarrival time (the definition is derived in this model from the standard definition) is drawn and added to the terminal time. Now it is important to notice the difference between the terminal time (tt) and the port time (pt). The port time represents the time the vessel has spent in port. The terminal time is a 'local' time for each terminal which will increase from its pre-defined condition to the level of the actual port time (excluding the shift time to the terminal currently visiting) by adding interarrival times and docking times of vessels visiting that terminal.

In the following chapter important processes of the 'sequential programming approach' will be discussed in more detail.

Description of important processes in the simulation model

In this paragraph the most important processes in the port call simulation tool will be described in more detail. First the process of 'Main' will start up the program and from there the 'Control process' will act as a central control unit. The processes of 'Main' and the control unit will be explained first:

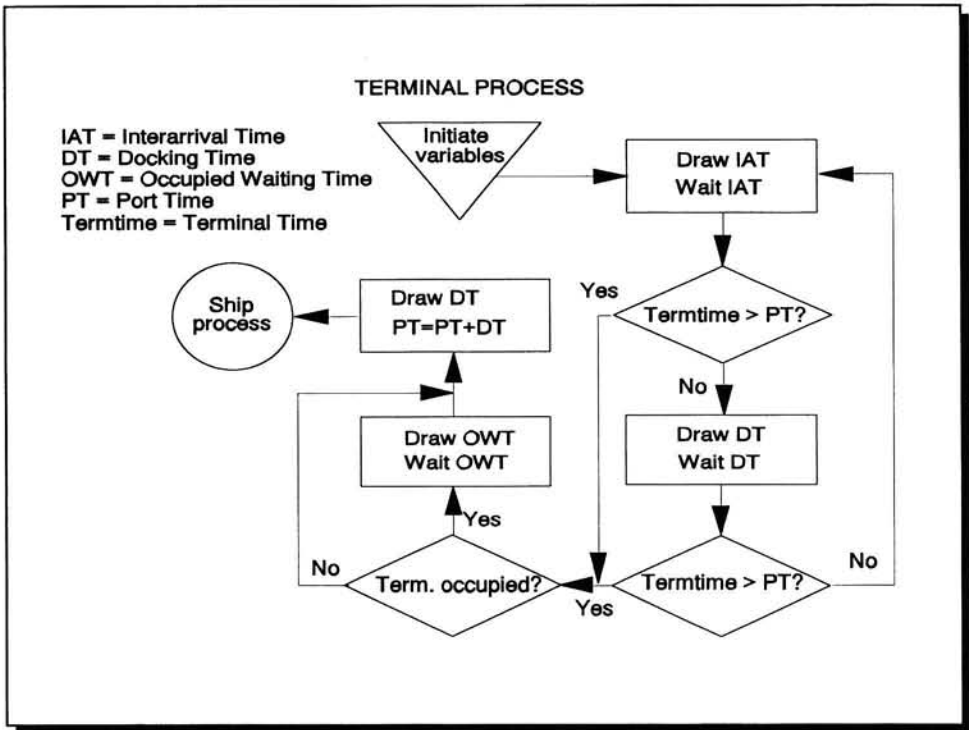


Figure 22

Process of Main¹⁴

- Give appropriate values to the system variables
- Open input files^a
- Repeat until input data is correct
 - Read input information^b
 - Print the input data on screen
- Read the shift matrix from file
- Make a route matrix^c
- Start control process
- Stop program

- a. Input files are files containing information about the matrix of shift times between the different terminals and some useful information concerning the creation of the routing possibilities.
- b. The procedure 'Inputdata' will be started up. In this procedure all the relevant information will be entered into the program by the user.
- c. Based on the input information all the feasible routings will be calculated.

Control process

For each different route doL

Take the first route out of the route file^a

Check the route feasibility^b

If the route is feasible do:

Repeat n times^c

Start ship process^d

Check accuracy of the port time

Save relevant data^e

Calculate the average port time (and the 90% quantile)

Reset port time

Print the best results and the acceptable alternatives^f

- a. The route file contains the remaining routes (terminals not visited yet) of the vessel (managed by the shipping company investigated);
- b. Check if the selected route complies with the restrictions entered into the program by the user;
- c. The number of simulations will depend on the accuracy required¹⁵;
- d. Now the procedure 'Shipprocess' will be called;
- e. The time used for each port visit (port time) is filed. With these data the average port time and the 90% quantiles¹⁶ can be calculated;
- f. The 90 percent quantiles and the average port times for the different routings will be compared with each other.

Process of ship

Repeat until all the terminals of the route have been visited

Get first terminal out of the route

Wait shift time^a

Start terminal process^b

Correct the value indicating the position of the vessel^c

Correct the route^d

- a. The shift time is added to the port time;
- b. Now the procedure 'Terminalprocess' will be called;
- c. A correct indication of the current position of the vessel is required in order to find the required shifting times in the matrix of shift times ('shiftmatrix');
- d. The terminal just visited will be excluded from the route.

Process of terminal

Give appropriate values to the terminal variables^a

Repeat until port time^b < terminal time^c

Sc = draw from interarrival time distribution

Add Sc to the terminal time

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

Sd = draw from docking time distribution

Add Sd to the terminal time

If (terminal time - Sd) < port time then

The terminal is occupied

If the terminal is occupied then

Draw waiting time from the OWT distribution^d

Add this waiting time to the port time

Draw docking time from the docking time distribution^e

Add the docking time to the port time

Reset the terminal variables^f

- a. Interarrival Time- (IAT), Docking Time- (DT), and Occupied Waiting Time- (OWT) distributions belonging to this specific terminal have to be defined. The terminal time will also get an appropriate value according to the existing auxiliary conditions. For example, if the terminal is occupied and will be available 20 hours from now (according to the dock master¹⁸ of the terminal), the terminal time will get the value 20. Notice that the terminal time is just the 'local' 'imaginary' time at the terminal and the port time is the 'real' time that the vessel of the shipping company investigated has spent in port.
- b. The shift time to the terminal visiting at the moment should not be added to the port time when checking whether the terminal is occupied. The vessel will tender NOR when finishing cargo handling at the previous terminal visited.
- c. Docking times and interarrival times will be added to the terminal time until the port time (actual situation) has been passed. Now can be concluded whether the terminal is occupied or not. Of course this procedure can only be executed if in the initial situation the port time is larger than the terminal time. If this is not the case, special arrangements have to be carried out.
- d. OWT = Occupied Waiting Time distribution.
- e. The docking times for vessels managed by the shipping company investigated are drawn from a different distribution than the docking times for all the other vessels visiting port. The vessels of the shipping company investigated are relative small and will therefore on average have shorter docking times than the average docking times of chemical vessels visiting port.
- f. This means that the distributions are destroyed and that the terminal time will get the value zero (which is the beginning point of the simulation) .

Notes

1. Including Texas City and Freeport.

2. The second modeling approach was chosen because the required input data could be constructed from information obtained from the US Coast Guard.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

3. For example, the DOW terminal has two docks (the A4 and the A8) of which the A8 dock has limited cargo handling capabilities. A similar situation appears at the Paktank Deer Park terminal.
4. Berth number one and berth number two of the Exxon terminal have occupancy rates of 24.58% and 13.42%, respectively. These numbers are based on information inquired from the US Coast Guard.
5. There are more than two possible programming approaches, but the two approaches presented in this paragraph are the most appropriate when considering the auxiliary conditions.
6. The pre-defined beginning point will get an appropriate value which is based on the actual situation in port.
7. It is easier for the users to visualize the modelled situation in port because it is similar to actual situation.
8. This conclusion is based on experience. Both ir. E.A.F. Kraan, member of the staff of the department Logistics within Delft University of Technology, and myself have experienced that 'standby' procedures can reduce the running speed of the program. It is important to notice that in most of the simulation models this loss in speed is of no importance (most often it is not noticed).
9. The port agent gathers the relevant input information by calling the terminals.
10. This means that the planning tool should be able to present conclusions within half an hour.
11. Restrictions in the rotation through port are most of the time caused by the stowage plan. This means that some cargoes have to be loaded or discharged before other specific cargoes. This is caused either by safety requirements directly concerning the cargo or by stability requirements of the vessel.
12. The port agent can obtain this information by calling the different terminals.
13. In the paragraph 'Description of important processes in the simulation model' the model will be explained in greater detail with the process-description-method [4]. This method is a way of modeling the desirable situation and has a near connection with the specialized program codes available for simulation (for instance like Pascal and Must).
14. In the source code the process of 'Main' will not be exactly the same as described in the 'process description'. In the source code the tasks as described in the 'process description' are spread over 3 procedures: 'Main' (which is not really a procedure), 'Mainmenu' and 'Startup'.
15. This is a management decision. In the configuration file the required accuracy used when running the program, can be changed according to the users preference.
16. Of course other quantiles than the 90 percent quantile can also be calculated.
17. The port time will be deduced by simulation.
18. The dock master is in charge of cargo handling operations at a terminal and will therefore be able to make an educated guess when the terminal will be available considering the vessels currently visiting the terminal and the vessels that have tendered NOR (Notice Of Readiness).

CHAPTER 6: ARRANGEMENT OF THE INPUT DATA

INTRODUCTION

The gathering and the arrangement of input data is one the most important activities when simulating real life situations, like the chemical shipping activities in the port of Houston¹. The previous chapter gave a detailed description of the gathering process. In this chapter the arrangement of the input data will be discussed.

First will be explained in which way the data needs to be presented for a computer program in order to draw from a distribution. Paragraph 'Drawing from a distribution' concludes with a brief explanation of the way the available statistics² need to be rearranged in order to fit into the statistical framework of the computer program. The paragraph 'IAT distributions' will in further detail explain how the IAT (Inter Arrival Time) distributions are constructed. Especially the influence of barge traffic will be explained. The following paragraph's will discuss the arrangement of the docking time distributions and the OWT (Occupied Waiting Time) distributions in more detail. Of course it also important to check the correlation between the statistics used in the computer model (paragraph 'The correlation between the statistics').

Some terminals can handle certain kinds of cargo at more than one dock. This influences the terminal performance and therefore adjusted statistics are required (paragraph 'Consequences of a flexible terminal layout'). This chapter concludes with a brief presentation of the arrangement of non-statistical input data.

DRAWING FROM A DISTRIBUTION

In order to simulate the real situation in port, the characteristics of the port has to be incorporated in the model. Both knowledge of the port layout and knowledge of the vessel movements is required. The vessel movements are incorporated in the interarrival time statistics and the docking time statistics of the terminal. These statistics are based on information inquired at the US Coast Guard office in Houston. Of course, some adjustments are required in order to draw from the distributions in a simulation environment.

In a simulation environment drawing from a distribution will proceed as follows (Figure 23):

The statistics need to be presented as cumulative distributions. When drawing, the program will shoot randomly on the Y-axis, between the minimum and

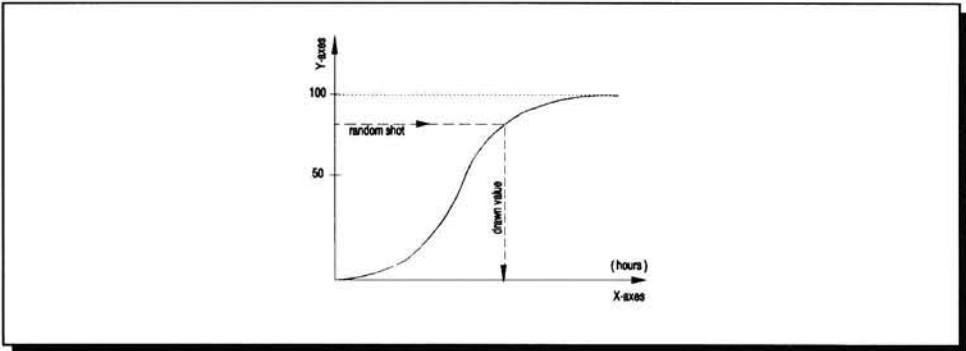


Figure 23: Drawing from a distribution

maximum value. This is shown in the graph above. The corresponding X-value is then the desired value from the distribution. This means that the frequency histograms of the interarrival times and the docking times need to be transformed into cumulative percentage frequency histograms. This transformation process will proceed as follows (Figure 24):

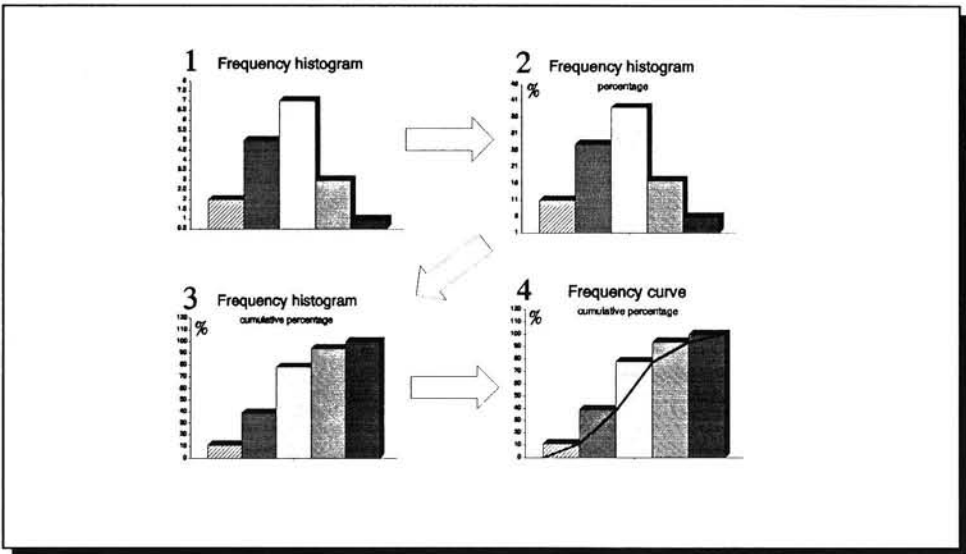


Figure 24: Transformation process of frequency histograms

In the simulation environment used for the 'Route Simulation Software'³, it is not required to transform the cumulative frequency distribution into cumulative percentage frequency diagrams. In this way many working hours can be saved.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

An example of the transformation process for the interarrival time distribution of ITC's berth 1 is shown in the following diagram (Figure 25):

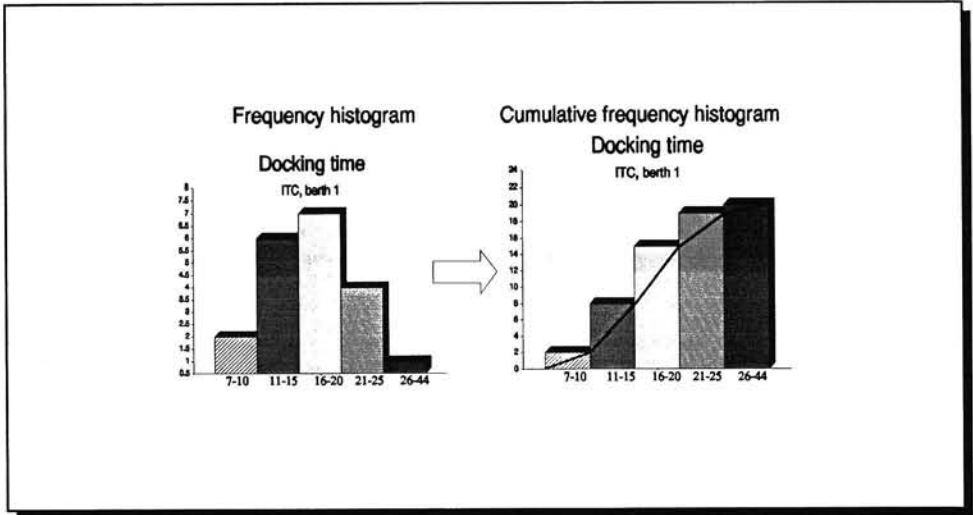


Figure 25: Histogram transformation process for ITC's dock number 1

The line drawn in the cumulative frequency diagram shows how the diagram is defined in the simulation environment used³. This distribution is created by the following command:

```
dockdis:=NewDis('table(7,0,10,2,15,8,20,15,25,19,44,20)',rando).
```

'Rando' is the random sequence which is 'shot' at the Y-axis. All the statistics concerning the docking times and the interarrival times for each dock are transformed in the same way as shown above, although corrections were necessary for some of the interarrival time distributions because of the influence of heavy barge traffic. This is explained in the following paragraph.

IAT DISTRIBUTIONS

From the US Coast Guard it appeared that about 65% of all movements in the port of Houston is barge traffic. It was pointed out that most of the vessels will not be delayed because of these barge activities because ship operators will sent larger demurrage bills than barge operators. But at a few terminals, barge activities could delay ship operators⁴. According to operational management these terminals are⁵:

- * GATX Galena Park;
- * Stantrans;

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

- * Petro United;
- * Paktank Deer Park;
- * Old Manchester;
- * DOW (Freeport).

According to an estimate of operational management, about 10% of the times that a vessel has to wait for an available dock is caused by a barge occupying that particular dock. In order to simulate the reality as well as possible, these barge activities have to be incorporated in the statistics of the relevant terminals. In the current statistics only the vessel movements are incorporated.

The barge activities result in an increase of the occupancy rate of the terminals. Correcting the statistics in such a way that the occupancy rate will be increased, can be done in several ways. Decreasing the average interarrival times seems an appropriate solution. When the required increase of the occupancy rate is known, the correction factor for the interarrival times can easily be calculated.

When 10% of the waiting time is caused by barges, in the current statistics just 90% of the relevant activities is incorporated. Increasing this number to 100% means that $10/90 \times 100 = 11.1\%$ increase of the number of terminal calls (in this way the barges arriving at the terminal are incorporated). In other words, 11.1% more vessels (or barges) will visit the terminal per unit of time. This results in an increase of the occupancy rate of 11.1% (Assuming that the arrival pattern of the barges is similar to the arriving pattern of the vessels).

The occupancy rate is calculated by the following formula:

$$Occu = 100 * DT / (DT + IAT_{old})$$

The symbols have the following meaning:

- * DT = average docking time
- * IAT_{old} = average interarrival time without barge activities
- * IAT_{new} = average interarrival time including barge activities
- * Occu = occupancy rate according to current statistics
- * f = Correction factor for the occupancy rate ($f = 1.11$)

When barge activities are included, the formula above will have changed to:

$$Occu * f = 100 * DT / (DT + IAT_{new})$$

From the formulas printed above IAT_{old} and IAT_{new} can be calculated. This results in:

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

$$IAT_{new} = ((1 - f * Occu / 100) / (f * (1 - Occu / 100))) * IAT_{old}$$

If, for example, $DT = 60$ and $IAT_{old} = 40$ the occupancy rate will be 60%. When correcting the statistics for barge activities the occupancy has to be increased to $1.11 \times 60\% = 66.67\%$. When filling in the appropriate values in the formula derived above, as explained above, IAT_{new} can be calculated. This results in:

$$IAT_{new} = 0.75 * 40 = 30$$

Now the occupancy rate will be:

$$Occu = (100 * 60) / (60 + 0.75 * 40) = 66.67\%$$

The interarrival time statistics of the terminals mentioned in the beginning of the paragraph will all be corrected according to the method described above. It is important to notice that the new statistics do not give a good picture of the barge activities at a specific dock according to the real situation. Only the barge activities that causes delays for one specific shipping company are incorporated.

DOCKING TIME DISTRIBUTIONS

The distribution of the docking times for a dock, shows how long a vessel stays at that specific berth. The statistics are based on all vessels that are visiting that dock during a specific period.

In the simulation model, described in **Chapter 5**, two kinds of vessels can be distinguished, vessels managed by the operator investigated and vessels managed by 'other' operators. The first category has its own 'process' ('Ship process'). Both types of vessels will visit different terminals and therefore docking times need to be drawn from the appropriate distributions. In this model, the docking times for vessels managed by the shipping company investigated and vessels managed by 'other' operators are drawn from different distributions. Investigation showed that it is not acceptable to draw the docking times for both types of vessels from the same distribution because the docking times for vessels operated by the shipping company investigated are in general smaller than the average docking times for all the vessels visiting port. This is caused by the fact that the shipping company investigated operates small vessels.

The distribution of the docking times for vessels managed by the shipping company investigated were made by studying docking times during the years 1991 and 1992 in the Daily Vessel Reports. The collection of data is converted into statistics in a similar way as done for the interarrival time statistics and the general docking time statistics as explained in the previous chapter.

The distributions of the docking time for the 'other' operators are based on information inquired at the US Coast Guard office in Houston.

OWT DISTRIBUTIONS

OWT (Occupied Waiting Time) is defined as the time that a vessel will be delayed when arriving at an occupied berth⁶. When simulating from the terminal point of view⁷ it is not sufficient to just wait until the vessel that is visiting the actual berth at that moment has left. The possibility that more than one vessel is waiting for the berth should be taken into consideration as well as time lost because of extra shifting activities⁸. This is the reason why special statistics concerning this subject should be made for each berth.

The OWT statistics can be based on available information in the administration of shipping company investigated. For terminals not visited very frequently and where delays caused by an occupied berth occur rarely, information for the OWT-statistics is hard to obtain. In this case estimates of the OWT-distribution are made in cooperation with the operational manager.

THE CORRELATION BETWEEN THE STATISTICS

Theory

In the model of the chemical shipping activities as explained in **Chapter 5**, the terminals are simulated as independent processes. In other words the model assumes that the state of one terminal does not influence the state of the other terminals. From the description of the activities in port (**Chapter 2**), it appeared that the assumption made above cannot be totally correct: Each shipping company will try to limit the port time of their vessels by minimizing the waiting time at the terminals. In other words the arrival distribution at a terminal will be influenced by the state of the terminal⁹ and the state of other terminals¹⁰. The vessels will try to avoid terminals which are occupied. Of course it is important to notice that many vessels do not have the possibility to visit another dock first. This occurs for example when just a few terminals are left in the rotation. In this context it is also important to notice that large vessels¹¹ have the tendency to visit less terminals¹² than smaller vessels and that barges most of the time transport commodities from just one terminal to another.

In the following paragraph will be checked to what extent the terminal processes are dependent, but first the phenomenon correlation will be explained. Assume that two situations exist, both based on the same data (**Figure 26**). When observing the two situations described above (black box approach¹³), statistics of each situation can be made (similar as the statistics of the interarrival times and the docking times were made). The statistical properties of each of the situations will be the same (the same data occurs in both situations). In other words, the average and the deviation will be the same in both situations. The

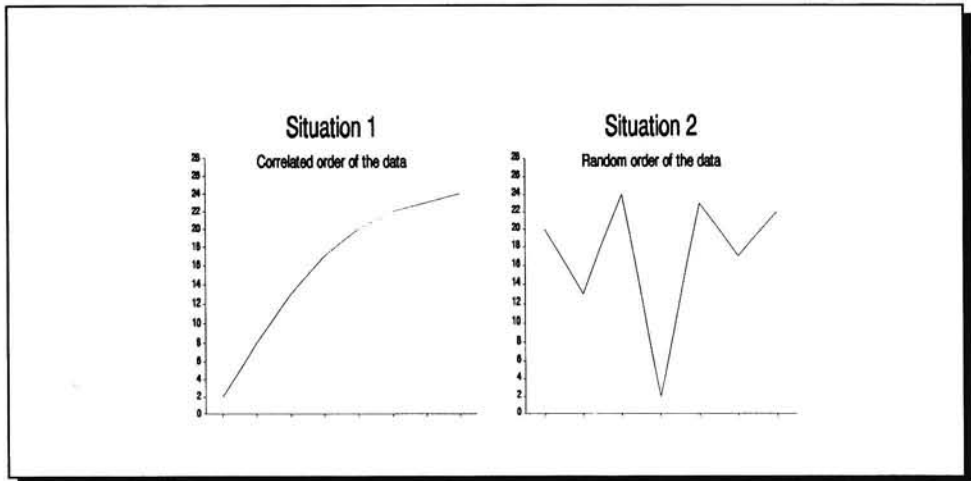


Figure 26: Difference between correlated data and data in random order

resulting statistics of the two situations described above will therefore be identical and shaped as the statistics shown in situation two (random order). It is obvious that the statistics in situation two do not give a correct picture of the actual performance of situation one; In situation one the data is correlated and in situation two the data is not correlated. In the gathering process of the data finally resulting in statistics, important information about the correlation between the data is lost. Therefore it is important to check whether or not the data within a distribution is correlated.

Until now only the correlation between data within one distribution was discussed. But there could also be a correlation between the different types of distributions. In this context two situations can be checked:

1. Are the docking times correlated with the interarrival times. For example, long docking times could result in short interarrival times because there is a greater chance that a vessel arrives at an occupied dock. Although theoretically, the interarrival time could influence the docking time, though this is not very likely.
2. Is the combination of the interarrival time and the following docking time correlated with the next interarrival time. Here the same argument as discussed in the previous point could be applied.

In the following paragraph, both the correlation between the data within a distribution and the cross correlation between the distributions will be checked.

The correlation check

The correlation between two variables can be expressed by calculating the correlation coefficient 'r'. The variable 'r' measures the strength of the linear relationship between the variables, say x and y [6]:

$$r = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2} \sqrt{\sum (y - \bar{y})^2}}$$

When checking the correlation between variables within one distribution, the formula above will change to [7]:

$$r = \frac{\sum_{i=2}^n (x_i - \bar{x})(x_{i-1} - \bar{x})}{\sum_{i=1}^n (x_i - \bar{x})^2}$$

The value of 'r' will be in the range of -1 to 1. When 'r' approaches zero, x and y will be totally un-correlated. If 'r' approaches one of the extremes (1 or -1), x and y will be totally correlated.

In order to calculate the correlation coefficient with sufficient accuracy at least 100 entries are desired [7]. Unfortunately, only 20 entries are available for both the interarrival time distributions as the docking time distributions¹⁴. Therefore the results should be interpreted with great care.

Correlation within a distribution

A program was designed to calculate the correlation coefficients. The formula above is incorporated in the program. The series of interarrival times and the docking times concerning several terminals were entered into the program¹⁵. The 90 percent confidence intervals (C_{int}) calculated for these terminals was (DT = Docking Time, IAT = Interarrival Time):

$$C_{int,DT} = (-0.13, 0.05) \text{ and } C_{int,IAT} = (-0.06, 0.11)$$

When interpreting this result it is important to notice that when entering 20 totally un-correlated numbers the 90 percent confidence interval would be: $C_{int} = (-0.05, 0.07)$. In other words, there could exist a limited correlation between both the data of the docking time statistics and between the data of the interarrival time statistics.

Cross correlation of distributions

In order to calculate the coefficient for the cross correlation between two distributions, another program was written. The following results were obtained:

1. The influence of the docking times on the interarrival times (90 percent confidence interval):

$$C_{int} = (-0.014, 0.149)$$

In this situation there could exist a limited correlation.

2. The influence of the combination of the interarrival time and the following docking time on the next interarrival time (90 percent confidence interval):

$$C_{int} = (0.053, 0.211)$$

Also in this case there could exist a limited correlation.

3. The influence of the interarrival time on the docking time (90 percent confidence interval):

$$C_{int} = (-0.015, 0.077)$$

As expected, the interarrival time does not influence the docking time.

The limited correlations found above will be neglected. If the port times of the simulations approximately correspond with the port times of the real situation, the assumption made above will be acceptable. If this is not the case, an adjusted approach of the drawing process from the distributions might be required (in order to incorporate the limited correlation). The simulation tool will be tested in **Chapter 9**.

CONSEQUENCES OF A FLEXIBLE TERMINAL LAYOUT

At some terminals vessels can dock at more than one berth. Such terminals can be considered as having a flexible layout. If the products which require cargo handling can be handled at more than one berth at a certain terminal, the statistics of the individual docks at these terminals do not give the actual picture of the situation. The chance of facing an occupied dock will be reduced substantially if more than one dock can be visited.

In order to cope with this problem, additional statistics are made. These statistics represent the overall performance of a terminal. This option will only be

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

used when the required cargo handling can be executed at any of the berth's available.

The overall terminal statistics were made with the help of a dedicated simulation model. In this model the docks of a certain terminal are simulated simultaneously in such a way that new statistics of interarrival times and docking times could be made. The following diagram shows how the process of the dock is modelled (Figure 27):

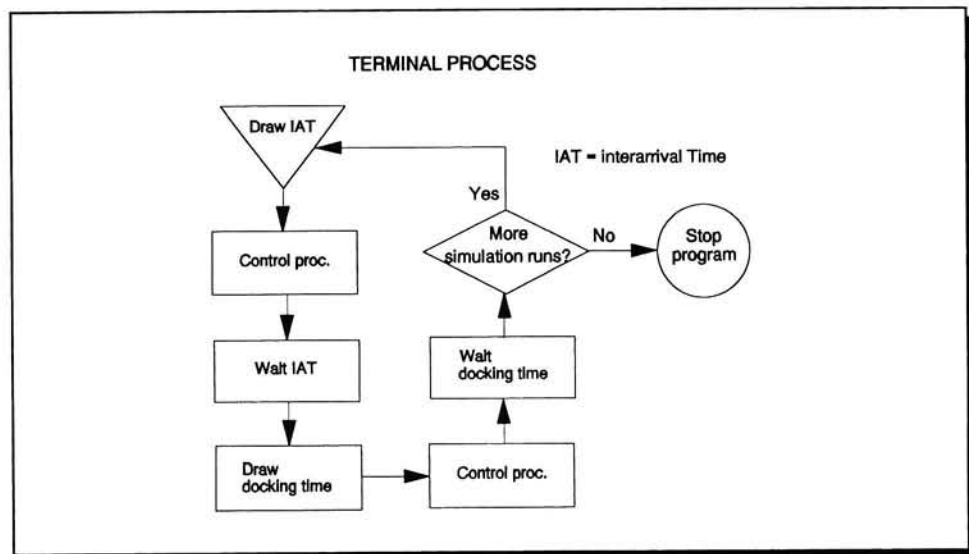


Figure 27

In the block 'Controlprocess', occurring twice in the model, the docking times and the interarrival times for the flexible terminal layout are initiated when necessary. The gathering of information resulting in statistics of docking times and interarrival times for the whole terminal is also taken care of by the control process.

The results of the program are printed in histograms. For example, the results for the Baytank terminal are printed in Figure 28 and Figure 29.

From Figure 28 can be concluded that the average docking time is 9.9 hours. This is considerably less than the average docking times available from the statistics for each separate berth of the Baytank terminal (18.87 hours and 25.82 hours). The average interarrival time is 61.89 hours for the terminal (Figure 29). The interarrival times of the two berth's separately was 30.95 hours and 45.25 hours.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

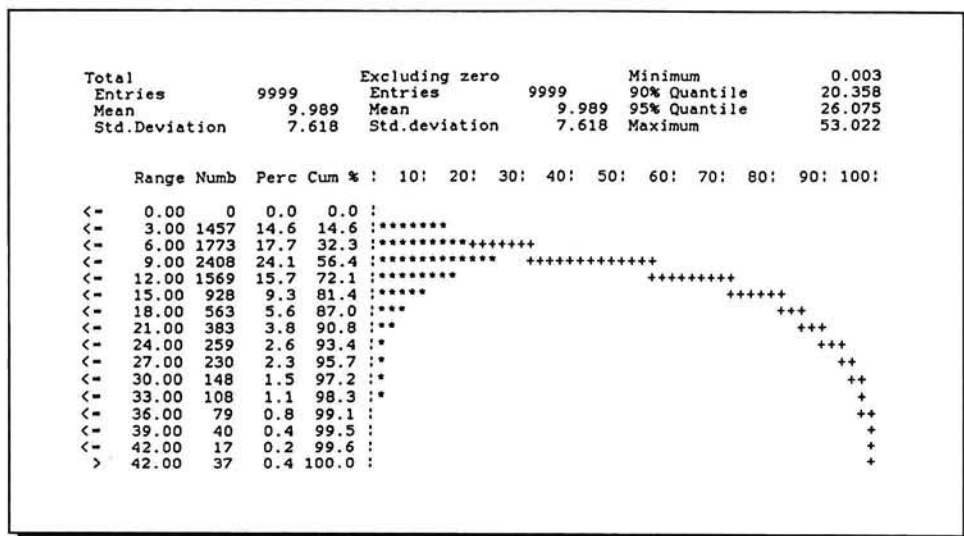


Figure 28: Histogram of docking time for the Baytank terminal

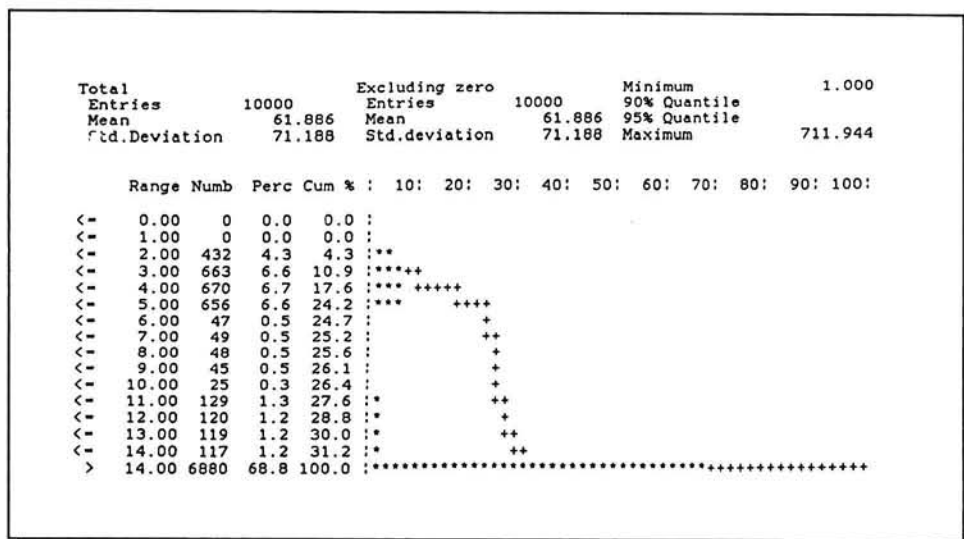


Figure 29: Histogram of interarrival times for the Baytank terminal

The decreasing docking times and the increasing interarrival times lowers the chance of facing delays because of non availability of a berth. Only 13.79 % of the time both berth's will be occupied at the same time.

Both the statistics of the docking times and the interarrival times concerning the overall terminal performance do not give a picture of the real situation at the

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

terminal as the terminal was just considered as being occupied when both berth's were occupied at the same time.

Additional statistics were made for each terminal which has more than one berth available for cargo handling. These terminals are:

- * Baytank;
- * City Dock;
- * Exxon;
- * ITC;
- * Oiltanking;
- * Paktank Deer Park;
- * Shell;
- * Stantrans;
- * Union Carbide;

OTHER INPUT INFORMATION

When making a characteristic of the chemical shipping activities in the port of Houston¹, this will include the statistics described in the former paragraph's and information about the port layout.

Information about the port layout is summarized in the matrix of shift times. This matrix contains the sailing times between all the different terminals. The data in the shiftmatrix will be read from an specially designed input file.

Information concerning the relevant terminals and the vessel which is going to be simulated will be entered into the model by the user. The information will be stored in different matrices.

Notes

1. Including Freeport and Texas City
2. This means the interarrival time statistics and the docking time statistics.
3. The program is written in Borland Turbo Pascal 6.0 together with Must 5.0.
4. It is important to notice that the largest barges could be of the same size (or even bigger) than the vessels managed by the shipping company investigated. Operators of larger vessels will therefore have less problems with the barge traffic.
5. This information concerns one specific shipping company and can very well be different for other shipping companies.
6. This involves vessels managed by the shipping company investigated.
7. Chapter 5 explains the concept of 'simulation from a terminal point of view'.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

8. When a vessel has to wait for a particular berth it has two possibilities: (1) Docking at a lay by berth or (2) Anchoring at Bolivar Road. Both alternatives will result in extra shifts.
9. Whether the terminal is occupied or not.
10. If the other terminals remaining in the route are available one of these might be visited first.
11. According to operational management 65% of the vessels visiting port can be considered as large vessels.
12. The number of terminals is reduced by transporting some of the commodities by barge to one terminal.
13. The observer will not have any knowledge of the way the data in the real situation is arranged.
14. More data for each terminal can be gathered by carrying out additional runs with the database of the US Coast Guard. **Chapter 5** described the gathering process of input data in detail.
15. The data of the 20 terminals were used when calculating the correlation coefficient.

CHAPTER 7: THE COMPUTER PROGRAM

INTRODUCTION

The 'Route Simulation Software' carries out the desired operations, as explained in the previous chapters. The program consists of more than 40 modules (procedures).

It is of great importance to document the program as well as possible so that other people besides the author can also carry out the desired operations successfully. The following strategy was chosen in order to document the program:

1. A definition of the objective of the program was given in **chapter 5**;
2. The most important processes were described with the process description method. In order to put these process descriptions in the right context, flow charts were introduced. The performance of the model was explained with the help of these diagrams. **Chapter 5** contains the diagrams of the model and the process descriptions;
3. Based on the process descriptions the computer program was made. The connection between the different modules (procedures) in the computer program will be explained in the following paragraph ('Connection between the modules'). This is visualized with the help of some diagrams;
4. The transformation process of data to program input data was explained in the previous chapter;
5. In order to explain how the program can be used, following chapter contains a users guide.

CONNECTION BETWEEN THE MODULES

The connection between the different modules of the program will be explained with the help of diagram techniques. The total diagram is split up into four different parts, as the complete diagram does not fit on one page. Each of the four diagrams will be explained.

Main

Each cube in **Figure 30** contains a procedure. 'Main' is not a procedure and is therefore printed as a cube with circular corners. The diagram should be read from the left to the right. Some procedures are called once from its 'parent-procedure' while others are called several times. Arrows with a striped line means that a procedure can be called several times. The bold line means that the procedure will be called once from its 'parent procedure'. When a 'bomb' appears in the right hand corner of a block it means that the contents of this

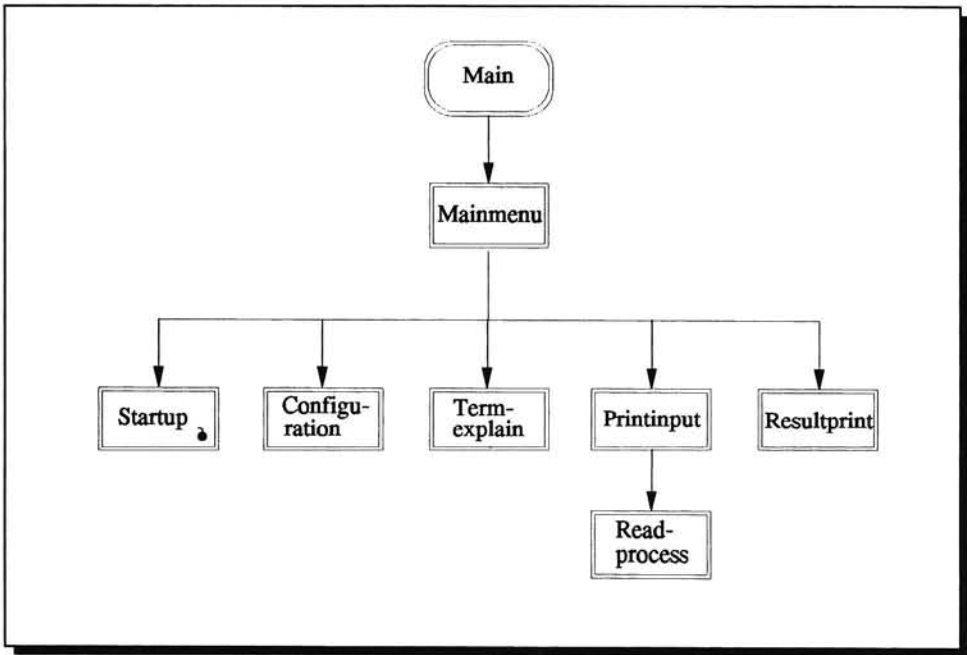


Figure 30: Connection between the modules, diagram I

procedure is explained in a separate diagram.

'Main' begins with calling the procedure 'Mainmenu'. In this procedure the main menu is printed on screen. The user has the option to start the program (procedure 'Startup'), change the configuration of the program (procedure 'Configuration') or get an explanation of what number belongs to what terminal (procedure 'Termexplain')¹. It is also possible to look at the latest input data or results by calling the procedures 'Printinput' and 'Resultprint', respectively². The layout of both the main menu and the configuration file will be explained in more detail in the next chapter 'The users guide'.

Startup

When the user has decided to start the program, the procedure 'Startup' will be called (Figure 31). This procedure starts with collecting the relevant input data by calling the procedure 'Inputdata'. Next the collected input data will be printed on screen (procedure 'Printinput'). If the user is not satisfied with the data, it is possible to return to the procedure 'Inputdata' and correct the mistakes.

After collecting the necessary input data, the program will read the shift times between the different terminals from the file 'shift.jdd' (procedure 'Make_shift-

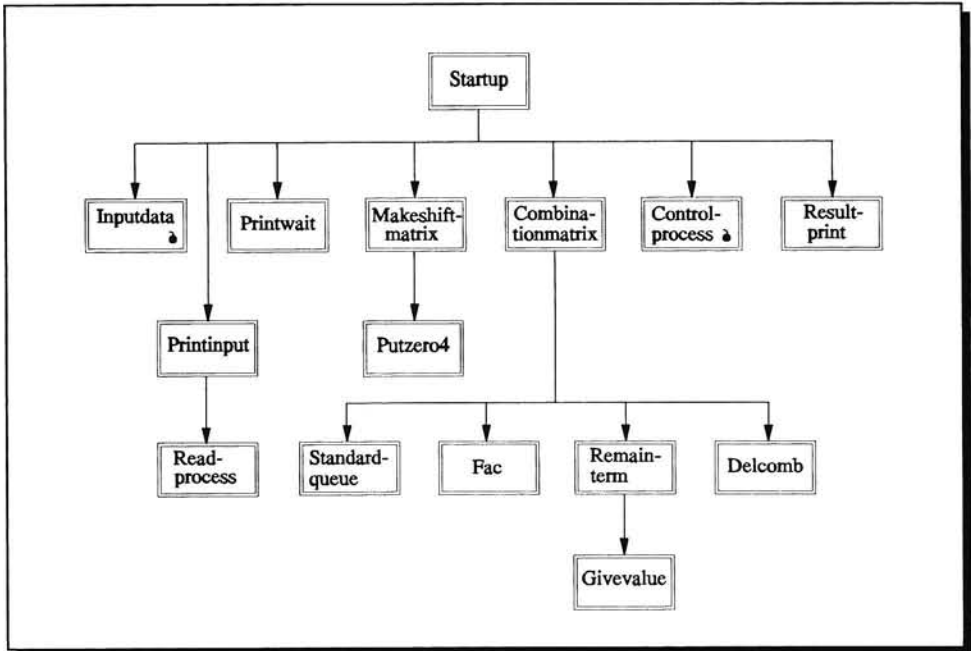


Figure 31: Connection between the modules, diagram II

matrix'). The shift times are stored in a matrix $(40 \times 40)^3$, but first all the components in the matrix are made zero by calling the procedure 'Putzero4'.

Before starting the simulation process by calling the 'Control_process' procedure (Figure 33), all the different routing possibilities need to be calculated. This is done by calling the procedure 'Combinationmatrix'. This procedure makes a matrix from which all the different routings can be derived. In some situations calculating the routing possibilities can be a time consuming event. In that case the procedure 'Printwait' will print a text on screen asking the user to wait a moment.

At this point, the program has stored the relevant input data, the shift times between the terminals and the routing possibilities in different matrices. Now the simulation process will be executed by calling the 'Control_process' procedure. In this procedure the rotation of the vessel through port will be simulated many times and repeated for each different routing possibility. The results will be stored in a matrix.

When the simulation is finished the program will finally call the procedure 'Resultprint'. Now the best solutions will be printed on screen. When quitting the result menu, the main menu will again appear on screen.

Input data

When the procedure input data is called, some general information is printed on screen (Figure 32). By pressing 'y' the program will proceed. In the process just described, the procedure 'Inputdata' is assisted by the procedure 'Readprocess'.

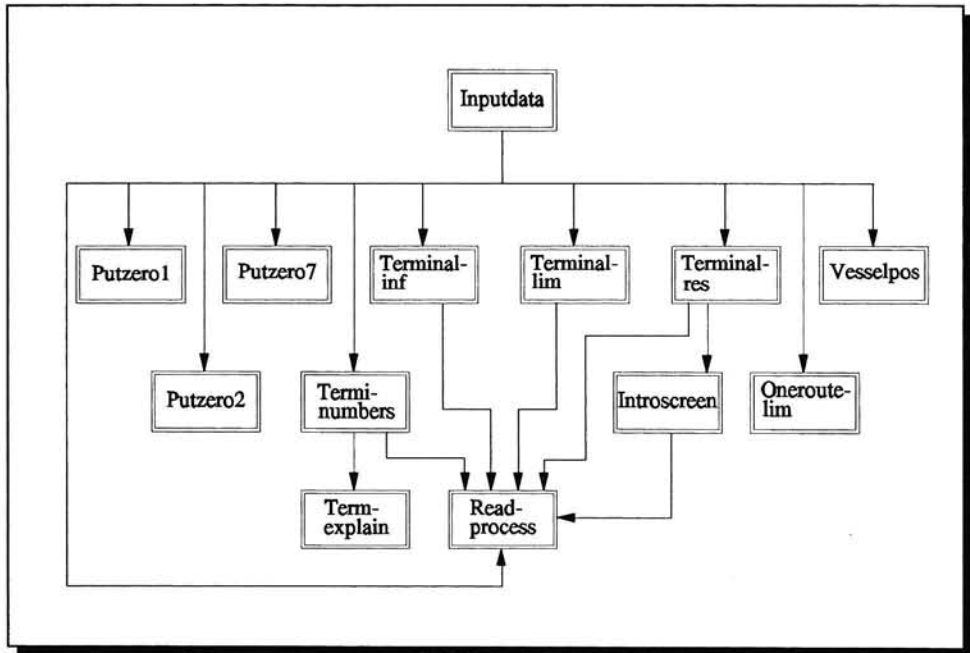


Figure 32: Connection between the modules, diagram III

The inputdata which is asked for, is stored in two matrices⁴. The components in these two matrices will get the value zero by calling the procedures 'Putzero1' and 'Putzero2'. Now the procedure 'Terminalnumbers' will be called. In this procedure the program will ask the user to enter the terminal numbers of the terminals which are going to be visited⁵. This information will be stored in a matrix called 'terminfo'.

When the program knows which terminals need to be visited it will call the procedure 'Terminalinf'. Now the program will ask for information about each terminal. This information is also stored in the matrix 'terminfo'.

Next, the program calls the procedures 'Terminallim' and 'Terminalres'. In these procedures the program asks if there are any limitations in the rotation of the vessel. The information is stored in the matrix 'restrictdata'.

Finally⁶, the procedure 'Inputdata' calls the procedure 'Vesselpos'. Here the current position of the vessel is asked for.

Control_process

The procedure 'Putzero5' first gives all the components in the matrix called 'bestmatrix' the value zero. 'Bestmatrix' is a matrix which is keeping track of the best results of the simulations.

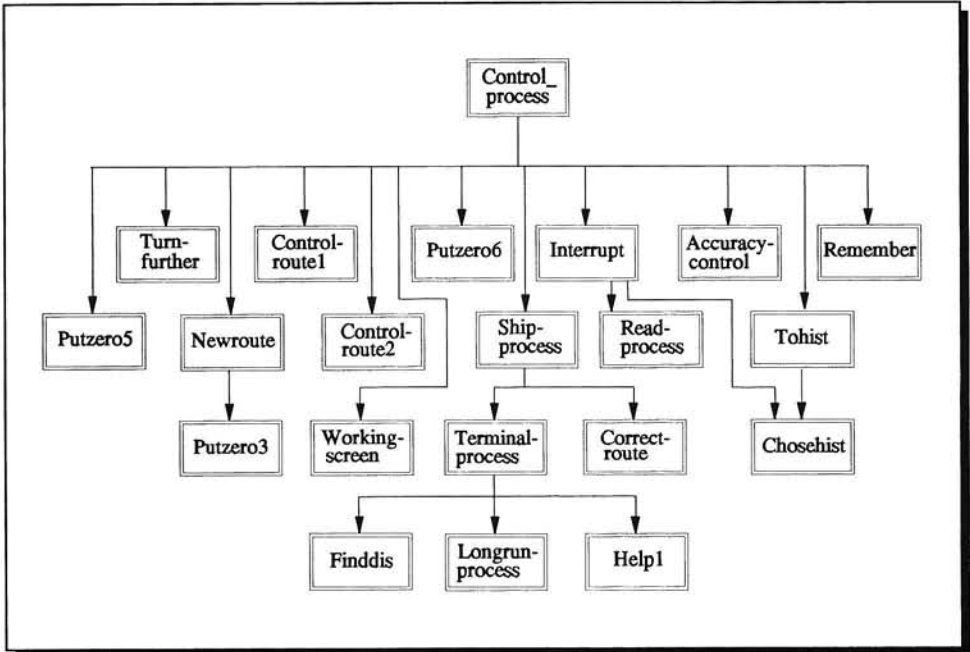


Figure 33: Connection between the modules, diagram IV

Next, the procedure 'Turn_further' is called. This procedure transforms the matrix of routes in a certain way such that all the different rotations can be deduced.

Before starting with the actual simulation, the route has to be deduced from the routing matrix (procedure 'Newroute'). Then the procedures 'Control_route1' and 'Control_route2' are called. In these procedures the actual route is checked on its feasibility. This is done by comparing the actual route with restrictions stored in the matrices 'restrict data' and 'resmatrix'. If the actual route is not feasible the program will go back to the procedure 'Newroute'. This process will continue until a feasible route is found.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

Before each simulation the procedure 'Workingscreen' is called. During the simulation this procedure will print on screen what percentage of the simulations required have been completed. In this way the user can approximately guess when the simulation results will appear on screen.

The next step⁷ is now to start up the simulation process by calling the procedure 'Shipprocess'. In the procedure 'Shipprocess' each of the terminals is visited by repeatedly calling the procedure 'Terminalprocess'. Before terminal operations can proceed it is of course necessary that all variables concerning that specific terminal get the appropriate values. In this context the procedure 'Finddis' is called. Each specific terminal needs to find the appropriate distributions for the interarrival times, docking times and the occupied waiting times. These distributions are stored in the procedure 'Finddis'. Other information concerning the actual situation at the terminal is asked from the matrix 'terminfo'.

The procedure 'Longrunprocess' is called when the user has indicated that there is no information about the actual situation in port available. In this case the procedure 'Longrunprocess' will 'create' the initial situation in the port by simulation⁸.

The procedure 'Help1' is used for validation of the program by storing specific information in histograms. The chapter 'Testing and using the Route Simulation Software' explains in greater detail the results obtained through this procedure.

Each time the vessel leaves a terminal, the procedure 'Correctroute' deletes that terminal from the set of terminals which still needs to be visited. When all the terminals have been visited, the port time is stored and the process described above is repeated again.

After several runs for a certain route, the program evaluates whether it is useful to go on with the simulation (procedure 'Interrupt'). This is done in order to save simulation time. The average port time and the 90 percent quantile of the port time of the actual route will be compared with the corresponding data of the best routing calculated at that time. If the difference is too large⁹ the simulation for the actual route will not be continued¹⁰.

After a certain amount of simulation runs the accuracy of the simulation result (the total port time) is checked (procedure 'Accuracycont'). If the accuracy calculated is not within a pre-defined limit¹¹, additional simulation runs will be carried out.

When all simulations for one route have been completed the results are stored in a histogram in such a way that the 90 percent quantile can be calculated. To achieve this, the procedure 'Tohist' is called. This procedure will then call the

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

procedure 'Chosehist'. Here the appropriate definition of the histogram is chosen.

Finally, the procedure 'Remember' will be called. Now the average port time and the 90 percent quantile of the port time will be compared with the corresponding values of other routes. If this calculated port time belongs to the 15 best results calculated until that moment, the port time and the corresponding route will be stored in a matrix called 'bestmatrix'.

Now the process described above is repeated for another route. When all the routes have been simulated the results are printed on screen as explained before.

STOP CRITERIUM FOR THE SIMULATION

When simulating the situation in the port of Houston, each specific route is simulated many times (with differing circumstances in port). Based on these simulations an average port time and a 90 percent quantile can be calculated. Of course, repeating the simulation of a rotation through port several times is a time consuming event. Therefore it is desirable to minimize the number of simulations executed for each rotation through port.

When comparing port times of different rotations it is desirable that each of the rotations have the same accuracy. In other words, the simulation of one specific route through port will be repeated until a certain pre-defined accuracy has been reached¹¹. Note that the number of times a simulation will be repeated will be different for each route, as the statistics concerning the routes can vary substantially.

The accuracy of the port time can be calculated in the following way:

1. First the simulation of the route will be repeated several times, for example 1000 times¹²;
2. The resulting 1000 port times are divided in 10 groups with each 100 entries;
3. For each of the 10 groups an average and the standard deviation of the port time is calculated (μ_a and σ_a). It is possible to enter these 10 average port times into a histogram, constructing a distribution (μ_b and σ_b , Figure 34);
4. Distribution B gives an indication of the average port time resulting from one run containing 100 simulations. But it is not desirable to know the average port time of one run but the distribution of these average port times. In other words, the average and the deviation of the average port time of the 10 groups constructed above have to be calculated. The average port time can be calculated by summarizing the average port time of each of the 10 groups and dividing the total through the number of

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

entries (10 in this case). It is important to notice that this process cannot be repeated for the standard deviation (Figure 35):

$$\mu_c = \frac{\sum \mu_i}{n} = \mu_b$$

$$\sigma_c = \frac{\sqrt{\sum \sigma_i^2}}{n} = \frac{\sigma_b}{\sqrt{n}}$$

5. When dividing σ_c through μ_c it is possible to get an indication of the simulation accuracy. When σ_c/μ_c is smaller than a certain pre-defined percentage of μ , the accuracy is good enough. If this is not the case, additional simulation runs have to be carried out. There are two possible ways of doing this:
 1. Increasing the number of entries in each of the 10 groups made. For example, 10 runs of 110 entries instead of 10 runs of 100 entries;
 2. Increasing the number of groups of 100 runs. For example, 11 runs with each of them 100 simulations instead of 10 runs with 100 simulations.

Each of the methods above will have the same result. In the route simulation software the second method described above was chosen. When increasing the number of runs carried out, the peak of distribution [C] will become narrower resulting in a lower value of σ_c .

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

The approach for the stop criterium suggested above is incorporated in the 'Route Simulation Software' in the procedure 'accuracycont'. The user can enter the required accuracy and the number of simulations carried out before the accuracy will be calculated in the configuration file. The following chapter contains more details about the configuration file.

COMPARING PORT TIMES OF DIFFERENT ROUTES

The main objective of the simulation tool is to give an indication of the fastest ways of rotating a vessel through the port of Houston. In order to draw conclusions, the total port time calculated for the different routes should be compared. There are different ways of comparing the port times. For example, the route with the shortest average port time can be considered as being the preferred route. It is also possible to compare the 90 percent quantiles¹³ of the port time. Combinations of both options mentioned above are also possible.

The easiest way of comparing the results is by comparing the average port times. But this is not a very good solution because just one of the statistical characteristics (the average) is taken into consideration. The spread of data is neglected. This can influence the results substantially and by just presenting the average port time it is possible to draw a wrong conclusion. This will be illustrated with an example (Figure 36).

In the graph above it is possible to distinguish two distributions both representing the port time for a specific route. Distribution [A] has a slightly smaller average port time and will therefore be selected as the preferred route. It is of course a subject of discussion whether this is really the best solution. It is clear that the spread in the data is substantially larger in distribution [A] when comparing with distribution [B]. The 90 percent quantile of distribution [B] will be lower than the 90 percent quantile of distribution [A]. Therefore in this particular case, distribution [B] represents the desired solution because the 90 percent quantile of distribution [B] is substantially lower than the 90 percent quantile of distribution [A] and the average port time is about the same for either of the proposed solutions. This example shows very clearly that just comparing the average port times is not a good way of making a proper decision about the desired rotation.

When just the 90 percent quantiles of the port times of different routings are compared with each other a similar situation as described above will appear. That is the reason why it is desirable to use a criterion which takes the average port time and the spread in the port time into account. This can be achieved by using both the average port time and the 90 percent quantile¹⁴ in the criterion:

Situation: There are two situations indicated by the indices 1 and 2 (μ is the average port time and q_{90} = 90 percent quantile).

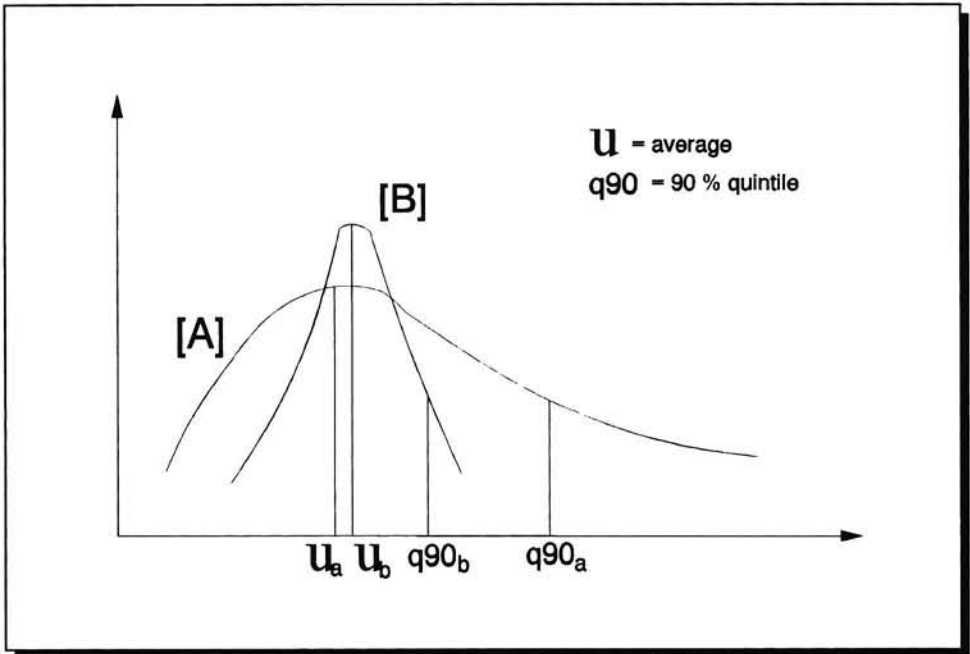


Figure 36: Two distributions of the port time for two different routes

Assume that: $\mu_1 > \mu_2$
 $q90_1 < q90_2$

Algorithm: $(\mu_1 - \mu_2) \times \text{fac} - (q90_2 - q90_1) = \text{result}$
 $\text{result} < 0 \implies \text{situation 1 is preferred}$
 $\text{result} > 0 \implies \text{situation 2 is preferred}$

If 'fac' has the value zero the value of the 90 percent quantiles will decide which situation will be preferred. On the other hand, if the value of 'fac' is large, the average port time will indicate which situation will be preferred. The value of 'fac' can be adjusted in the configuration file¹⁵. The factor 'fac' is a management parameter and can have different values in different situations. For example, if management attaches great value to the fact that the vessel will have left port within a certain amount of hours, it could be desirable to attach great value to the 90 percent quantiles. This results in a small value for the factor 'fac'. On the other hand, if an overall (in the long term) optimal performance is desired, the factor 'fac' will have a greater value.

The compare-algorithm described above is incorporated in the 'Route Simulation Software' in the procedure 'Remember'.

SAVING SIMULATION TIME

In Chapter 5 was explained that the time required for a simulation run should be minimized because the program is designed for operational use. It is desirable to present the results within half an hour after starting up the program.

There are several ways of reducing the time required for a simulation run:

- * The program should run efficiently. Therefore the 'sequential programming approach' was preferred instead of the 'simultaneous programming approach'¹⁶;
- * It is possible to increase the running speed by running the simulation tool on a faster computer¹⁷;
- * It is possible to reduce the time required by reducing the number of routing possibilities.

The simulation tool has a feature where it is possible to reduce the number of routing possibilities. This is done by combining 2 terminals (or 3 terminals) which are located near each other and have low occupancy rates; couples of terminals are created. In other words, when a vessel visits one terminal in a couple, it is very likely that the next terminal visited will be the remaining terminal in the couple, because that terminal is located near the terminal just visited and it will most likely be available (low occupancy rate)¹⁸. Of course it is important to choose the terminals which will be considered as a pair with great care.

Creating couples of terminals reduces the number of routing possibilities and therefore the simulation time substantially. For example, when visiting 4 terminals the creation of one couple of terminals (for example terminal number 3 and 4 will be visited together, either 3 and then 4 or the other way) will reduce the number of routing possibilities from $4! = 24$ to 12 (50% reduction). Introducing one more couple will again reduce the number of routing possibilities but the impact will be less than when the first couple of terminals was introduced¹⁹.

In the computer program the coupling of terminals is realized by the procedures 'Terminalres' and 'Controll-route2'. In the procedure 'Terminalres' the terminals which can be considered as a pair are stored in the matrix 'resmatrix'. Later on, each proposed route will be checked on its feasibility concerning couples in the procedure 'Controll-route2'. This process is similar to the process 'Controll-route1' where is checked if the route complies with the restrictions stored in the matrix 'restrictdata'²⁰.

Notes

1. Each dock has a unique number.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

2. The last option is to quit the program.
3. In the program this matrix is called 'shiftmatrix'.
4. In the program these matrices are called 'terminfo' and 'restrictdata'.
5. The user can get information about the terminal numbers (dock numbers would be a better name) by calling the procedure 'Termexplain'.
6. The procedure 'Oneroutelim' will be called when the port time only of one specific route has to be calculated (This is an option in the mainmenu). More information about the option of calculating one specific route will be given in the users guide (next chapter).
7. After giving all the entries in the matrix 'rememdata' the value zero (procedure 'Putzer6'). The total port times resulting from the simulations are stored in the matrix 'rememdata'.
8. The initial terminal conditions are simulated by starting the simulations of the terminals long time back in the time. For example, starting with a terminal time of -1000 (terminal time=0 => initial situation (now)).
9. The limit can be adjusted in the configuration file.
10. Of course, the simulation process will be continued if the port time of the actual route is smaller than the best port time calculated.
11. In the configuration file the user can enter the required accuracy into the program. Next chapter contains detailed information about the configuration file.
12. The number of simulations to be carried out can be entered into the program by the user before the accuracy of the results is checked (configuration file, see next chapter).
13. Of course, other quantiles than the 90 percent quantile can also be considered.
14. It is also possible to use the deviation of the port time in the criterium instead of a quantile. It will not make much difference because a quantile can be considered as an injunction of the average and a factor multiplied by the deviation. In other words, the 90 percent quantile is dependent on the value of the deviation (the relation of this dependency will differ for each type of distribution).
15. See next chapter for more detailed information about the configuration file.
16. In the chapter 'Modeling the activities in port' both the 'sequential programming approach' and the 'simultaneous programming approach' were explained in more detail.
17. For example, a 486PC with a frequency of 66Mhz or the new 586 PC.
18. The terminals located in Texas City, Bayport or far up in the Houston ship channel can be suitable candidates when couples have to be created. Of course a good choice of a couple will depend on the other terminals in the routing.
19. The impact of creating couples is larger when more terminals need to be visited.
20. These restrictions concern the order in which the terminals should be visited (for example caused by the stowage plan).

CHAPTER 8: THE USERS GUIDE

INTRODUCTION

This chapter explains how the 'Route Simulation Model' can be operated. When the program is started the main menu will appear on screen:

```
***** Optimal Rotation Program *****
                J.D.Doornbos

1) Optimal route calculation
2) Port time of a specific route
3) Long run simulation
4) Program configuration
5) Terminal numbers
6) Latest input
7) Latest results
8) Exit program

Option:

*****
```

The first three options in the main menu each start the simulation process with a specific objective. This is the paragraph 'Simulation options'. Before starting the program it might be necessary to adjust the configuration variables (option 4 in the main menu, paragraph 'The configuration file').

When selecting option 5 in the main menu all the docks that can be selected in the program are printed on screen with their corresponding number. Each dock has a unique number. For example, when selecting dock number 2, Baytank berth number 1 is selected (see a print of the dock numbers on the next page). Sometimes the vessel can load or discharge at every dock at a specific terminal (flexible terminal layout). In the case of Baytank, dock number 4 should be selected. When selecting dock number 4 the corresponding statistics are adjusted for this flexible terminal layout. This was explained in **Chapter 6**.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

***** Optimal Rotation Program *****
J.D.Doornbos

# Terminal	# Terminal	# Terminal
1 Amoco	14 GATX GP	27 Shell bE
2 Baytank b1	15 ITC b1	28 Shell bW
3 Baytank b2	16 ITC b2	29 Shell b2
4 Baytank	17 ITC	30 Shell
5 Celanese	18 Oiltan b2	31 Stantr b1
6 City Dock b1E	19 Oiltan b3	32 Stantr b2
7 City Dock b1W	20 Oiltanking	33 Stantrans
8 City Dock b2	21 Old man	34 Sterling
9 City Dock	22 Paktank DPb1	35 UCC bT66
10 DOW	23 Paktank DPb2	36 UCC bT67
11 Exxon b1	24 Paktank	37 UCC
12 Exxon b2	25 Paktank GP	38-39 ----
13 Exxon	26 Petro United	40 Entrance

*****Press r to return to previous menu*****

When selecting option 6 and 7 from the main menu the latest input and the corresponding results are printed on screen, respectively. It is possible to exit the program by choosing 8 on the mainmenu.

THE CONFIGURATION FILE

When selecting the configuration file in the main menu the following screen appears on screen:

***** Optimal Rotation Program *****
J.D.Doornbos

1] Minimum number of runs for each route configuration	400
2] Number of runs before feasibility check will be executed	100
3] Interrupt limit for the average port time	1.1
4] Interrupt limit for the 90% quantile	1.1
5] Percentage deviation allowed	5.0
6] Compare parameter (c1)	8.0
7] Limit when results are printed on screen	2.0
8] Long run pre simulation time	400
9] Return to main menu	

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

Each of the options can change a specific configuration parameter of the program:

1) Minimum number of runs for each route configuration

When selecting this option it is possible to adjust the parameter called 'nofrun', indicating how many simulations have to be executed for one specific route before the accuracy check is carried out. For example, when 'nofrun' = 400, the simulation is repeated 400 times. Thereafter it is checked if the accuracy of the result has met a certain pre-defined limit¹. If this is not the case, 100 additional simulations are carried out and the accuracy of the result is checked again. This process is repeated until the accuracy of the result is satisfactory.

The variable 'nofrun' has to be a multiple of 100. The value of 'nofrun' should not be smaller than 400 and the maximum value should not exceed 1900.

2) Number of runs before feasibility check is executed

In order to gain simulation time, the program contains a feature which can stop the simulation untimely if it is obvious that the current port time is 'much' larger² than the best port time currently obtained. In this way the simulation can be stopped even if the pre-defined accuracy requirement has not yet been met. Of course it is not necessary to use a lot of simulation time calculating an accurate port time of a route which will not be selected anyway. For example, when 'contofrun' = 100 the program will compare the port time obtained after 100 simulations with the best result at that time.

The value of 'contofrun' should be an integer value. If the value of 'contofrun' exceeds the value of 'nofrun' the feasibility check will not be carried out.

3) Interrupt limit for the average port time

After several runs the result is checked on its feasibility as explained above. When selecting option 3 in the configuration menu it is possible to adjust a variable called 'factor1'. In the feasibility check the simulation is interrupted if the average port time of the current simulation is larger than the best port time currently obtained multiplied by 'factor1'.

For example:

- * Best average port time = 100
- * Average port time of the current simulation = 115
- * 'factor1' = 1.1

Result: $100 \times 1.1 < 115 \Rightarrow$ interrupt the simulation

'Factor1' should have a real value of at least 1. Large values of 'factor1' can result in longer simulation times because more routings are simulated until the accuracy requirement has been met (also dependent on the value of 'factor2'). On the other hand, when the value of 'factor1' approaches 1, almost all simulation runs are interrupted untimely. In this case a large value of the parameter 'contofrun' is required because otherwise some appropriate solutions may not be taken into consideration.

4) Interrupt limit for the 90% quantile

When selecting option number 4 in the configuration menu it is possible to adjust a variable called 'factor2'. This variable has the same function for the 90 percent quantile as the variable 'factor1' has for the average port time (as explained above). In other words, the simulation is interrupted if either the average port time is not in the pre-defined range or the 90 percent quantile is not in the pre-defined range.

5) Percentage deviation allowed

When selecting option number 5 in the configuration menu the variable 'diflim' can be adjusted. 'Diflim' indicates what maximum value of $\sigma_c \times 100 / \mu_c$ is allowed. In the formula μ_c is the average port time and σ_c is the deviation of the distribution containing average port times each based on 100 simulation runs. The process of calculating the accuracy of the results of the simulation was explained in detail in **Chapter 7**. For example, if 'diflim' = 5.0 and $\sigma_c \times 100 / \mu_c < 5.0$ the pre-defined accuracy requirement has been met and the simulation is stopped. If this is not the case additional simulations are carried out in order to meet the accuracy requirement.

'Diflim' should be a real value larger than zero. Small values of 'diflim' result in very long simulations and should therefore be avoided.

6) Compare parameter (c1)

The compare parameter 'c1' is related to the process of comparing the average port times and the 90 percent quantiles of the port times of the different routes with each other. This process was explained in **Chapter 7**, paragraph 'Comparing port times of different routes'. Notice that the parameter 'c1' corresponds to the parameter 'fac' in this specific paragraph.

The value of 'c1' should be a real value larger than zero. If 'c1' has a very small value ($c1 = > 0$) the 90 percent quantiles of the port time will decide which route will be preferred. On the other hand, if 'c1' has a large value the average port time will decide which route will be preferred.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

7) Limit when results are printed on screen

When presenting the best result after completing the simulation, several good alternative routings are also be printed on screen. A routing is considered as a good alternative if the result does not deviate more than a pre-defined limit from the best result. This limit can be adjusted by selecting option 7 in the configuration menu changing the variable called 'prper'. The result will be printed on screen if³

(average pt < 'prper' x best average) and (quant pt < 'prper' x best quantile)

average pt = average port time

quant pt = 90 percent quantile of the port time

'Prper' should have a real value larger than 1. Large values of 'Prper' result in many feasible solutions but the number of solutions printed on screen will never exceed 15. Small values of 'prper' prevent that any other solutions than the best solution is printed on screen.

8) Long run pre simulation time

When selecting option number 8 in the configuration file the variable 'lrtime' can be adjusted. This parameter is related to simulation option number 3 (long run simulation) in the main menu. The simulation of the terminals starts at 'terminal time' = '-lrtime'. This is explained in more detail in the following paragraph.

The value of 'lrtime' should be an integer larger than 400.

9) Return to main menu

When pressing 9 in the configuration file the main menu will again appear on the screen. From this menu the desired simulation can be executed.

SIMULATION OPTIONS

Three different simulation options

The 'Route Simulation Software' contains three different options concerning simulation⁴:

1. The option 'Optimal route calculation' simulates the chemical shipping activities in port resulting in a list of appropriate routings. This simulation is useful for the port agent when making decisions concerning the rotation of the vessels through port.

2. When selecting the option 'Port time of a specific route' the port time of one specific route is calculated. This option might be useful in order to evaluate the chosen route afterwards.
3. The option 'Long run simulation' simulates the chemical tanker activities in port without having any knowledge of the auxiliary conditions in port (such as if a dock is occupied or not). The auxiliary conditions are deduced by simulation. This is achieved by starting the terminal simulation many hours before the actual simulation should start (For example: 'terminal time' = -400). The initial state⁵ of the different terminals is drawn randomly.

This option might be useful if management wants in advance an indication of the routing possibilities. This information can be used when planning the activities in port⁶.

When starting up any of the available simulation options, the user has to provide appropriate information to the program. The required information depends on the kind of simulation executed. The answer-question procedures when starting up the simulation are explained in the following paragraph.

Executing a simulation

When starting⁴ a simulation the following information appears on screen:

```
***** Optimal Rotation Program *****
                        J.D.Doornbos

In order to simulate the optimal route in port some
information concerning both the terminals and the
vessel is required.

Proceed (y/n)? y

*****
```

When typing 'y' the following questions will appear on screen:

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

***** Optimal Rotation Program *****
J.D.Doornbos

How many terminals need to be visited? 4

Do you want to see an explanation of the terminal numbers (y/n) ? n

Give the terminal numbers separated by the space bar:

22 33 4 7

First will be asked how many terminals are going to be visited. The terminals are specified by a unique number (last question). If the user does not know the terminal numbers, it is possible to get assistance by answering 'y' at the second question printed on the screen. In this case all the docks appear on screen with their corresponding number (as explained in paragraph 4.1).

The program proceeds by asking some questions about each specific dock in the route:

***** Optimal Rotation Program *****
J.D.Doornbos

Some information about each specific berth is needed.
The following questions concern berth number 22.
Is the berth occupied (y/n)?

If 'y' => For how many hours will the berth be occupied? 4.3

If 'n' => How many hours ago did the last vessel departure
from the terminal? 9.5

Next, the program asks if there are any limitations in the order the terminals should be visited. For example, if dock number 22 should be visited before dock number 7 because of the stowage of the vessel, the user should proceed as follows:

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

***** Optimal Rotation Program *****
J.D.Doornbos

Are there any limitations in the order the terminals

should be visited (y/n)? y

Which terminal should be visited before which other terminal,

separated by space bar? 22 7

More restrictions (y/n)? n

When five or more terminals are going to be visited, the required time for the simulation can become very large. This is dependent on how many limitations exist in the rotation⁷ and the required accuracy of the results⁸. Therefore the program contains a feature which enables the user to combine some terminals. This reduces the number of routing possibilities considerably. Paragraph 3.5 contains a detailed explanation. When the user wants to combine some terminals 'y' should be answered on the question 'Proceed (y/n)?':

***** Optimal Rotation Program *****
J.D.Doornbos

In order to save simulation time it might be useful to reduce the number of terminals that are going to be visited by combining some of the terminals. A reduction to four terminals is desirable.

Proceed (y/n)? y

The following questions now appear on screen:

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

***** Optimal Rotation Program *****
J.D.Doornbos

How many terminals do you want to combine (2-3)? 2

Give the terminal numbers separated by the space bar:

22 33

Do you want to combine more terminals (y/n)? n

In the example above the terminals 22 and 33 are combined to a couple. Finally, the simulation tool needs the vessel position. The vessel will be at one of the terminals or at the pilot station (position number 40):

***** Optimal Rotation Program *****
J.D.Doornbos

Give the current position of the vessel: 40

Before starting the actual simulation, the input data entered into the program is shown on screen:

***** Optimal Rotation Program *****
J.D.Doornbos

OVERVIEW OF THE INPUT DATA:

Termino:	Terminal#	Occupied	Oc./Lvd.
	22	Y	4.30
	33	N	15.00
	4	Y	8.25
	7	Y	22.33

Restrictions: (22 7)
Couples: (22 33)
Vesselposition: 40

Is the input data correct? y

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

The information printed in the example above has the following meaning:

1. Dock number 22, 33, 4 and 7 are going to be visited;
2. Dock number 22 is occupied and the terminal will be available in 4.3 hours (according to an estimate of the terminal). Dock number 33 is available at the moment. The last vessel visiting this dock left 15 hours ago;
3. Dock number 22 always has to be visited before dock number 7;
4. Dock number 22 and 33 are considered as a couple in the simulation. This leaves only six routing possibilities;
5. At the moment the vessel is at the pilot station (position number 40).

If the input data is not correct, the question-answer procedures will be repeated all over again. If the input data is correct the simulation is executed. During the simulation the following message appears on screen:

```
***** Optimal Rotation Program *****  
J.D.Doornbos
```

The program is calculating the optimal route.

Proceeding: 22.20%

```
*****
```

The percentage printed gives an impression of how many of the routings have been simulated. In the example above 22.20 percent of the routings have been simulated.

During simulation when calculating the port time for one specific route (option 2 of the main menu), it is not useful to show a percentage of the number of routes that have been simulated on screen (there is just one route). In this case the following message will appear on screen:

```
***** Optimal Rotation Program *****  
J.D.Doornbos
```

Please wait....

```
*****
```

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

When the simulation has been completed the results are printed on screen. For example:

```
***** Optimal Rotation Program *****
                          J.D.Doornbos

The program is calculating the optimal route.
The best routings will be printed:
route           average      90% quant
33 22 7 4      65.21      89.12
22 33 7 4      66.70      80.36
22 33 4 7      67.27      80.84
33 22 4 7      67.84      90.69

*****Press m to return to the main menu*****
```

When pressing 'm' the main menu will again appear on screen. Now a new simulation can be carried out.

Notes

1. When selecting option 5 in the configuration menu the pre-defined limit for the accuracy of the result can be adjusted.
2. The limit of the allowed percentage deviation can be adjusted by selecting the options 3 and 4 in the configuration file.
3. The number of solutions printed on screen will never exceed 15, even if more solutions meet the presented requirement.
4. Option number 1, 2 and 3 in the main menu.
5. Whether the terminal is occupied or not.
6. Commercial and operational management could benefit from this information.
7. More restriction concerning the order of the terminals in the route will result in less feasible routings.
8. If a high accuracy is required, more simulation runs have to be carried out for each route. This results in a longer simulation time.

CHAPTER 9: TESTING AND USING THE ROUTE SIMULATION SOFTWARE

INTRODUCTION

After designing a computer program it is important to evaluate its performance. Fishman and Kiviat [3] divide the process of evaluation into three categories:

1. *Verification*: To insure that the model behaves as the modeler intends;
2. *Validation*: To test the performance of the behaviour of the model and that of the real system;
3. *Problem analysis*: Deals with the analysis and interpretation of the data generated by experiments.

In other words, we are concerned with the internal consistency of the model, its correspondence with the real life situation and the correct interpretation of the resulting data.

In relation to the 'Route Simulation Software' the following approach will be followed:

1. The simulation was executed for many different situations. In each case was checked whether or not any error messages occurred. Also, extreme values of the auxiliary conditions and control-parameters were entered into the program in order to insure that the program did not return absurd answers (the values of the different parameters were within the pre-described limits explained in the previous chapter, 'The user guide').
2. Detailed analysis of the software was carried out by using the debugging tools available in turbo pascal. In the paragraph 'Step by step simulation' the results of one of these 'step by step' simulations will be presented.
3. When running the program many times for a specific route involving many different auxiliary conditions, the number of times that the vessel has to wait for a specific dock divided by the number of calls to that dock should match the occupancy rate of the dock. The occupancy rates of the docks were calculated with information inquired at the US Coast Guard office in Houston¹. In this case the problem occurs that the auxiliary conditions influence the real occupancy rates of the terminals substantially². This is why the test is carried out with the 'longrun simulation option'³ where the auxiliary conditions are detected by simulation. The results are presented in the paragraph 'Checking the occupancy rates of the docks'.
4. The program is also evaluated by presenting situations to the 'Route Simulation Software' of which the results can easily be predicted. In this

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

way it is checked that results obtained from the computer program for these clearly evident situations match the expected results. The results are presented in the paragraph 'Evident situations and the simulation software'.

5. The range of the calculated port times with the 'Route Simulation Software' has to be in the order of magnitude of the port times obtained in the real life situation. Experiments concerning this subject are carried out in the paragraph 'The order of magnitude of the simulation results'.

The paragraph 'Evaluating the results' evaluates whether or not the results obtained with the 'Route Simulation Software' are better than the results obtained in the real life situation. In the next paragraph the experience of using the 'Route Simulation Software' at both the shipping company investigated and its port agent in Houston is described (paragraph 'Introducing and using the 'Route Simulation Software'). Finally, **Chapter 9** concludes with a short evaluation of the current scheduling approach used (paragraph 'Evaluation of the current scheduling strategy used').

STEP BY STEP SIMULATION

Many different situations were simulated and evaluated by following the simulation process step by step. This was done in order to check whether the program simulates the activities in port as intended⁴. One of the simulations will be presented in this paragraph. The example presented below will also contribute to a more detailed understanding of the modeling approach as explained in the chapter 'Modeling the activities in port' .

In the example 4 docks are visited, Paktank Deer Park berth 1 (22), Exxon berth 1 (11), City Dock berth 1 West (7) and Sterling (34) (**Figure 37**).

The input data is arranged as following:

```
***** Optimal Rotation Program *****
J.D.Doornbos
```

OVERVIEW OF THE INPUT DATA:

Terminfo:	Terminal#	Occupied	Oc./Lvd.
	22	N	3.00
	11	Y	20.00
	7	N	2.00
	34	Y	15.00

Vesselposition: 40

Is the input data correct? y

```
*****
```


Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

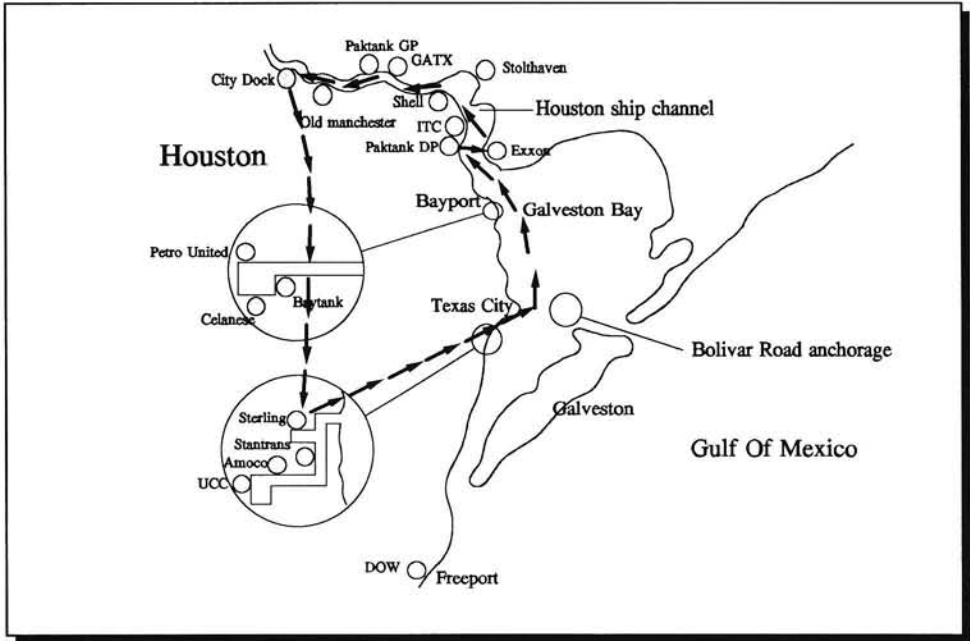


Figure 37: Port of Houston

First Paktank Deer Park will be visited. According to the input information this dock is available so that when tendering NOR the vessel will be able to dock at Paktank Deer Park right away. Of course, the vessel first has to sail from the pilot station (position number 40) to Paktank Deer Park. The port time will therefore be raised from its initial value of zero to 4.15 hours. Next, the docking time of the vessel is drawn from the appropriate distribution. In this case the docking time is 10.50 hours which results in a total port time of 14.65 hours.

Now the vessel is going to visit the Exxon terminal. Exxon berth number 1 is occupied and will not be available until 20 hours from the starting moment. This means that the vessel has to wait 5.35 hours before starting cargo handling operations (port time = 20 hours). In this case the docking time is drawn to be 21.15 hours, resulting in a total port time of 41.7 hours (including a shift time of 0.55 hours).

Next, the vessel shifts from Exxon to City Dock raising the port time with 1.72 hours to 43.42 hours. According to the information from City Dock their berth number 1 West was available at the moment the vessel managed by the shipping company investigated was at the pilot station and the last vessel left that particular berth 2 hours ago. The terminal process of this particular dock will therefore start at a terminal time of minus 2 hours. Next, an interarrival time and a docking time will be drawn from the appropriate distributions (interarrival

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

time = 53.22 hours and docking time = 10.14 hours). Adding the interarrival time to the terminal time of minus 2 hours will result in a terminal time of 51.22 hours which is larger than the actual port time (41.7 hours) when tendering NOR. In other words, when the vessel arrives at this particular dock, it can dock right away and start cargo handling operations. The docking time for the vessel is drawn to be 5.99 hours resulting in a port time of 49.41 hours.

The vessel will now sail to Sterling terminal which is located in Texas City. Sterling was occupied when the vessel entered the port. The initial terminal time for this specific terminal will therefore be 15 hours (according to the input data). The interarrival time and a docking time are drawn to be 89.78 and 16.97 hours, respectively. The vessel managed by the shipping company investigated is ready to shift to the Sterling terminal when the port time is 49.41 hours, which means that the Sterling terminal will be available at the moment ($49.41 < 15 + 89.78$). Adding the docking time, the shift time from City Dock to Sterling (5.08 hours) and the shift time from Texas City to the pilot station to the port time will result in a final port time of 69.35 hours.

After repeating the process described above for many different values of the input data it can be concluded that the procedures 'Shipprocess' and 'Terminalprocess' work as intended.

When carrying out many runs for each of the chosen configurations, statistics can be made for each terminal/dock concerning the docking times of the vessel operated by the shipping company investigated, docking times of all vessels visiting a specific dock and the interarrival times of each dock. Next, these statistics were compared with the original statistics based on the information inquired at the US Coast Guard. It could be concluded that the values derived by simulation match the original values on which the statistics used in the simulation are based.

The values of the 'shiftmatrix' and the values of the waiting times were checked on its feasibility in a similar way as described above.

Of course it is also interesting to see how often the vessels had to wait for each of the docks visited. For the example, presented in this paragraph, the results are as following (Table I):

Dock number	Occ.rate through sim.	Occu.rate statistics
22	0.00 %	74.34 %
11	80.40 %	23.44 %
7	31.90 %	20.20 %
34	28.70 %	22.70 %

Table I

The numbers in the second column represent the occupancy rates experienced by the vessels managed by the shipping company investigated and the numbers in the third column represent the overall occupancy rates for the docks.

It is clear that the occupancy rate experienced by the vessels managed by the shipping company investigated when visiting the docks will be different from the overall occupancy rates of the terminals calculated with the information from the US Coast Guard (third column). This is caused by the specific auxiliary conditions in this situation. When many simulations are carried out for different auxiliary conditions, the occupancy rates experienced by the vessels should match the overall occupancy rates of the terminals. Tests concerning this matter are carried out in the next paragraph.

CHECKING THE OCCUPANCY RATES OF THE DOCKS

In this paragraph is checked whether or not the occupancy rates of the docks experienced by the vessels correspond with the values of the occupancy rates obtained from the real life situation on which the program is based⁴. Of course the occupancy rates will only correspond with each other if the occupancy rates deduced from simulation are based on situations in which all the possible auxiliary conditions are incorporated. This can be achieved by starting the simulation with the 'longrun simulation' option⁵ in the main menu. In this case the auxiliary conditions are deduced by simulation.

Next, the results of the occupancy rates experienced by the vessels will be presented for the same route presented in the previous paragraph (Table II). The 'longrun simulation' was carried out for 1000 runs with each a pre-simulation time of 1000 hours (the terminal process will start its process with a 'termtime' of minus 1000 hours)⁶.

Dock number	Occ.rate through sim.	Occu.rate statistics
22	71.4 %	74.34 %
11	24.58 %	23.44 %
7	20.20 %	20.20 %
34	22.70 %	22.70 %

Table II

The numbers in the second column represent the occupancy rates experienced by the vessels and the numbers in the third column represent the overall occupancy rates for the docks (as explained in the first part of this study).

It is clear that there are small differences between the percentages in the second and third column. The reason for this could be that the interarrival times and the docking times statistics in the computer are an estimate of the statistics deduced from the information of the US Coast Guard⁷. The differences are within acceptable limits and will therefore be tolerated.

The process described above was repeated so that data could be generated for all the terminals. It seemed that the deviation between the two kinds of occupancy rates (as explained above) for all the terminals are within acceptable limits.

EVIDENT SITUATIONS AND THE SIMULATION SOFTWARE

According to Shannon [3] the demonstration of the ability of the model to predict some future events helps both the analyst and the user to develop confidence in the model. That is why several situations were simulated by the 'Route Simulation Software' of which the results can easily be predicted. The different situations tested will be presented in this paragraph. A reader familiar with the situation in the port of Houston⁷ will notice that the port times presented seem to be high, compared to the real life situation. This will be explained in more detail in the next paragraph.

For the convenience of the reader the map of the port of Houston will be printed so that the docks discussed in the different situations can easily be located (Figure 38):

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

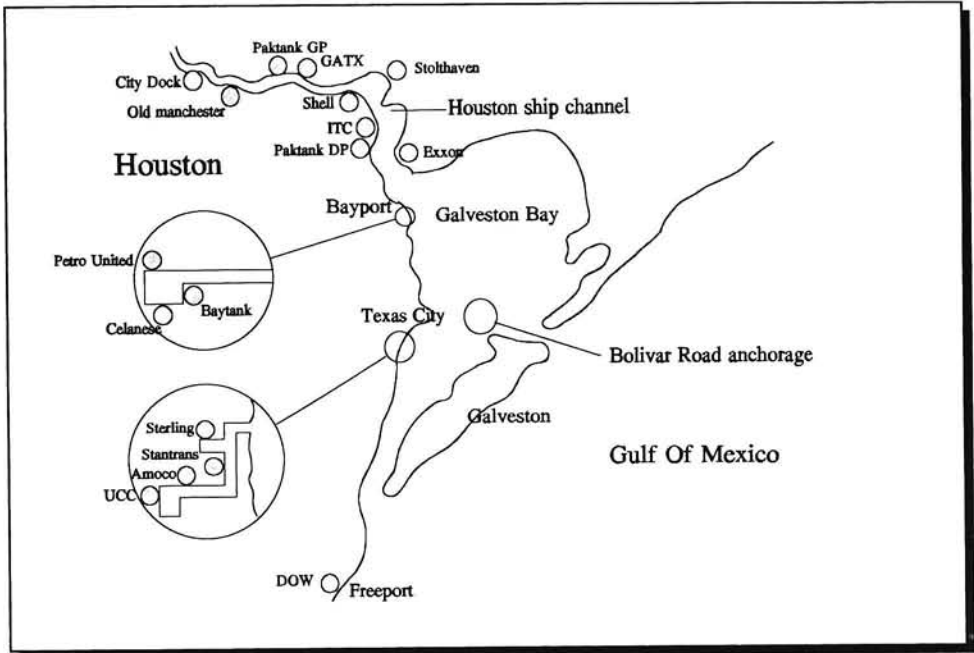


Figure 38: The port of Houston

Situation 1

In this situation the terminals Paktank Deer Park berth 1 (22), City Dock berth 2 (8), Baytank berth 1 (2) and Shell berth East (27) are visited. All these terminals are available and the last vessel leaving the terminals left two hours ago. The current position of the vessel is the pilot station (40). In this situation it is obvious that Paktank Deer Park should be visited first because this terminal has the highest occupancy rate and a visit to this terminal would not result in a raise of the shift time compared to the fasted route through port (when taking the shift time into consideration). The 'Route Simulation Software' supports this decision:

***** Optimal Rotation Program *****
 J.D.Doornbos

The program is calculating the optimal route.
 The best routings will be printed:

route	average	90% quant
22 27 8 2	58.84	74.32
22 8 27 2	60.64	78.41
22 2 8 27	61.69	79.56
22 2 27 8	62.19	79.14

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

*****Press m to return to the main menu*****

Situation 2

This situation is the same as the situation described above but now the vessel position will be ITC dock number 1 (16). In this situation Paktank Deer Park will also be preferred by the port agent as the first terminal to visit, although this will introduce a small increase in the total shift time (twice the shift between ITC and Paktank Deer Park). The 'Route Simulation Software' supports the decision of the port agent.

Situation 3

In this situation the same situation applies as described in the previous situation, but the vessel is now positioned at City dock, meaning that an extra shift totaling 2.36 hours will be involved if Paktank Deer Park is visited first. Again the 'Route Simulation Software' indicates that Paktank Deer Park should be visited first, as expected.

Situation 4

Now, two terminals remain to be visited, City Dock berth number 2 (8) and UCC berth number 66 (35). Both docks are occupied for the next 5 hours. In the current situation the vessel is located at ITC which is located between City Dock and UCC. In this case the port agent would prefer to visit City Dock first although UCC has a much higher occupancy rate than City Dock berth number 2. The 'Route Simulation Software' supports this decision:

***** Optimal Rotation Program *****

J.D.Doornbos

The program is calculating the optimal route.

The best routings will be printed:

route	average	90% quant
8 35	35.70	47.11
35 8	43.67	55.35

*****Press m to return to the main menu*****

Obviously, the extra shift time involved when visiting the highly occupied UCC terminal first is too high.

Situation 5

In this situation 3 docks are selected each of them having an occupancy rate of around 40%. The docks selected are ITC berth number 1 (15) Petro United (26) and UCC berth number 66 (35). When the vessel is located at the end of the ship channel (City Dock) and all the docks are occupied for another two hours, the port agent expects that ITC will be visited first because this is the first

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

terminal on the route back to the pilot station. The 'Route Simulation Program' draws the same conclusion:

***** Optimal Rotation Program *****

J.D.Doornbos

The program is calculating the optimal route.

The best routings will be printed:

route	average	90%quant
15 26 35	46.29	60.50
15 35 26	51.17	65.28

*****Press m to return to the main menu*****

Situation 6

In this situation Paktank Galena Park (25), GATX Galena Park (14) and Old Manchester (21) need to be visited. The vessel is at the pilot station (40). When both GATX and Old Manchester are occupied for the next 10 hours and Paktank Galena Park is available (last vessel departure = 10 hours), the port agent would prefer to visit Paktank Galena Park first. Again, the 'Route Simulation Software' supports this position:

***** Optimal Rotation Program *****

J.D.Doornbos

The program is calculating the optimal route.

The best routings will be printed:

route	average	90%quant
25 14 21	37.72	47.71
25 21 14	39.20	51.45

*****Press m to return to the main menu*****

Situation 7

Now, the same situation applies as described in the previous situation, but now GATX will also be available (last vessel departure = 10 hours). In this case the port agent would prefer to visit GATX first because this terminal is much busier than Paktank Galena Park. The 'Route Simulation Software' draws the same conclusion.

THE ORDER OF MAGNITUDE OF THE SIMULATION RESULTS

The range of the port times calculated with the 'Route Simulation Software' should be in the order of magnitude of the port times obtained from the real life situation. However in the previous paragraph was mentioned that some of the port times for specific routes seem to be high compared to the real life situation. Therefore, it will first be explained why this difference exists (the paragraph 'Theory') and then a testing procedure is suggested in order to check whether

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

the proposed explanation is acceptable (the paragraph 'Testing approach'). Finally, the results of the test are presented (paragraph 'Results').

Theory

The port time calculated in the 'Route Simulation Software' for a specific route is the average of all the simulations carried out for that specific route. This means that both 'favourable' and 'bad' situations occurring during the simulations are incorporated in the result. For example, sometimes the vessel does not have to wait for any of the terminals visited ('favourable' situation) and on other times the vessel will for example wait 36 hours for a specific dock ('bad' situation). If this situation occurs in reality, the vessel will first visit the other terminals remaining in the route (if any)⁸ and then return to the dock which was occupied. In other words, the vessel will then prefer another route. This means that the average port time calculated with the 'Route Simulation Software' will be larger than the average port time for that particular route in the real situation. Therefore it will be expected that the port times obtained from the real life situation will be a low quantile of the port time calculated for that same route with the 'Route Simulation Software'. If the rotation through port was completed very favourable (not waiting for any terminal), the real port time should be a very low quantile of the calculated port time for the same route. If many problems occur during the rotation, this quantile will be substantially higher. In other words, the average port time calculated by the 'Route Simulation Software' is a statistical quantity and can not be compared with the port times obtained from the real situation without any adjustments. The situation described above is summarized in **Figure 39**.

It is important to keep in mind that the port agent will reschedule the vessel every time it leaves a dock (instead of keeping to a pre-defined route as the Route Simulation Software does). Each time up to date information about the state of other terminals will be available. The 'Route Simulation Software' should be set up in a similar way. But in the description above, the 'Route Simulation Software' will just be executed once. In other words, the port time calculated by the 'Route Simulation Software' is based on less accurate information⁹ than the real rotation in port scheduled by the port agent. The port agent uses information which was not available when the 'Route Simulation Software' was executed. This is why the difference in port times occurs as described above.

Testing Approach

According to the previous paragraph the port times obtained in the real life situations should be low quantiles of the calculated port time. In this paragraph a procedure will be suggested in order to check whether the assumption mentioned above is correct.

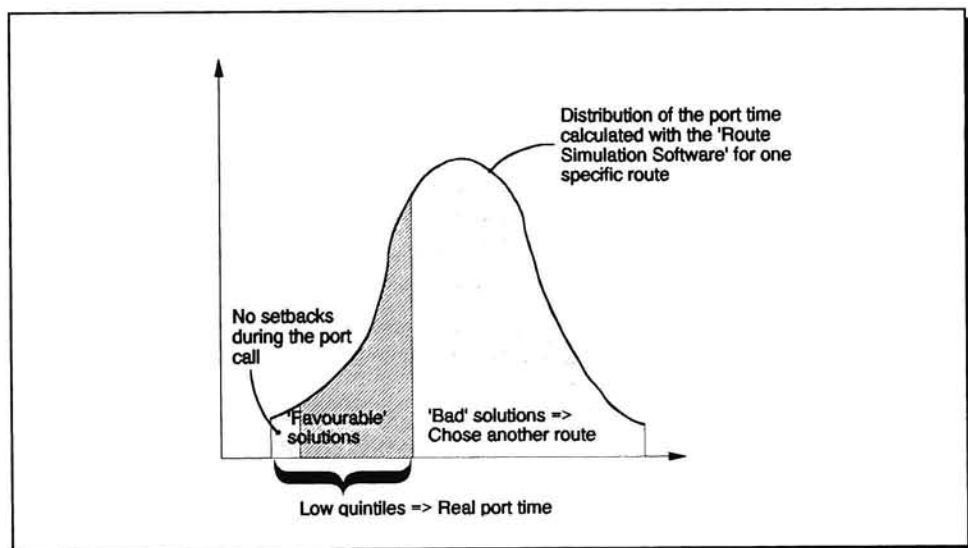


Figure 39: Interpretation of the calculated port time

The port time for each rotation through port should be compared with the port time calculated by the 'Route Simulation Software' for that particular route (same order of the terminals)¹⁰ and the same auxiliary conditions.

In order to achieve this, the port agent can carry out simulations for the vessels arriving at the port. With an average of one vessel (managed by the shipping company investigated) visiting the port of Houston⁷ each week, this way of gathering the desired information is time consuming¹¹. Therefore an adjusted approach will be required. In this case simulations should be carried out for port calls from the past. However, in this case the problem exists that the auxiliary conditions on which the port agent based his decisions are not recorded. If possible, these auxiliary conditions have to be reconstructed.

When taking the available administrative files into consideration the following procedure is suggested in order to reconstruct the auxiliary conditions:

1. In the Daily Vessel Reports is printed when a vessel enters and when it leaves the port of Houston¹². In this way the total time in the port of Houston can be calculated¹³. In **Chapter 3** was explained in detail what kind of information the Daily Vessel Report contains and what it is used for¹⁴.
2. From the rearranged files of the Vessel Transit Log (information sorted by dock number)¹⁵, the auxiliary conditions can approximately be reconstructed. For every dock in the rotation can be checked whether it was occupied or available. Also information about the last vessel departure

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

from a specific dock and the number of hours before a dock will be available can be deduced from the rearranged files of the Vessel Transit Log. Of course this is a time consuming procedure but it has the advantage that all the necessary information can be gathered from behind the desk.

When gathering the auxiliary conditions in port by the method described above the following should be kept in mind:

1. The port agent bases his routing schedule partly on information which will not be taken into consideration by the 'Route Simulation Software'. This additional information is not filed anywhere and can therefore not be reconstructed.
2. The information deduced from the Vessel Transit Log (USCG) is data concerning the situation in port as it occurred in reality. The information given to the port agent at the moment he is making the decision about the rotation through port might differ from what occurred in reality. For example, the dock master of a terminal might say that a berth will be available in 10 hours when in reality the berth was occupied for 20 more hours. Then the port agent will base his decision on incorrect information. Of course this does not apply for information about the last vessels departing from the terminal.

Results

Based on the available Transit Vessels Logs from the three month period during the summer of 1993¹⁶ several tests were carried out according to the procedure described above.

Before presenting the results for all the routes tested, two examples will be presented, one of a case where no delays occurred during the rotation through port and one where several delays occurred.

First, the visit of a vessel to the port of Houston and Texas City starting at the 4th of July will be presented (VOY 209/93). During this visit the vessel visited the terminals Stolthaven (Oiltanking), Petro United, Union Carbide (dock number 66) and Paktank Deer Park (dock number 1)¹⁷. The vessel used 72.9 hours to visit these terminals. Carrying out a simulation for this particular route with the 'Route Simulation Software' resulted in a specific distribution of the port time (Figure 40).

From Figure 40 it appears that the real port time is a 2 percent quantile¹⁸ of the port time calculated in the 'Route Simulation Software'. This corresponds with the expectation described in the paragraph 'Theory'. The quantile calculated above is low because there occurred no drawbacks during this specific rotation through port. The vessel did not have to wait on the availability of any of the

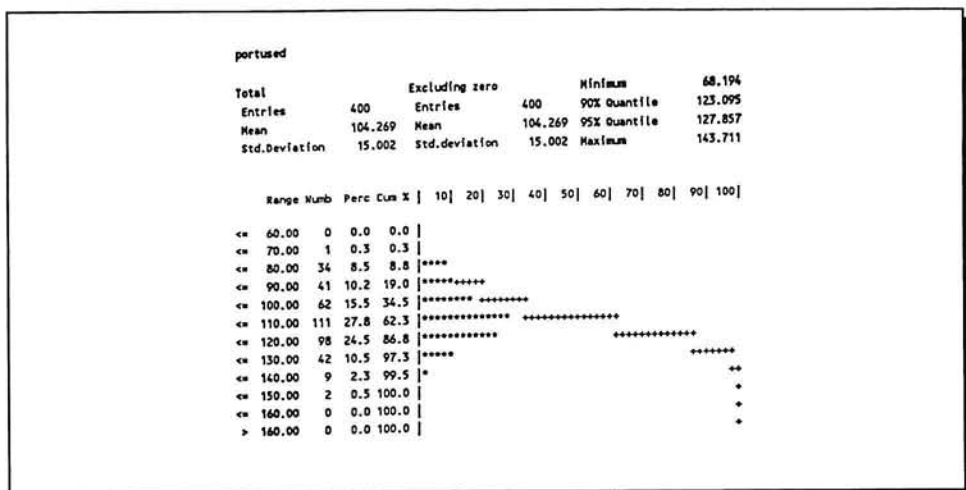


Figure 40: Distribution of the port time

docks neither did any problems occur during cargo handling.

Of course, when several problems occur during a port call, the real port time will be a higher quantile of the calculated port time with the 'Route Simulation Software' than occurred in the example above. In this case an example will be presented concerning a vessel visiting the port of Houston (including Texas City) at the 22nd. of July 1993 (VOY 210/93). During this port call the vessel visited Amoco, Union Carbide (dock number 66), City Dock, ITC (dock number 1) and Paktank Deer Park (dock number 1). The total port time was 84 hours. Carrying out a simulation for this particular route with the 'Route Simulation Software' resulted in a specific distribution of the port time (Figure 41).

From Figure 41 it appears that the real port time is a 32 percent quantile of the port time calculated with the 'Route Simulation Software'. This quantile is substantially higher than the quantile presented in the first example because the vessel had to wait for more than 17 hours for an available berth at the ITC terminal. When subtracting the 17 hours delay of the total port time, the quantile will decrease to approximately 10 %. Again this supports the suggestion that the real port times are low quantiles of the calculated port times with the 'Route Simulation Software'.

The test described above was carried out for all vessels of the shipping company investigated visiting the port of Houston during the month's June, July and August 1993¹⁹. The results are summarized in Table III.

The first column in the table shows the number of the test carried out (a unique number was assigned to each test). The second column shows the port time in

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

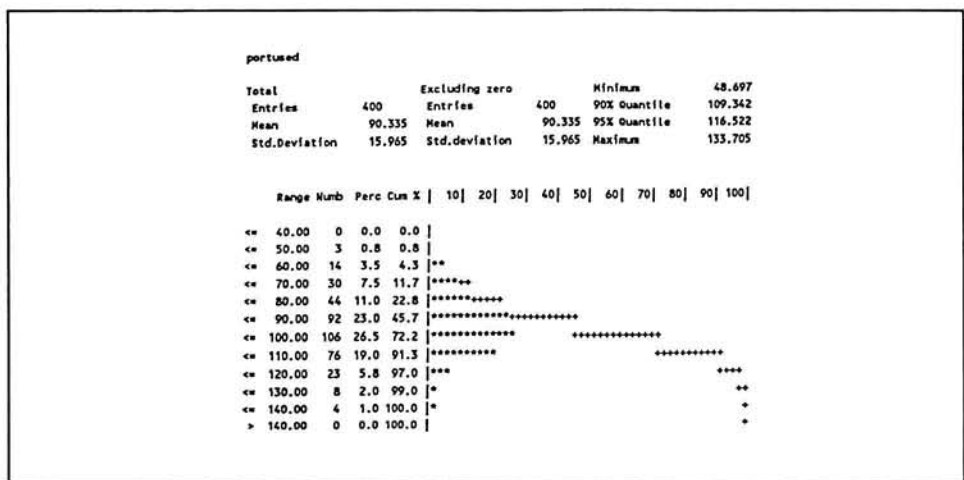


Figure 41: Distribution of the port time calculated

the real life situation and in the third column the results obtained by the 'Route Simulation Software' for this particular route is presented (the same auxiliary conditions as experienced in reality apply). In the fourth column the result of the calculations is printed:

$$(\text{port time of the real life situation} / \text{calculated port time}) * 100.$$

The fifth column presents the estimate of the quantiles, as explained in the previous paragraph's. In the sixth column the port time obtained from the real situation is corrected for obvious visible delays (for example waiting for an available dock or very long docking times²⁰). In the context of the example presented on the previous page, the 17 hour delay at ITC will be subtracted from the total port time of 84 hours. Of course when no large delays occurred, the results presented in the sixth column will be identical to the results presented in the second column. Now the port time again, obtained from the real situation (including correction), is compared with the results from the simulation (seventh column) and the corrected quantiles are calculated (last column).

From the table can be concluded that the port time in the real life situation is a low quantile of the port time calculated with the 'Route Simulation Software' for the same route and under the same auxiliary conditions. In average this quantile will have the value of 32.3 percent and when large delays are subtracted from the port times the average quantile will be as low as 10.7 percent. The results correspond with the expectations explained in the theory in the beginning of the paragraph 'The order of magnitude of the simulation results'. In other words, the results obtained through simulation (when

Test-number	Port time* (real sit.)	Port time* (simul.)	Pt _{real} /Pt _{sim} (%)	Quantile (%)	Port time Corrected	Pt _{real} /Pt _{sim} (%)	Quantile (%)
1	72.9	104.3	69.9	2.0	69.9	67.0	0.2
2	80.8	75.8	106.6	67.9	62.2	82.1	15.9
3	84.0	90.3	93.0	32.0	62.6	69.3	6.3
4	68.0	86.7	78.4	11.8	68.0	78.4	11.8
5	123.5	114.3	108.0	48.4	92.3	80.7	11.9
6	78.5	104.8	74.9	8.0	70.3	67.1	3.7
7	67.0	53.9	124.3	86.3	46.2	85.7	28.0
8	97.0	128.0	75.8	5.7	89.5	69.9	1.7
9	32.4	41.1	78.8	18.2	78.5	74.9	18.2
10	97.0	130.6	74.3	5.8	97.0	74.3	5.8
11	61.0	56.3	92.8	67.4	47.7	84.7	23.0
12	79.5	66.4	119.7	85.9	51.6	77.7	11.0
13	66.0	93.8	70.4	10.3	66.0	70.4	10.3
14	60.0	87.6	68.5	2.0	60.0	68.5	2.0
Average	76.3	88.1	88.2	32.3	68.7	75.1	10.7

Table III

interpreting it correctly) are in the order of magnitude of the port times obtained from the real life situation. This indicates that the 'Route Simulation Software' simulates the chemical shipping activities in port realistically²¹.

EVALUATING THE RESULTS

When introducing the 'Route Simulation Software' it is desirable to evaluate whether or not the software improves the scheduling performance of the port agent and commercial management of the shipping company investigated. But because of the nature of the tasks for which the software is designed (scheduling) combined with lack of relevant information, a complete evaluation is difficult to achieve.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

Next, some of the possible evaluation procedures are summarized:

Method 1

Evaluation of the program by comparing the results obtained by the program with the results obtained in the real situation by scheduling simultaneously with the port agent (such that the same auxiliary conditions apply). For this method the problem arises that the 'Route Simulation Software' and the port agent often will take different decisions concerning the next berth to visit in the rotation. If the vessel deviates from the proposed route by the 'Route Simulation Software' the visit to the remaining terminals have to be simulated in order to say anything about the total port time. It is difficult to simulate these activities because the scheduling strategy of the competitors is not known and because the required information concerning the different docks is hard to reconstruct.

If the port agent draws the same conclusions as the 'Route Simulation Software' it will still be difficult to draw any conclusions whether the actual rotation through port was the best one when taking the auxiliary conditions into consideration.

Method 2

Evaluating the results by analyzing rotations from the past. This can for example be achieved by carrying out simulations for each of the port calls during a certain period (for example last year) and comparing these results with the actual time spent in the port.

In this case the same problems arise as described above. It is of course possible to estimate the auxiliary conditions when running the 'Route Simulation Software' once when the vessels enters the port (as explained in the paragraph 'The order of magnitude of the simulation results'). When applying the theory from the previous paragraph a rough estimate of the actual port time can be made when following the advice of the 'Route Simulation Software'. Of course, a rough estimate of the port time when using the scheduling tool is not sufficient enough to draw any conclusions about the performance of the 'Route Simulation Software'²² (unless the improvement is in the order of magnitude of 100 percent or more²³).

Method 3

Evaluation of the results through simulation. In this case the results obtained when simulating the rotation according to the strategy of the port agent are compared with the results obtained when using the scheduling tool. Several problems arise when introducing this evaluation procedure:

1. The strategy of the port agent has to be translated into computer software. This is difficult because no structured approach is used when making the decisions concerning the scheduling of the vessels.

2. The results from the evaluation should be easy to communicate with the users of the 'Route Simulation Software'. That is why a link with the actual situation in port is preferred.
3. The 'sequential programming approach' used for the 'Route Simulation Software' is not very suitable for implementing the proposed evaluation procedure²⁴. Another drawback of this method is that the required modeling and programming will be time consuming²⁵.

Method 4

Evaluation of the scheduling tool by using it in day to day operations. Again in this case the problem arises that it is almost impossible to compare the achieved results with the other possible solutions (as described above for method 1 and 2). However, an experienced scheduler (like the port agent) will after a certain amount of time be able to get an impression whether the 'Route Simulation Software' performs adequately (qualitative results). Then it will also be possible to formulate possible adjustments.

It is clear that presenting accurate quantitative results about the performance of the 'Route Simulation Software' is difficult. It seems that the last method described is the best option in order to get an impression about the performance of the scheduling tool but when this method is pursued it will not be possible to present any of the results in this report.

In order to generate some numbers concerning the performance of the 'Route Simulation Software' the following procedure is proposed: The auxiliary conditions for some port calls in the past are reconstructed and an optimal route simulation is carried out. Then the actual rotation carried out is simulated and the resulting port time will be compared with the port time calculated for the best route. In this case the same rotations are simulated as in the previous paragraph.

It is important to notice that in reality the 'Route Simulation Software' will be used in a different way as proposed in the procedure above (the vessel will be rescheduled after each terminal which has been visited²⁶). That is the reason why the numbers presented in the table below just give a rough indication of the possible increase in performance (Table IV, ^a The simulation results are in hours).

The first number in the table shows the number of the test carried out. The results when running the scheduling tool for the chosen route in the real situation are printed in the second column. The port times calculated for the best route with the 'Route Simulation Software' are printed in the third column and then in the fourth column the difference between the results obtained in the

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

Test number	Simul. result* (chosen route)	Simul. result* (best route)	$Pt_{\text{best r.}} - Pt_{\text{chosen r.}}^a$	Increase of performance (%)
1	104.3	63.4	40.9	39.2
2	75.8	72.4	3.4	4.5
3	90.3	85.8	4.5	5.0
4	86.7	68.9	17.8	20.5
5	114.3			
6	104.8	85.4	19.4	18.5
7	53.9	49.8	4.1	7.6
8	128.0			
9	41.1	38.1	3.0	7.3
10	130.6	108.2	22.4	17.2
11	56.3	56.3	0.0	0.0
12	66.4	62.6	3.8	5.7
13	93.8	92.3	1.6	1.7
14	87.6	87.6	0.0	0.0
Average	88.1	72.6	10.1	10.6

Table IV

two previous columns is printed: In the last column this difference is related to the simulation result of the chosen route in the following way:

$$\frac{100 * (\text{port time of chosen route} - \text{port time of best route})}{\text{port time of chosen route}}$$

From the table can be concluded that about 140 hours could be saved when comparing the results of the chosen rotations with the best rotations according to the 'Route Simulation Software'²⁷. This corresponds with a decrease of the port time of 10.6 percent. In the chapter 'Port costs' was explained that a 10 percent improvement through better scheduling of the vessels in the port of Houston will generate additional earnings of about US\$ 10000 a year. Of course once again, it is important to notice that the numbers generated above are based on a approach which differs substantially from the approach used in the real life scheduling environment.

INTRODUCING AND USING THE 'ROUTE SIMULATION SOFTWARE'

Introduction

This paragraph contains a description of the experience of using the 'Route Simulation Software' for scheduling purposes. First is explained in what way the 'Route Simulation Software' can be used (paragraph 'Application possibilities') and next the introduction of the 'Route Simulation Software' at a port agency is described (paragraph 'Introduction of the RSS at the port agency'). Finally, an example of a scheduling decision made by the 'Route Simulation Software' in a real life situation is presented (paragraph 'Using the 'Route Simulation Software'').

Application possibilities

There are two different ways in which the 'Route Simulation Software' can be used:

Port Agency

The port agent can use the 'Route Simulation Software' for scheduling the vessels through port. Before every shift relevant information is entered into the computer and then the optimal rotations are calculated and printed on screen. Based on this information and other relevant information the port agent makes a decision about the next berth to be visited. In other words, the 'Route Simulation Software' assists the port agent in his decision process and does not replace the port agent.

Commercial department of the shipping company

The commercial manager can use the 'Route Simulation Software' to quantify some of the decisions concerning the booking of cargoes from certain terminals. By running the 'Route Simulation Software' it is possible to deduce how much more time a vessel approximately will stay in port and this can then be compared with the profit made on the deal. This way it can be quantified if certain business propositions are acceptable.

Introduction of the RSS at the port agency

The 'Route Simulation Software' is especially designed to assist the port agent with scheduling the vessel through port²⁸. Even though the software is tailor made for its application there always exists resistance among the users when introducing the new software. There are several reasons for this:

1. The benefit of using the new software application is not clear. The employees are used to proceed in a certain way and find it difficult to change these procedures ('It did always go well, so why change?').

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

2. When formulating the business problem, the relation to the goal of the organisation is often not clear.
3. The users are not prepared to the fact that often some discipline is required in order collect the necessary input data completely.

If not probably dealt with the issues described above an information technology project can fail. The users feel that they are managed by the computer software though the intension was the other way around. Most of these problems boil down to the problem of communication. In order to implement software successfully communication towards the users seems to be of great importance.

In order to minimize the resistance of introducing the 'Route Simulation Software' the following approach was used:

1. The user²⁹ was involved in the project in an early phase. In this way thiswishes and possibilities were formulated. Involving the users in an early phase has more advantages:
 - * Access to relevant information and experience;
 - * The project will to a larger extent be considered as their own;
 - * Reduce the resistance to change.
2. Knowledge of the way in which the program works gives the user more confidence in the results. Therefore the way the activities in port are simulated was gradually explained to the port agent.
3. The process of using the scheduling tool is explained to the port agent and in several cases the author scheduled vessels simultaneous with the port agent. In the folowingparagraph several examples of the scheduling process with the 'Route Simulation Software' will be presented. The contents of scheduling simultaneously with the user is:
 - * Get acquainted with the 'Route Simulation Software'
 - * How to interpret the results
 - * Get acquainted with the process of experimenting with the software

Of course, during the implementation of the 'Route Simulation Software' several problems arose:

1. One problem is connected to the relationship between the port agency and the shipping company investigated. The shipping company hires the port agency to take care of the practical matters when visiting the port of Houston³⁰. In other words, the port agency for which the program is designed, did not initiate this study (the shipping company initiated the project). In the beginning of this project the port agent did not really believe that the objectives of the project could be realized, which of course does not make the acceptance of the 'Route Simulation Software' easier. Nevertheless, the port agent has always supported this project totally in every possible way.

2. The designers of the computer software most often have more knowledge about the future application (of the computer program) than the user. In this case it is clear that it was difficult for the user to imagine what the possibilities of simulation are which makes the process of gathering the right information more difficult.
3. When the 'Route Simulation Software' was first introduced, the port agent hesitated with gathering all information required. When using the computer tool, only one additional question has to be asked when calling the terminals though this seemed to be difficult. But after actually doing it a few times it was clear that the terminals were very cooperative and can provide the desired information.
4. As stated before, when introducing computer software it is important to involve the users, also during the building of the actual program itself. In this project direct feedback from the users during the building of the program was not possible because the program was written in Delft, The Netherlands.
5. When introducing new computer software the users should have the chance to get acquainted with the system over a certain amount of time. A gradual introduction of the 'Route Simulation Software' at the port agency is preferred. It is obvious that the time available for this phase in this project is too short. By the time the port agent gets used to the idea of the fact that the scheduling process of vessels can be assisted by the 'Route Simulation Software', the author headed back to Europe. Therefore active support from the shipping company is required in the future. A 3 month³¹ period will be required in order to completely incorporate the software in the scheduling procedures of the port agent³². When putting up this time table one should keep in mind that interesting situations in which the 'Route Simulation Software' can be useful do not appear every day.
6. Sometimes decisions about the rotation have to be made during the night. Of course it is not very likely that the port agent is going to simulate the situation during his sleep. In these cases possible scenarios have to be simulated at day time. This requires some extra effort from the scheduler.
7. When using the 'Route Simulation Software' it is sometimes useful to simulate several scenarios. Of course, the computer should be able to perform the required calculations within a certain amount of time. Unfortunately the computer facilities at the port agency do not meet the required standard. In order to work successfully with the 'Route Simulation Software' a faster computer should be purchased. In this case it is important to notice that a co-processor³³ might improve performance sufficiently.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

Using the 'Route Simulation Software'

Now a situation in which the 'Route Simulation Software' was used for scheduling a vessel to the next berth is explained:

The situation described below occurred at the 22nd. of January 1994 when a vessel managed by the shipping company investigated finished cargo handling at Union Carbide (35) in Texas City. Three more docks needed to be visited during the port call: ITC dock number 1 (15), Sterling (34) and Celanese (5). Sterling is located in Texas City, Celanese in Bayport and ITC is located on the Houston ship channel³⁴.

Both Sterling and Celanese are available and ITC dock number 1 is occupied for another 6 hours. The last vessel departed from Sterling and Celanese 26 and 14 hours ago, respectively. ITC also told the port agent that if the vessel is not going to tender NOR to ITC first, most likely a Stolt vessel will tender NOR and the dock will then be occupied for another 12 hours. In other words there are two scenario's:

- (1) ITC dock number 1 is going to be occupied for the next 6 hours;
- (2) ITC dock number 1 is going to be occupied for the next 18 hours;

In this context the question arose if it is economical to visit ITC first although this will result in a six hours wait. In this case it is important to keep in mind that ITC is a highly occupied terminal. Running scenario 1 on the 'Route Simulation Software' results in:

***** Optimal Rotation Program *****
J.D.Doornbos

The program is calculating the optimal route.
The best routings will be printed:

route	average	90% quant
34 15 5	44.87	63.00
15 5 34	47.29	59.21
34 5 15	47.55	60.00
5 15 34	47.99	63.08
15 34 5	55.78	72.00

*****Press m to return to the main menu*****

In this case the 'Route Simulation Software' advises to visit Sterling (34) first, but visiting either Celanese or ITC first will not result in an enormous loss of time.

According to the port agent it is likely that the departure of the vessel currently occupying ITC will be delayed for 2 hours which means that ITC dock number 1

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

will be occupied for the next 8 hours (instead of 6 hours). Entering this information into the 'Route Simulation Software' results in:

***** Optimal Rotation Program *****
J.D.Doornbos

The program is calculating the optimal route.
The best routings will be printed:

route	average	90% quant
34 15 5	43.87	61.71
5 15 34	44.56	60.23
34 5 15	47.92	61.27
15 5 34	50.41	63.43
5 34 15	54.87	69.57
15 34 5	58.25	72.00

*****Press m to return to the main menu*****

In this case the computer advises to visit either Sterling or Celanese first. If the vessel occupying ITC dock number 1 is delayed for an additional 2 hours the 'Route Simulation Software' will still chose to visit Sterling first.

Now it is interesting to see what will be the most favourable terminal to visit first when the Stolt vessel tenders NOR to ITC before the vessel managed by the shipping company investigated. In this case ITC dock number 1 will be occupied for the next 18 hours:

***** Optimal Rotation Program *****
J.D.Doornbos

The program is calculating the optimal route.
The best routings will be printed:

route	average	90% quant
5 15 34	45.52	56.85
34 5 15	45.23	63.94
34 15 5	48.69	59.66
15 5 34	61.49	76.36
15 34 5	67.49	80.77

*****Press m to return to the main menu*****

It is clear that either Celanese or Sterling should be visited first. If the ITC berth will be available four hours later than predicted by the terminal (which is very likely according to the port agent) the 'Route Simulation Software' will generate the following results:

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

***** Optimal Rotation Program *****
J.D.Doornbos

The program is calculating the optimal route.
The best routings will be printed:

route	average	90% quant
34 5 15	42.05	57.64
5 15 34	49.00	59.59
15 5 34	65.32	76.89
15 34 5	71.69	84.80
15 34 5	66.07	77.24

*****Press m to return to the main menu*****

It seems that the route where Sterling (34) is visited first performs better and the route where Celanese (5) is visited first performs worse. In this case Sterling is clearly preferred to become the first terminal to be visited.

Considering the conclusions drawn for both the scenario's above Sterling will be preferred as the terminal which is going to be visited first. The port agent draws the same conclusion.

In the real situation the ship visited the remaining terminals in the rotation in the order Sterling, Celanese and finally ITC. Unfortunately ITC dock number 1 was occupied when the Catalina finished cargo handling at Celanese and therefore it had to anchor for about 7 hours at Bolivar Road.

EVALUATING CURRENT SCHEDULING STRATEGY USED

In the description of the objective of this study was explained that in the current situation the following scheduling approach applies:

1. The port agent tries to schedule the vessels to the terminal that is located furthest in the Houston ship channel first (situation 1);
2. Paktank Deer Park is always visited right away when it is available (situation 2).

It is possible to evaluate the scheduling approach described above by using the 'Route Simulation Software' for a period of time and collecting the necessary data. In order to get an impression of the outcome of the evaluation several imaginary rotations were simulated with the 'Route Simulation Software'³⁵.

Situation 1: Terminal furthest in the ship channel first³⁶

In this case 10 different situations were simulated in which the vessel is located at the pilot station and the terminals that are going to be visited are all available³⁷. Now was checked how often the 'Route Simulation Software'

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

preferred the terminal located furthest in the ship channel. The results are summarized in Table V.

Number of rotations carried out	Terminal with highest occupancy rate preferred first	Terminal located furthest on the ship channel first
12	9	2

Table V

In only 2 of the 12 situations simulated, the terminal furthest on the ship channel was preferred. In more than 80 percent of the cases the terminal with the highest occupancy rate was preferred. When excluding the rotations in which the terminal located furthest down in the ship channel also happened to be the terminal with the highest occupancy rate from the tests, the terminal located furthest in the ship channel was not selected once. In other words, the first part of the scheduling approach currently used (as explained above) is not good.

Situation 2: Visit Paktank DP if the terminal is available³⁶

In the situation 1, it was concluded that the terminal with the highest occupancy rate often is preferred as the terminal to be visited first. Paktank DP is the terminal with the highest occupancy rate of all the terminals in Houston. Tests with the 'Route Simulation Software' showed that Paktank Deer Park should always be visited right away if this terminal is available. Most of the times Paktank Deer Park was even preferred if the vessel had to wait for a couple of hours before it was possible to dock at the terminal.

In order to get an impression of how many hours waiting for the Paktank Deer Park³⁸ terminal is acceptable, 10 tests with different rotations were carried out with the 'Route Simulation Software'. The first 5 tests concern rotations in which several terminals with high occupancy rates are incorporated and in which the current location of the vessel was selected in such a way that a visit to Paktank Deer Park first can result in extra shift time. The last 5 tests concern rotations where it is obvious that Paktank Deer Park is going to be visited first. The results are summarized in Table VI (^a Number of hours it is acceptable to wait until Paktank Deer Park dock number 1 is available).

From the table it can be concluded that waiting times between 4 and 8 hours are acceptable when visiting Paktank Deer Park first. Of course the number of hours acceptable will be different for each situation. This means that the 'Route Simulation Software' should be used each time the vessel is going to be

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

Test number	Terminal numbers in route	Nof h. waiting time accep. ^a
1	22 19 16 28	5
2	22 32 34 4	4
3	22 7	4
4	22 26 2	6
5	22 15 30	4
6	9 30 22	7
7	13 4 22	11
8	22 25 1 30	7
9	20 22	6
10	37 33 20 22	7

Table VI

scheduled. The results presented above are just examples in order to get an impression of the order of magnitude of the acceptable waiting times when visiting Paktank Deer Park.

Notes

1. Of course the correction for barge traffic at some of the terminals should be taken into consideration when viewing the occupancy rates of the terminals. This was explained in Chapter 6.
2. Which is one of the reasons for designing the 'Route Simulation Software'.
3. This was explained in greater detail in 'The users guide', Chapter 8.
4. The 'real' life situation in port is incorporated in the statistics of the docking times and the interarrival times obtained from the US Coast Guard and the administration of the shipping company investigated.
5. In the paragraph 'Simulation options' (Chapter 8) a detailed explanation of the 'longrun simulation' option was given.
6. This was explained in 'The users guide'.
7. Including Texas City and Freeport.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

8. Assuming that the port agent knows that the waiting time at that terminal will be 36 hours (the terminals do not always give correct information to the port agent).
9. In the 'Route Simulation Software' the future auxiliary conditions of the different docks are deduced by simulation which of course is less accurate than information directly obtained from the terminals (assuming that their information is correct which is not always the case).
10. This can be achieved by starting up the simulation through option number two in the main menu of the 'Route simulation Software', 'Port time of a specific route'.
11. Only two weeks were available for this phase of the project.
12. Including Texas City and Freeport. However, Freeport (DOW) will be excluded from this test.
13. The DOW terminal in Freeport is excluded from this test.
14. Paragraph 'Structure of the administration'
15. Paragraph 'The US Coast Guard' in Chapter 5.
16. The statistics of the interarrival times and the docking times (of all vessels) was based on the Vessel Transit Logs from this period.
17. The last terminal visited was DOW in Freeport. This terminal is excluded from this example because the information available in the 'Route Simulation Software' concerning this terminal is not accurate.
18. It was assumed that the quantiles are linear between the values presented in the histograms. In reality this is most likely not true but this approach will give a good estimate of the desired quantiles.
19. Voyages where not all the desired information was available were excluded.
20. The port time is corrected for long docking times if the docking time exceeds the average docking time with more than 35 percent.
21. The port times obtained through simulation approximately correspond with the port times obtained from the real life situation. Therefore the assumption about neglecting the supposed limited correlation between some of the statistics (as stated in Chapter 6) will be acceptable.
22. Especially when taking the variation of the quantiles into consideration.
23. Which is not the case.
24. In Chapter 5 was explained that the resulting software when using the 'sequential programming approach' will be designed for one specific application and will therefore be difficult to extend.
25. The time available for this phase of the project is limited.
26. Of course it is also possible that certain decisions concerning the scheduling of the vessel is based on information not taken into consideration by the 'Route Simulation Software'. It is important to remember that the 'Route Simulation Software' is just a planning tool and the final decision about the scheduling should both be based on the port agent's judgement (taking information not available for the 'Route Simulation Software' into consideration) and the statistical results obtained from the computer.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

27. Remember that the real port times are low quantiles of the real port time calculated by the 'Route Simulation Software'.
28. The role of the port agent was explained in **Chapter 2**.
29. The port agency and commercial management of the shipping company.
30. Including Texas City and Freeport.
31. This is an estimate.
32. Some other conditions also need to be fulfilled in order to achieve full acceptance of the software.
33. They cost about US\$100.
34. The paragraph 'Evident situations and the simulation software' contains a map of the port of Houston, Texas City and Freeport.
35. There was not enough time available in order to carry out a sufficient number of tests in the real situation in port.
36. Excluding DOW.
37. Four terminals in each rotation.
38. Berth number 1.

CHAPTER 10: CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The objective of this study was to make an user friendly operational port call planning model in order to reduce the port time of chemical tankers in the port of Houston¹. From the 'Disturbance analysis' is known that substantial time savings can be gained:

- * 43 percent of the time spent in port is lost because of delays;
- * The biggest single reason for delays in port is waiting for an occupied berth (40 % of the time lost);
- * Additional earnings of US\$1065 a year can be generated for each percent time saving achieved when scheduling the vessel through the port of Houston¹.

Based on the information above, the scheduling of the vessels through port was analyzed in more detail and in this context the 'Route Simulation Software' was developed.

Now the most important conclusions concerning the scheduling tool are presented:

1. The 'Route Simulation Software' satisfies the pre-defined objective of this study. The project was realized within the available time (6 month's) and budget.
2. The 'Route Simulation Software' calculates the statistical fastest route through port when taking the auxiliary conditions into consideration. The real port time is a low quantile of the port time calculated with the scheduling tool for that specific route².
3. It is difficult to quantify how much time will be saved when using the 'Route Simulation Software' during the scheduling process. This is caused by the nature of the tasks for which the software is designed (scheduling) combined with lack of relevant information³.
4. The terminals can provide the port agent with the required information in order to start the computer simulation.
5. The 'Route Simulation Software' assists the port agent in his decision process and does not replace the port agent. Information which is not taken into consideration by the 'Route Simulation Software' can influence the decision about the next berth to be visited substantially.
6. The port agent can work with the software without any assistance from the author. He was taught how to work with the 'Route Simulation

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

Software' and he learned to experiment with the software (calculating different scenario's).

7. Some extra effort from the scheduler is required when decisions about the rotation are made at night. In this case the port agent needs to calculate several scenario's during the day in advance.
8. In the current strategy, the port agent prefers to schedule the vessels to the terminal which is located furthest on the Houston ship channel. Tests showed that this is not a good criterion when scheduling the vessels through the port of Houston. The strategy of always visiting Paktank Deer Park when the terminal is available seems to be a good strategy.

RECOMMENDATIONS

1. In order to incorporate the 'Route Simulation Software' in day to day scheduling operations of the port agency the following will be required:
 - * A gradual introduction of the 'Route Simulation Software' at the port agency is preferred. The users should get the chance to get acquainted with the system over a certain amount of time. Therefore active support from the shipping company is required in the near future.
 - * The computer facilities at the port agency do not meet the required standard in order to work sufficiently with the 'Route Simulation Software'. A faster computer should be purchased⁴.
2. After working with the 'Route Simulation Software' for a period of time the experience with the scheduling tool should be evaluated and possible extensions of the software can be suggested. The assumptions⁵ made when designing the 'Route Simulation Software' should also be evaluated. These assumptions are:
 - * A possible correlation between some of the statistics is neglected⁶.
 - * The OWT-statistics (occupied waiting time) are rough estimates of the real life situation.
 - * The statistics concerning the DOW terminal in Freeport were made by an educated guess. Therefore it is better to exclude the DOW terminal from the simulation until accurate statistics for this terminal have been obtained.
 - * The correction of the statistics for barge traffic are based on rough estimates of the real life situation.

If commercial management wants to quantify how much time is saved when scheduling with the 'Route Simulation Software' special arrangements concerning the administration have to be made⁷.

3. The maintenance of the software also requires proper attention. This concerns both the maintenance of the software and the maintenance of the statistics on which the simulation is based⁸. In this case, manpower with sufficient skills is required. The computer department of the shipping company investigated has no experience with Turbo Pascal and does not have any experience with simulation software whatsoever. The same

situation applies for the port agency. The commercial manager of the shipping company is therefore the only person in the company who is able to maintain the system⁹.

4. This project concerning the scheduling of the vessels through port was executed according to the point of view of one single shipping company. Analyzing the scheduling situation from another point of view might result in a different scheduling approach. Scheduling possibilities when using a top-down approach should be studied in greater detail because big savings concerning both time and money might be gained. The next paragraph gives a brief introduction of planning in a broader perspective.

PLANNING IN A BROADER PERSPECTIVE

Introduction

When taking this project concerning the scheduling of the vessels in the port of Houston¹ in a broader perspective, it is obvious that more cooperation between the different parties¹⁰ will, in general, shorten the port times of the vessels. For the completeness, first the way the vessels are scheduled through the port of Houston¹ are summarized: A vessel enters the port and needs to visit several terminals. The scheduling of the vessels is not coordinated (on macro-level)¹¹. Each vessel tries to find the best way through port separately. The scheduler¹² has limited information available when making decisions. It is very difficult to estimate what future positions the other vessels in port will have.

According to the experience of the port agent¹³ in Houston¹, the scheduling of the vessels through port is easier when he has several vessels in port at the same time¹⁴. This is caused by the fact that more information is then available and the scheduling of the vessels is arranged by one authority. In other words, the information availability and concentrated scheduling power are of great importance when seeking improvement in scheduling the rotation of the vessels. Based on this information the following paragraph discusses a possible direction of a solution.

General scheduling model

The first step in order to improve scheduling procedures in the port of Houston¹, would be that the shipowners (or its agents) and the terminals provide more information to each other. In this case the individual scheduling process of each of the operators can improve, although the final objective should be to integrate the scheduling tasks of all the operators with each other. If all the operators integrate their scheduling task with each other we can speak of a central planning system:

1. Each vessel visiting the port keeps a central authority (e.g. the harbour master) up to date with the following information:

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

- * Which docks have to be visited;
 - * Which cargoes have to be loaded or discharged and the relevant quantities of the cargoes;
 - * Restrictions in the rotation;
 - * Possible visits to dry docks for repairs and estimates of the time required.
2. The terminals provide the harbour master with the following information:
 - * Estimates of the time required for cargo handling for the vessels currently docked at the terminal and for the vessels which are going to visit the terminal in the near future;
 - * Giving notice of any problems which can influence cargo handling capabilities.
 3. The US Coast Guard can provide information concerning vessel traffic and weather conditions¹⁵.
 4. Several times a day a schedule will be made for all the vessels visiting the chemical docks in port with a port planning tool¹⁶. The computer program should calculate the average best solution for all the vessels involved. This means that sometimes the interests of a specific operator has to be sacrificed for interests of other operators, but in average all the vessels will be better off. In order to ensure a fair scheduling approach for all the parties it could be useful to keep a record of how often the interests of each operator had to be sacrificed.

In the context of scheduling vessels through port, it might be useful to study air control systems of airports. The proposed model is roughly summarized in **Figure 42**.

When a central planning procedure is introduced successfully, the following advantages can be obtained:

Shipowners/operators:

- * More business can be generated with each vessel because the average port time decreases;
- * More reliable estimates concerning the time spent in port can be made resulting in a higher service level towards the clients;
- * The amount of money spent on demurrage will be reduced as well as the time and money lost during the six hours grace period before any demurrage can be collected¹⁷.

Shippers:

- * Higher service level of the operators.
- * Reduced demurrage claims.
- * The increased ship-efficiency may lower the freight rates.

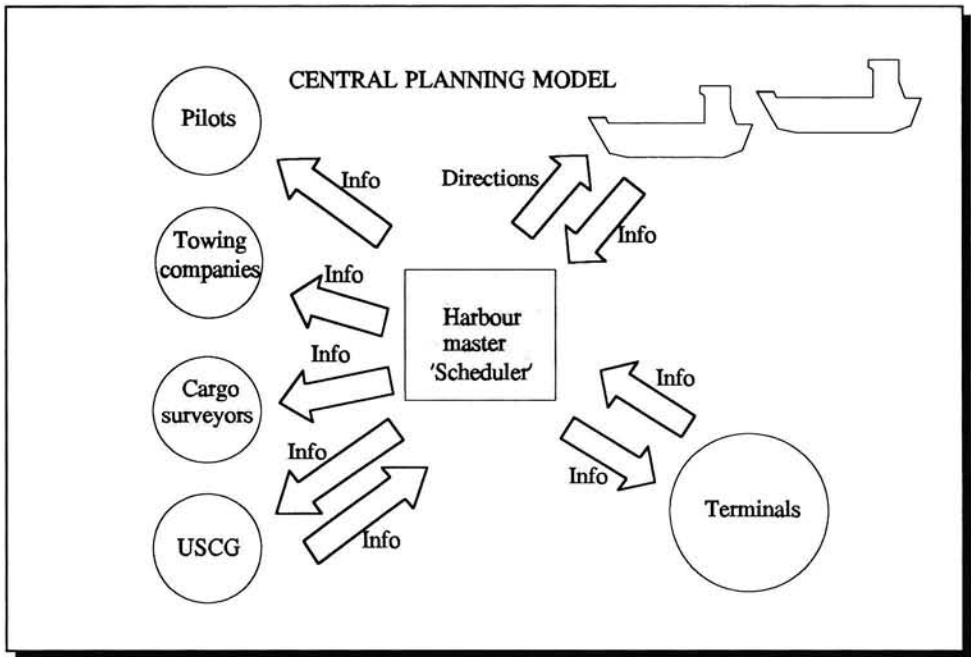


Figure 42

Terminals:

- * Reduced demurrage claims;
- * Attract business from competing ports;
- * Higher service level towards clients¹⁸.

Project proposal

In order to implement the proposed central scheduling unit, the following approach is suggested:

Phase 1

This phase can be considered as the pilot-project in which the objective is to draw up an inventory of possible savings concerning both time and money:

- * Analyze how much time can be saved when the central planning unit is introduced. It might be possible to do this by simulation¹⁹;
- * Quantify the time saved and the financial consequences for the different types of companies involved;
- * Make a project proposal (including manpower requirements and costs).

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

Phase 2

The second phase will be pursued if in the first phase it is concluded that the financial consequences are positive (also when taking the costs of implementing the scheduling tool into consideration). In this case the main objective will be to get all the companies involved and the different authorities to support this approach. Of course, there should be made arrangements for the required financial resources:

- * Start a task force which has as objective to arrange meetings, give presentations and structure the wishes and requirements of all parties involved. It seems that in this process the port authorities of the ports involved can play an important role;
- * Study how the cooperation between the port authorities of Houston and Texas City can be intensified (or integrated);
- * Define selection criteria in case different vessels are competing for the same dock.

Phase 3

When phase number 2 has successfully been completed, the process of designing the model can be started:

- * Build the model and design a computer program;
- * Testing of the computer program;
- * Implementation of the computer program. This also includes all the required organizational adaptations and aspects concerning legal procedures (if necessary), and electronic data interchange (EDIT).

Of course it is clear that a lot of resistance within conservative shipping circles will exist against the progressive approach suggested in this paragraph. It is clear that convincing results from the first phase will be required in order to get enough of the parties involved and financially committed to the project. Therefore the first phase should be considered as a crucial phase in the proposed project.

Notes

1. Including Texas City and Freeport.
2. This was explained in detail in **Chapter 9**, paragraph 'The order of magnitude of the simulation results'
3. This was explained in **Chapter 9**, paragraph 'Evaluating the results'.
4. A 486PC, 66 Mhz. or the new 586PC is preferred.
5. Assumptions were made in order to simplify the simulation process or because it was not possible to gather appropriate input data.

Part II: Port Time Analysis of Chemical Tankers in the Port of Houston

6. **Chapter 6** explained about the correlation between the statistics.
7. In **Chapter 9** was explained which problems exist when evaluating the 'Route Simulation Software'.
8. The way the statistics are inquired is explained in **Chapter 5**.
9. The commercial manager of the shipping company investigated is an engineer of education and has much experience in programming with Turbo Pascal.
10. Shipowners/operators and terminals.
11. Coordination is only possible on micro-level, meaning that operators take vessel movements of their own vessels in port into consideration when scheduling.
12. The port agency carries out the scheduling tasks of the vessels for the shipping company investigated.
13. The port agent working for the shipping company investigated.
14. Assuming that the vessels not all have to visit different terminals.
15. Fog is a common problem in Houston, especially during the winter.
16. Which has to be tailor made for this specific situation.
17. The first six hours are for the owners expense.
18. Or towards the relevant parts of its own organisation.
19. This might be an interesting task for a student.

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TECHNICAL TERMINOLOGY AND ABBREVIATIONS

Charter-party	Contract setting out terms on which the shipper contracts for transportation of his cargo or the charterer contracts for the hire of a ship.
Demurrage	Demurrage is payed to the shipping company when cargo handling takes a longer period of time than agreed on in the charter party. The demurrage rate is also laid down in the charter party.
Draught	Vertical distance between water surface and keel of a ship.
DEA	Drug Enforcement Agency
Docking time	The time that a vessel is docked at a particular berth (laytime).
DT	Docking time.
IAT	Interarrival time.
Layby berth	A berth where a vessel can dock when waiting for an occupied berth.
Laytime	The time that a vessel is docked at a particular berth (docking time).
NA berth	Not Available berth = Berth is occupied.
NOR	Notice Of Readiness. NOR is tendered to the next terminal when the vessel is ready to leave the terminal it is visiting at that moment.
Pilot	A pilot is responsible for manoeuvring a vessel safely through port.
Rotation	The rotation of a vessel in port is the order in which the different terminals are visited.
RSS	Route Simulation Software.
Sea leg	The part of the voyage when the vessel is outside port.
Shift	The movement of a vessel between two berth's.
Time charter	The vessel is hired for a specific period of time for payment of a daily, monthly or annual fee. The shipowner retains possession and mans and operates the vessel under instruction from the 'charterer' who pays the voyage costs.
USCG	US Coast Guard.
USDA	US department of Agriculture.
VTS	Vessel Traffic Control department (of USCG).

PART III - SLOPS TREATMENT ONBOARD; THE SEATREAT SYSTEM

Table of Contents

CHAPTER 1:	ENVIRONMENTAL REGULATIONS	192
CHAPTER 2:	SLOPS PRODUCTION ON SHORTSEA CHEMICAL-TANKERS	200
CHAPTER 3:	SLOPS COSTS	207
CHAPTER 4:	SLOPSTREATMENT	213
CHAPTER 5:	OUTLINE SPECIFICATION FOR A SLOPS TREATMENT SYSTEM ONBOARD	228
CHAPTER 6:	CHEMICAL TANKER DESIGN CONSTRAINTS	239
CHAPTER 7:	ECONOMIC EVALUATION	265

PART III - SLOPS TREATMENT ONBOARD; THE SEATREAT SYSTEM

Slops on a chemical tanker are the result of the cleaning of the cargo tanks with water. The mixture of chemicals and water can sometimes be discharged at sea or, in other cases, it has to be delivered at shore reception facilities for further treatment. Little is published about the volumes which are produced by a chemical tanker operating in European shortsea trades, as well as the costs for its removal. This is why a large chemical tanker company was prepared to cooperate in a study which has two objectives.

1. Measuring the slops production for its fleet of chemical tankers over a number of years;
2. Developing means to reduce the slops production, and to treat slops onboard the vessel.

This resulted in a cooperation with a specialist in chemical waste water treatment equipment, ENCON B.V. of Rotterdam, which developed, based on the specifications of the study, a relatively simple, but elegant solution for the treatment of slops onboard. A system which can be implemented on every vessel, and can in principle be cost-effective. These encouraging results are especially relevant in the light of the increasing number of environmental regulations.

CHAPTER 1: ENVIRONMENTAL REGULATIONS

ENVIRONMENT REGULATIONS

In 1973 a treaty on "Maritime Pollution" (MARPOL) was established. In 1978 some subjects of this treaty were modified and since then the treaty is known as MARPOL 73/78.

In The Netherlands the treaty was incorporated as a part of the "Prevention of Pollution by Ships Act" (WVVS '86). This act imposes sanctions on violations of the MARPOL regulations by ships sailing under the Dutch flag and foreign ships within Dutch territories.

This treaty consists of:

- * 20 articles;
- * 2 protocols;
- * 5 technical annexes.

For the design and exploitation of a chemical tanker, Annex II is the most important one. This annex contains the procedures and regulations for operational activities and equipment of the ship.

The annexes deal with the following subjects:

- * Annex I : oil;
- * Annex II : noxious liquid substances in bulk;
- * Annex III : chemicals in packaged form;
- * Annex IV : sewage;
- * Annex V : garbage.

Description of ANNEX II

On 7 April 1987 the regulations, described in Annex II, have taken international effect. This annex comprises 14 regulations which contain the basic directives. These directives contain 5 appendices:

- * Guidelines for classification of noxious liquids;
- * List of noxious liquids which are transported in bulk;
- * List of other liquids which are transported in bulk;
- * Loading journal;
- * Certificate.

The annex also contains the chapter "Guidelines for Procedures and Equipment for Unloading and Discharging Noxious Liquids". This chapter comprises the following appendices:

- * Determination of remainders in cargo tanks, pumps and pipes;
- * Pre-wash procedures;
- * Ventilation procedures;
- * Standard execution of the "Procedures and Arrangement Manual", in short P&A Manual.

Definition of 'Noxious Liquids'

The definition of noxious liquids is determined by the following factors:

- * Bioaccumulation; The quantities in which living organisms absorb substances and the threat they, because of this, directly or indirectly are, for the life in the sea and the health of men;
- * The toxicity for the organisms that live in the water;
- * The threat for the health of people, who take in the polluted water;
- * The threat for recreation areas or other sea activities.

Part III: Slop-treatment Onboard; The Seatreat System

The "Group of Experts on the Scientific Aspects of Marine Pollution" (GESAMP) developed, by orders of the IMO, a guideline for every factor. With these guidelines the GESAMP classified the noxious liquids into four product categories. It divided the products into A, B, C and D substances. A-substances are the most toxic and D-substances are the least toxic.

OPERATIONAL CONDITIONS

The objective of Annex II is based on two principles:

1. Limitation of the spill of noxious liquids in case of accidents;
2. Limitation of the operational discharge.

Limitation of the spill of noxious liquid

To achieve this, Annex II puts restrictions on the transport of chemicals. The connection between Annex II and the IBC/BCC becomes evident:

- * Transport of most noxious liquids (A, B and C) by sea must be carried out by chemical tankers;
- * Some oil-alike liquids (C and D) can be transported by product tankers;
- * Some D-liquids can be transported in deep tanks of dry cargo ships, if they are not mentioned in the IBC/BCC code;
- * Transport of packaged noxious liquids is connected with Annex III.

In summary:

- * A-substances: ship type I or II;
- * B-substances: ship type II or III;
- * C-substances: ship type III;
- * D-substances: no requirements concerning ship types.

Besides the requirements of Annex II, every (Dutch) ship has to meet other requirements. If a ship has to transport substances of Annex II in bulk, it needs a Certificate of Fitness (CoF). Internationally this certificate is called the NLS (Noxious Liquid Substance)-certificate. It is issued by the "Scheepvaart Inspectie", when the ship satisfies all the requirements of Annex II.

Limitation of the operational discharge

To satisfy the second principle of Annex II, the following operational regulations have to be met:

Maximum discharge amount

Table I gives an overview of the maximum amounts which a ship may discharge. Tanks of type A-products have to be cleaned until the concentration of the remainders in the wash water is:

- * 0.1% outside vulnerable areas;
- * 0.05% inside vulnerable areas.

All wash water must be delivered at the shore reception facilities.

	Built before 1-7-86		Built after 1-7-86	
	Amount per tank (m ³)	Total Amount (ltr)	Amount per tank (m ³)	Total Amount (ltr)
A-product	0	0	0	0
B-product	0.3	150	0.1	350
C-product	0.9	950	0.3	350
D-product	no limit	no limit	no limit	no limit

Table I: Maximum discharge

At 2-10-94 the distinction between new and old ships will disappear and all ships must meet the same, strict, requirements.

Discharge locations

Ships are allowed to discharge at sea (if the product and the quantity are allowed) if they follow the following regulations:

- * The ship must be more than 12 miles out of the nearest coast;
- * The waterdepth must be at least 25 meters;
- * The ship should not be inside a vulnerable area ('Special Areas'), i.e.:
 - The Baltic Sea;
 - The Black Sea.

In these areas, discharge of some substances is forbidden and for other substances the permitted amounts are limited.

Part III: Slop-treatment Onboard; The Seatreat System

Other conditions

The following conditions are based on the possibility that even if one satisfies the regulations which are described before, the concentration of noxious liquid on one location can be too high:

- * By mixing or thinning of B, C and D products, their concentrations in the wake should be less than:
 - B-product: 1 ppm;
 - C-product: 10 ppm;
 - D-product: The remainders of this type of liquid have to be discharged with a minimum ratio of 1 volume part substance to 10 volume parts of water.
- * The ship must be en route, which means that the slops may not be discharged on one location;
- * The ships speed must be at least 7 knots during discharge;
- * The discharge must be made below the water-line. This way substances will be spread in the turbulent layer alongside the ship, which prevents them from entering the wake.

Exemptions

There are a number of exceptions which justify deviation from the regulations.

- * The ship is in such a danger that the captain decides to discharge the entire cargo or a part of it. It is his judgement that this action will save lives of seamen. The discharge must be reported as soon as possible.
- * If the ship transports only one product, which means that washing is not required, it can get a certificate of exemption. Of course the ship must satisfy the demands, which are required for that type of product.
- * The port authorities can give an exemption to a ship which is obliged to do a prewash in the following circumstances:
 - The ship will load the same cargo as it has unloaded;
 - The captain has a written confirmation of the next port, that the ship can unload its slops over there;
 - The remainder of the cargo can be removed, using ventilation.

Shore Reception Facilities

Regulation 7 of annex II determines that:

- * Ports that receive A-substances, and solidifying and viscous B- and C-substances must have sufficient Shore Reception Facilities to take in all the products;
- * Ports with repair facilities for chemical tankers must have shore reception installations.

Shore reception facilities not only take in slops but have often also the facilities to clean a ship. The permit for a shore reception facility can be obtained from the local port authorities.

PROCEDURES AND ARRANGEMENTS

As mentioned before, Annex II contains an additional chapter called "Procedures and Arrangements" (P&A). As in the annex the categorisation of noxious liquids and the permitted discharge amounts are discussed, the P&A gives more information about:

- * The substances;
- * The way of discharge;
- * The construction requirements of the Underwater discharge outlet;
- * Regulations for drawing up a P&A manual.

In four appendices the following items are discussed:

- * The water testing procedure, to determine the amount of liquids remaining in the tanks and in the pipes;
- * The prewash procedure;
- * The ventilation procedure;
- * Guidelines for the P&A manual onboard.

To make it possible, to satisfy Annex II requirements onboard a ship, the P&A guidelines are included in a manual: the P&A manual. This manual is composed according to the forementioned guidelines and is approved by the Shipping Inspectorate.

This manual has the following functions:

- * To make clear to the responsible officers, how Annex II should be used;
- * To make it possible for the Shipping Inspectorate to approve the equipment and operations;
- * To be an independent means of control.

Part III: Slop-treatment Onboard; The Seatreat System

The manual is divided into the following parts:

- * Section I : Main characteristics of MARPOL 73/78, annex II;
- * Section II : Description of the ship's equipment and layout, general arrangement, cargo part with a tank plan, loadpump and stripping system, load pipesystem, ballast system, slopstairs with pumps and pipes, underwater discharge outlet, ventilation system and tank wash system;
- * Section III : Load and unload procedures and stripping;
- * Section IV : Procedures for the cleaning of the tanks, discharging of remainders, ballasting and deballasting;
- * Table I : List of all noxious liquids which can be transported;
- * Table II : Cargo tanks capacity;
- * Table III : Ballast capacity;
- * Addendum A : Flowdiagrams for section IV;
- * Addendum B : Prewash programs;
- * Addendum C : Ventilation procedures.

THE CARGO RECORD BOOK

Every tanker which is allowed to transport Annex II-products, must keep a so-called *cargo record book*. In this book all activities concerning the transport, unloading/loading and cleaning of noxious liquids must be recorded. This is a way to make control of the use of the regulations possible. The officer in charge records all activities and the captain signs this book as the responsible authority.

The book is subdivided in a general part and a part for notes. The general part deals with general data, like name of the vessel, call signal, BRT and the period which is covered by the cargo record book. The note-part consists of an enumeration of activities which are standardized in 11 main subjects. These subjects are marked with a letter (A till K).

The main subjects concern the following activities:

- A. Loading of the cargo tanks;
- B. Pumping cargo;
- C. Unloading of the cargo tanks;
- D. Required prewash according to the P&A manual;
- E. Cleaning of the cargo tanks;
- F. Discharge of wash water at sea;
- G. Ballasting of cargo tanks;
- H. Discharge of ballast water from cargo tanks;
- I. Discharge due to an accident or special discharge;
- J. Checking by the competent surveyors;

K. Extra operational procedures and remarks.

This cargo record book gives a lot of information which is useful for the analysis of the slops problem, like:

- * Number of ports;
- * The products;
- * Number of washes;
- * The amount of prewash water which is delivered ashore;
- * The amount of wash water discharged at sea.

CHANGE OF ENVIRONMENTAL REGULATIONS

It is almost sure that in the future the environmental regulations will change, though it is difficult to predict in which way. At this moment the IMO wants to revise Annex I and Annex II of MARPOL and possibly merge it into one Annex called "Noxious Liquids in Bulk". At present there are some contradictions between the two annexes.

The fact that some product may be transported according to the requirements of Annex I as well as according to the requirements of Annex II, means that oil-like products can be transported in a chemical tanker of IMO type III. This however is not permitted according to the new regulations 13F and 13G of Annex I. These regulations, among others, prescribe that an oil tanker must have a double hull. A chemical tanker of type III however, does not need to have a double hull.

For other products, like naphta solvent and white spirit, there are differences between the discharge requirements. According to Annex I a ship with a cargo of 30,000 m³ may discharge at sea only 1 m³. According to Annex II however, the ship is allowed to discharge at least 27 m³.

Furthermore, there are plans to revise the categorisation of Annex II. One possibility is decreasing the number of categories from four to two. The first category is for products which require a prewash, like A-products. The second category comprises products of which the maximum amount of remainders in the tanks may not exceed 100 liters. This quantity is deduced from the present requirements for B-products. The requirements for C-products will decay, because all IMO II tankers satisfy the B-limits. It will also be examined, for each product, whether the discharge requirements must be adjusted. This concerns mainly the D-products.

It is difficult to predict whether these changes will lead to an increase in the amount of slops which has to be delivered ashore.

CHAPTER 2: SLOPS PRODUCTION ON SHORTSEA CHEMICAL-TANKERS

This chapter will discuss the quantitative aspects of slops. The data for this chapter are gathered from three seagoing chemical tankers, which have been monitored for the last two years. The information is obtained from the *cargo record book*. This document contains all data concerning cargo handling.

THE CARGO RECORD BOOK

As mentioned before, every tanker which is allowed to transport Annex II substances is obliged to keep a *cargo record book*. In this book all activities concerning transport, loading, unloading and cleaning of noxious substances are recorded.

A database was composed, using the computer program dBase III+, to sort out the slops statistics. The records of this file contain the following data:

- * Date of washing/disposal;
- * Ship;
- * Product;
- * Product category (MARPOL class of the product);
- * Loading and unloading port;
- * Does this type of product needs a prewash?
- * Number of tanks, with the same products;
- * Total washing time of the tank;
- * Is the wash cold or warm?
- * The amount of slops (discharged or delivered in the port);
- * Is the product removed using ventilation?
- * Shore reception facilities. This field states whether the slops are delivered in port, and if so, this field contains the name of the shore reception facility.

Often more than one product is unloaded in a port. The tanks with the remainders of the different products are washed simultaneously and the water is discharged or collected in slop tanks. In this case the cargo record book does not mention the different slop volumes per product. The wash water contains more than one product and it is very difficult to sort out the amount of slops per product.

Furthermore, the amount of useful information depends on the person who keeps the book. Sometimes the book contains information about the pressure, duration and number of machines that were used for the wash. Combined with the output characteristics of the washing machines it is possible to calculate

the slopvolumes per product (tank). However, often the amount of information is very limited.

SELECTION OF THE SHIPS

As examination of the cargo record books of all seagoing ships would take too much time, a representative selection is made. Three ships are selected. All of them operate on the spot-market and are also engaged in longterm chartercontracts. These operate in shortsea trades within Europe.

The first ship, built in 1988, is the biggest one of the three selected ships (large). The third ship, built in 1969, is the oldest and smallest one (small). The size of the second ship is between the size of the first and the third ship (medium).

Because a small part of the cargo record book of the medium size ship was missing (10/91 to 3/92), the statistics of this period are estimated on basis of the statistics of 1991. All three ships are representative of their type. **Table II** contains some characteristics of the ships.

AMOUNTS

In **Table III** an overview of slops amounts is given. The amounts are given in cubic metres (m³). The periods are divided as follows:

- * 1991 covers the period 10/90 to 10/91;
- * 1992 covers the period 10/91 to 10/92.

The item "number of ports" gives the number of ports which the ship has called at during that year. "Slops excl." gives the amount of slops without the chemical-mixes. The next two rows give the amount of slops which has been delivered, specified for obligatory prewash and non obligatory prewash.

The row "chemicals mix" gives the amount of slops which contain several different substances. The last row of the table gives the total amount of slops (discharged or delivered).

The amount of slops discharged by the medium size ship over 1992, is estimated as follows:

First half of 1991 (until 30-03-91)

Slops, excl.	934.0 m ³
Chemical mix	<u>597.0 m³</u>
Total	1525.0 m ³

Part III: Slop-treatment Onboard; The Seatreat System

Size	Large	Medium	Small
Deadweight (tons)	5098	2570	1774
Stainless steel tanks, incl. slopstanks	16	12	12
Capacity excl. slopstanks (m ³)	5099	2548	1629
Capacity incl. slopstanks (m ³)	5308.4	2717	1819
Dimensions tank midship (L*B*D) (m)	8.5*7.5*6.8	8.0*6.0*5.5	9.5*5.0*5.0
Average tankvolume, excl. slopstanks (m ³)	425	255	163
Average tankvolume, incl. slopstanks (m ³)	332	226	152
Number of washing machines	6	6	4
Number of washing machines for hot washes	4	4	
Output of washing machines, at pressure	13.5 m ³ /hr 8 bar	13.5 m ³ /hr 8 bar	9.0 m ³ /hr 4 bar
Maximum flow per UDO	60 m ³ /h	27.5 m ³ /h	21.8 m ³ /h

Table II: Ships characteristics

Second half of 1992

Slops, excl.	1028.0 m ³
Chemical mix	<u>670.0 m³</u>
Total	1698.5 m ³

The amount of liquid which was delivered, though not obligatory, for this ship is estimated as follows:

First half 1991:	166 m ³
Second half of 1992:	<u>150 m³</u>
Total:	316 m ³

Size		Large		Medium		Small	
Year		1991	1992	1991	1992	1991	1992
Number of ports		102	128	172	152	123	157
slops excl.		1650	1360	1903	1962	1120	1289
Delivered	obligatory	33	0	45	<u>80</u>	47	121
	not obl.	3	17	290	316	50	44
Chemical mix		828	1624	1115	122	234	304
total	discharged	2478	2984	1028	2324	1353	1593
	delivered	66	17	335	396	97	191

The underlined figure only concerns the period 17-4-92 to 5-10-92

Table III: Overview slops statistics

No estimate is made of the amount of slops, which was obligatory delivered in port, because the amounts are very erratic. For example, the ship delivered more obligatory prewash water in the second half of 1992 than in entire 1991.

Product categories

Table IV gives an overview of the amount of slops and number of parcels that were delivered, per product category.

A category III-product is a substance which is mentioned in Appendix II of Annex II. An 'oil'-product is a product that is mentioned in Annex I of MARPOL.

The slops production depends indirectly on the amount and type of cargo. The number of tanks filled with cargo, determines the number of washing machines which is used for cleaning. Washing time and water pressure of the machine, determine the amount of water used, and therefore the slopsvolume per tank. The volume of the remainders is not significant: a few dozen liters. The washing time is mainly determined by the number of cycles which is required for a substance. This means that the number of cycles for solidifying substances is higher than for non-solidifying substances (**Table V**).

Part III: Slop-treatment Onboard; The Seatreat System

Size ship		Large		Medium		Small	
Year		1991	1992	1991	1992	1991	1991
D-product	Number	32	16	24	16	14	16
	Volume	893.5	422.0	295.5	247.0	127.5	276.5
C-product	Numer	10	6	57	45	28	21
	Volume	384.0	294.0	1195.5	1305.0	406.0	404.5
B-product	Number	8	12	20	17	31	20
	Volume	264.0	478.0	579.5	455.0	516.5	610.0
A-product	Number	2	0	0	2	3	1
	Volume	66.0	0	0	11.0	49.0	86.0
Ill-product	Number	3	5	12	8	5	1
	Volume	52.0	150.0	149.5	127.5	72.5	18.0
Oil-product	Number	0	0	0	3	0	2
	Volume	0	0	0	68.0	0	?

Table IV: Amounts of slops per product categorie

Category of substance	Number of washing machine cycles	
	non-solidifying substances	solidifying substances
Category A (Residual concentration 0.1% or 0.05%)	1	2
Category A (Residual concentration 0.01% or 0.005%)	2	3
Category B	½	1
Category C	½	1

Table V: Number of washing machine cycles

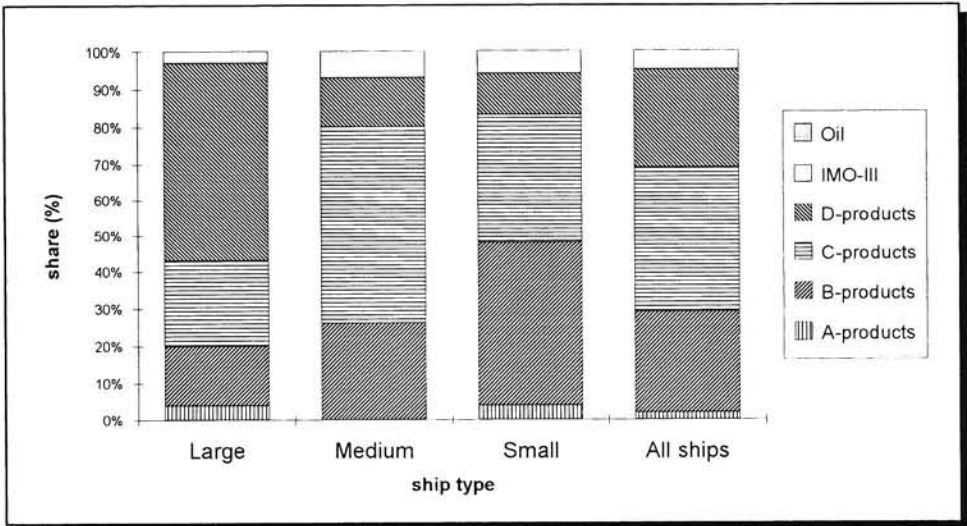


Figure 1: Product category shares, 1991

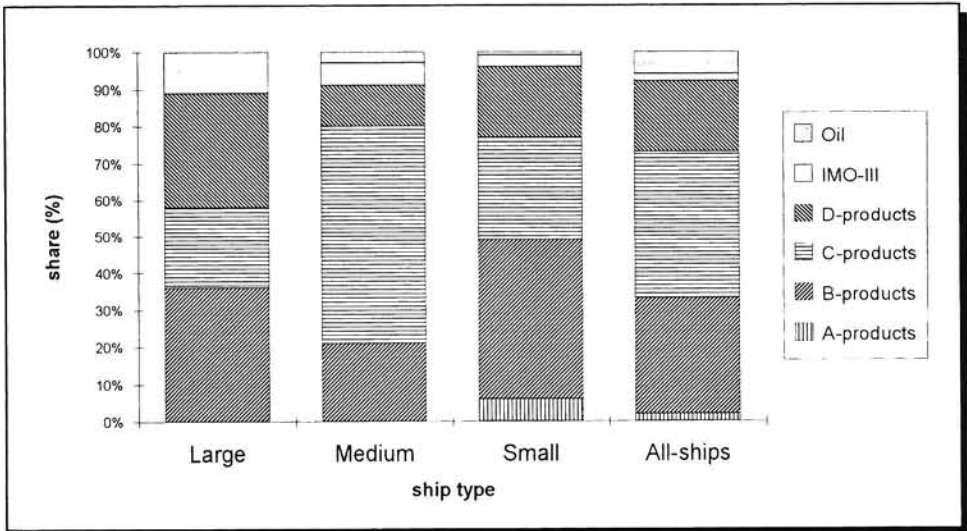


Figure 2: Product category shares, 1992

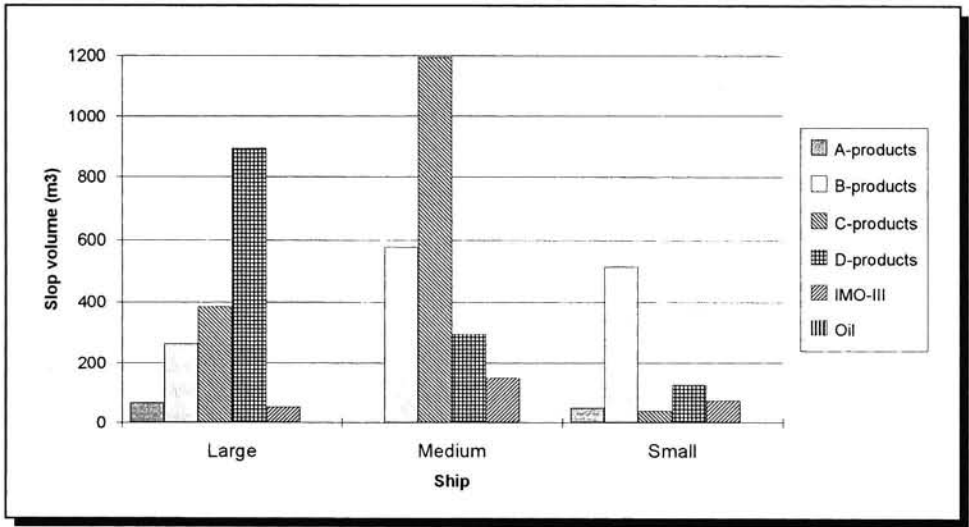


Figure 3: Slops amounts per product category, 1991

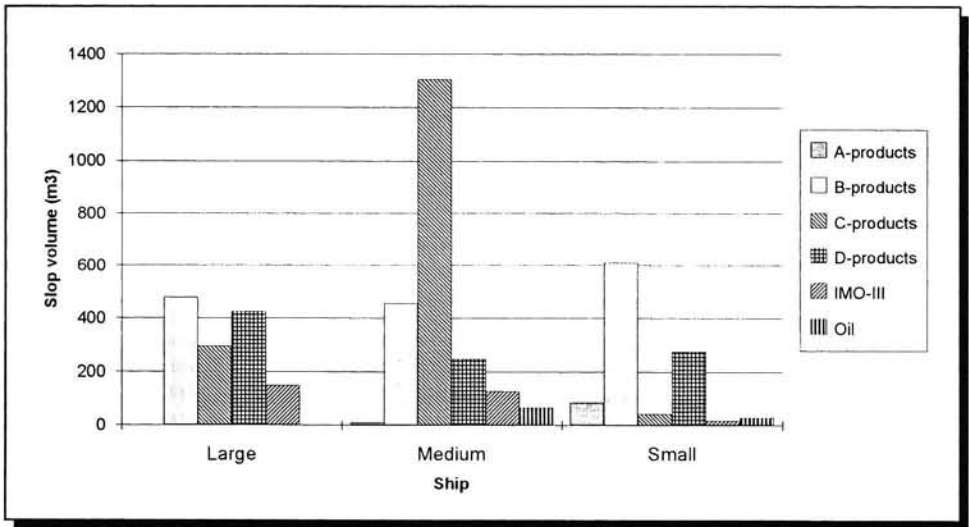


Figure 4: Slops amounts per product category, 1992

CHAPTER 3: SLOPS COSTS

WASHING TIME

Just as it is difficult to calculate the slops volume per product, it is also difficult to calculate the washing time per product. When the tanks which are washed contain different products, it is only possible to calculate the washing time per product if data are available about the washing time per tank and the number of washing machines used. It could be assumed that always the maximum number of machines and the maximum pressure is used, but experience learns that this is not always true. In spite of that, an estimate is made on the basis of these assumptions.

The washing time is also affected by the temperature of the washwater. A cold and a warm wash cannot be made at the same moment. Though the number of available washing machines permits it to wash several tanks at the same time, this is impossible because the pipesystem does not have separate warm and cold water pipes. Usually first the tanks which requires a cold wash, are washed and then the tanks which require a warm wash.

It is almost impossible to find out whether the tanks have been washed at sea or in port. Because of the forementioned reasons it is hard to find out how much time was actually spent on washing in port.

The values for 1992 of the medium size ship are estimated as follows:

First part 1991:

- * Total washing time = 3555 min.
- * Number of tanks = 474

Second part 1992:

- * Total washing time = 3299 min.
- * Number of tanks = 404

Total:

- * Total washing time = 6854 min.
- * Number of tanks = 878

Table VI gives an overview of the washing times and the number of washed tanks in 1991 and 1992. One could consider using these figures to estimate an average washing time. However, this is not possible, as the tanks are not washed one at a time. During a cold wash of the large vessel, six tanks can be washed simultaneously; four during a hot wash.

Part III: Slop-treatment Onboard; The Seatreat System

Ship	Large		Medium size		Small	
	1991	1992	1991	1992 ^{*)}	1991	1992
Washing time (min.)	3565	3410	6800	3299	4188	6240
Number of washed tanks	308	401	835	404	586	656

^{*)} These values are for the second part of 1992

Table VI: Overview washing times

Suppose that an average of four tanks is washed simultaneously. This means that the average washing time per tank for the large ship in 1992 was:

$$\frac{\text{number of tanks} * \text{washing time}}{\text{average number of tanks}} = \frac{401 * 3410}{4} = 34 \text{ minutes}$$

For a more detailed calculation of the average washing time, extra information of the database is required (Table VII):

Ship	Large		Medium size		Small	
	1991	1992	1991	1992 ^{*)}	1991	1992
Hot wash	93	189	412	225	146	228
Cold wash	215	212	423	161	430	402

^{*)} These values are for the second part of 1992

Table VII: Overview number of washed tanks

Using the data from this table the following calculation can be made:

$$\text{Average washing time} = \frac{\text{Washing time}}{\left(\frac{\text{Number of hot tanks}}{4} + \frac{\text{Number of cold tanks}}{6} \right)}$$

Part III: Slop-treatment Onboard; The Seatreat System

Which results in the following figures:

Ship	Large		Medium size		Small	
	1991	1992	1991	1992 ¹⁾	1991	1992
Average washing time (min.)	60	41	39	40	23	29

These numbers represent the maximum average washing time per tank per wash. It is assumed that always the maximum number of machines is used. In reality this is not always true and the number of washes is higher, which means the average washing time is lower.

The average washing time can also be estimated by combining the maximum water output of the washing machine (Table II) and the total amount of slops.

For example, the large ship in 1991:

Number of washed tanks:	308
Total amount of slops:	2545.0 m ³
Butter water usage:	13.5 m ³ /hour

This means the average washing time is 36.7 minutes. This calculation results in the following figures:

Ship	Large		Medium size		Small	
	1991	1992	1991	1992 ¹⁾	1991	1992
Average washing time (min.)	37	33	18	18	17	18

These average washing times deviate much from the other estimated values. They can be considered as a minimum. If the washing time would be longer, this would mean that more water would have been used, which is not possible. The values are probably higher because it is not always possible to wash with the maximum pressure.

ESTIMATE OF THE SLOPS AMOUNTS FOR THE ENTIRE FLEET

In this paragraph an estimate is made of the amount of slops of the entire fleet of this shipowner. The ships are classified by size, because the deadweight of the ship determines the market in which it operates. This indirectly affects the slops production. For example, small ships sail short distances which means they wash their tanks more often than larger ships, which sail longer distances. This means that small ships produce relatively more slops.

Part III: Slop-treatment Onboard; The Seatreat System

Four ships belong to the category large, three to the category medium size and two to the category small. Two other ships are neglected. The first one, because it is employed in a dedicated trade, the second one because it is a coated, single hull ship, which has totally different washing characteristics. The results are given in **Table VIII**.

Category	Large		Medium size		Small		Total	
Number of ships	5		4		3		12	
Year	1991	1992	1991	1992	1991	1992	1991	1992
Discharged (m ³)	12390	14918	12070	12894	4059	4779	28519	32591
Total delivered to reception facility (m ³)	330	289	1340	1582	291	483	1961	2354
Obligatory delivered to reception facility (m ³)	165	0	180	318	141	363	486	681

Table VIII: Slops overview of the entire fleet

ESTIMATED COSTS FOR THE FLEET OF CHEMICAL TANKERS

The shipowner has no information on the costs which pertain to the delivery of slops ashore. These costs are usually not paid by the shipowner, but by the shipper. Sometimes companies (owners of the cargo), like Bayer or ICI, do a prewash on request. They take care of the wash water and receive it at their terminal, even if this is not required. Besides the extra port time, there are no extra costs for the shipowner.

As there are no direct costs for the shipowner for delivering slops, one could think this is not an issue for the shipowner. This is not true. When the shipowner can limit the amount of slops which must be delivered, the costs for the shipper are less. So the shipowner can attract more cargo. Furthermore, the shipowner benefits from a decrease of washing time.

Using the tariffs that are paid by inland tankers, an estimate can be made on the prices paid for the treatment of slops. Starting point is the maximum tariff of NLG 375,- per ton which is paid for treating slops of A-products. The products and the amount of A-products slops that were delivered (in 1991 en 1992 together, of all three ships) are as follows:

Part III: Slop-treatment Onboard; The Seatreat System

Product	Volume (m ³)
Acetone cyano hydrine	137.0
Di butyl phtalate	5.5
Ethyl acrylate	5.5
Butyl bezyl phtalate	25.0
Di isopropyl benzene	<u>21.0</u>
	194.0

This means that the cost for three vessels is NLG 72,750.-. This is the cost for three ships, over a period of two years. Using the following assumptions, an estimate is made of the costs for the entire fleet, over a period of one year.

The fleet consists of 14 tankers, of which one does not produce slops because it is dedicated to one route. The three ships that are examined, are representative for the entire fleet, so the costs for the entire fleet are NLG 157.625,- per year.

SLOPS COSTS AND THE FUTURE

Based on several scenarios an estimate is made on the future costs for the delivery of slops. The scenarios depend on the future regulations, the public opinion and changes in mentality of the shipowner and shippers. The possible scenarios are:

1. For approximately 50% of the B-products a prewash will be required;
2. Regulations will be even more strict and a prewash will be required for all B-products;
3. All B-products and 25% of all C-products must be delivered.

For all slops tariffs, the average tariffs for slops of inland tankers are used.

Figure 1 and Figure 2 (for all ships) show that 30% of the entire slops production comes from B-products. The total slops production for seagoing ships is:

	1991	1992
Discharged:	28519 m ³	32591 m ³
To reception facility:	1961 m ³	2354 m ³
Obligatory to reception facility:	486 m ³	681 m ³

If the slops production of B-products is 30% of the total slops production, this means a slops production of 9144 m³ in 1991 and a slops production of 10484 m³ in 1992.

Part III: Slop-treatment Onboard; The Seatreat System

Scenario 1

Scenario 1 supposes that 50% of the B-products cargoes require a prewash. Because sometimes only the obligatory prewash is delivered and the afterwash is legally discharged at sea, the real amounts will be smaller.

50 % of B-slops is 4572 m³ (1991) and 5242 m³ (1992). Suppose that 65% of this is delivered (in two third of the cases also the afterwash is delivered) this means the extra amount of slops delivered, is 2970 m³ (1991) and 3407 m³ (1992).

Scenario 2

If all B-products require a prewash the amounts are 5945 m³ (1991) and 6815 m³ (1992), assuming 65% is delivered.

Scenario 3

40% of the slops are caused by C-products. This means the extra amounts of slops are 3048 m³ (1991) and 3465 m³ (1992). As it is supposed that slops of C-products are delivered voluntarily, it is assumed that only 40% is of the afterwash is delivered. This means the amounts are 1219 m³ (1991) and 1386 m³ (1992). Because all B-products slops are delivered, these amounts must be added to scenario 2.

Costs

The present (estimated) slops cost for seagoing ships are NLG 157,625 per year. In scenario 1 the costs will increase NLG 594,400 (1991) and NLG 681,400 (1992), assuming that the costs are NLG 200 per m³ for B-products. This is an average of NLG 637,900.

In scenario 2 the costs will increase NLG 1,189,000 (1991) and NLG 1,363,000 (1992) which is an average of NLG 1,276,000. In scenario 3 the cost will increase NLG 1,249,950 (1991) and NLG 1,432,300 (1992), assuming the costs are NLG 50 per m³ for C-products. This is an average of NLG 1,341,125.

Summarizing this means that the total slops costs are:

Present situation:	NLG	157,625
Scenario 1 :	NLG	795,525
Scenario 2 :	NLG	1,433,625
Scenario 3 :	NLG	1,498,750

CHAPTER 4: SLOPSTREATMENT

This chapter discusses the present slopstreatment methods. The overview is made from the perspective that the best opportunity for solving the slops problem is slopstreatment onboard the ship.

There is little information about the present slopstreatment methods available in literature. Many books on waste water treatment discuss public waste water installations, but not industrial installations. This means that most information in this chapter had to come from other sources. Therefore the writer visited the "Afvalstoffen Terminal Moerdijk" and Encon, which is the supplier of the Rotterdam waste water treatment plants, based in Rotterdam.

WASTE WATER TREATMENT METHODS

The definition of waste water is: *water which remains after the washing of a tank from a tanktruck, rail car or ship*. The product which was in the tank before it was cleaned, polluted the wash water. This water must be treated before it is discharged into the environment. Treatment is generally based on conventional techniques. Other equipment is designed for specific waste flows. There is a great variety of waste water treatment methods available. Treatment methods can be divided into three categories:

- * Physical treatment;
- * Physical-chemical treatment;
- * Biological treatment.

For complex waste water flows several treatment methods are used in succession. These methods are briefly discussed in this paragraph.

Physical treatment methods

Physical treatment of waste water comprises those techniques that separate the pollution from the water using differences in:

- * Specific weight;
- * Size of particles/molecules.

Separation methods based on specific weight are called gravity separation methods. These methods only work for substances that do not dissolve in water. Products which are lighter than water, oil-alike products, float; products that are heavier than water will sink. This category comprises installations like the conventional settling tanks, oil/water separators and oil/sludge separators. Modern equipment is provided with fully automatic skimmers en sludge

Part III: Slop-treatment Onboard; The Seatreat System

removers. Other separators based on the gravity principle are the Dortmund-tanks (sedimentation) and the float installations.

Waste water can be treated with chemical or biological methods, before it is treated with physical methods. These methods creates flocks that can be separated by a physical method.

Filtering is a physical separation method, based on the size of the particles or molecules. The micro or ultra filtering methods originated from the process industries. They can only be used for slightly polluted water, with only limited amounts of different substances. Heavily polluted water will cause excessive pollution and wear of the membranes of the filter.

Chemical treatment methods

Chemical treatment methods add chemicals to the waste water, so it can be treated better by physical methods. The most used chemical method is the coagulation/flocculation method.

During the coagulation process a coagulant, for example iron or aluminiumchloride, is added to the water. This coagulant neutralises the colloidal particles that are in the waste water. Colloidal particles are tiny solid or fluid particles, which are usually charged negatively and repell each other. The neutralising effect of the coagulant, makes that the particles loose their repelling power and stick together and build up flocks. Next sodium hydroxide or lime is added to neutralise the effects of the acid coagulant. After the coagulation phase follows the flocculation phase, in which large flocks originate from the small flocks. This makes it easier to separate them physically.

Besides the coagulation/flocculation methods there are some other chemical treatment methods. Presently the treatment of waste water with ozone, sometimes combined with hydrogen peroxide and ultraviolet light, is increasing in popularity. This method oxidizes organic pollution completely. A disadvantage of this method is the price of the ozone generators. Therefore this method is restricted to the situations in which it is most effective. Photo degradation with ultraviolet light and hydrogen peroxide only might be an interesting alternative for the treatment of specific chemicals like chlorinated hydrocarbons

Biological treatment methods

If the concentration of pollution or noxious substances in the waste water is limited, it can be treated by a biological method. These methods can be divided into two categories:

- * aerobic (with oxygen);
- * anaerobic (without oxygen).

In the aerobic treatment method the waste water is oxydized in a way that the micro-organisms together with oxygen convert organic pollution into new biomass. This way organic pollution is converted into biological sludge. Ap-

proximately half of the pollution is converted into biomass, the rest is used by the micro-organisms for energy production.

If the treatment is carried out without oxygen, it is called anaerobic treatment. The external energy required for this method is less than for the aerobic treatment. The sludge production of an anaerobic system is smaller than of a similar aerobic system. The anaerobic system however is much more sensitive to toxic substances and variations in concentration and composition. Nowadays much attention is paid to this aspect, because a small sludge production is very attractive. Often the water is treated using an aerobic system after it has been treated with an anaerobic system, to ensure a more constant effluent.

EQUIPMENT

On the following pages descriptions and pictures will be given of the equipment which is used most often for the treatment of waste water.

Combinator

The combinator is specially developed for the treatment of polluted waste water with a very variable composition. This method originates from the cleaning of transport tanks. A combinator carries out physical separation, as well as buffering and equalization of the effluent.

The combinator consists of an upper- and lowertank (**Figure 5**). The uppertank is a physical separator. The lowertank is used for buffering and equalization. The combinator is constructed in such a way that the water which is treated, is pumped up only once. After the physical separation, all liquids flow downwards using gravity.

The uppertank is used for floating as well as for sedimentation. Both are types of physical separation. The floating sludge is skimmed continuously, using a skimmer, and collected in a floating sludge tank. In this tank the remaining water, which came with the floating sludge, is separated further. Then the thickened floating sludge is collected in a (chemical) waste tank. The sediment is collected using a bottom propeller or a remover, depending on the size and type of the combinator. The sediment can be carried off to a sediment sludge draining tank or to the lowertank of the combinator for further treatment. The water leaves the uppertank via a system which prevents taking the floating sludge and the sediment, and enters the lowertank.

The lowertank or buffertank collects the water and possible sediment of the uppertank. The water is circulated to obtain a good equalization. The equalization enables discharging without much differentiation. Furthermore, this equalized water is a good influent for treatment with chemical methods.

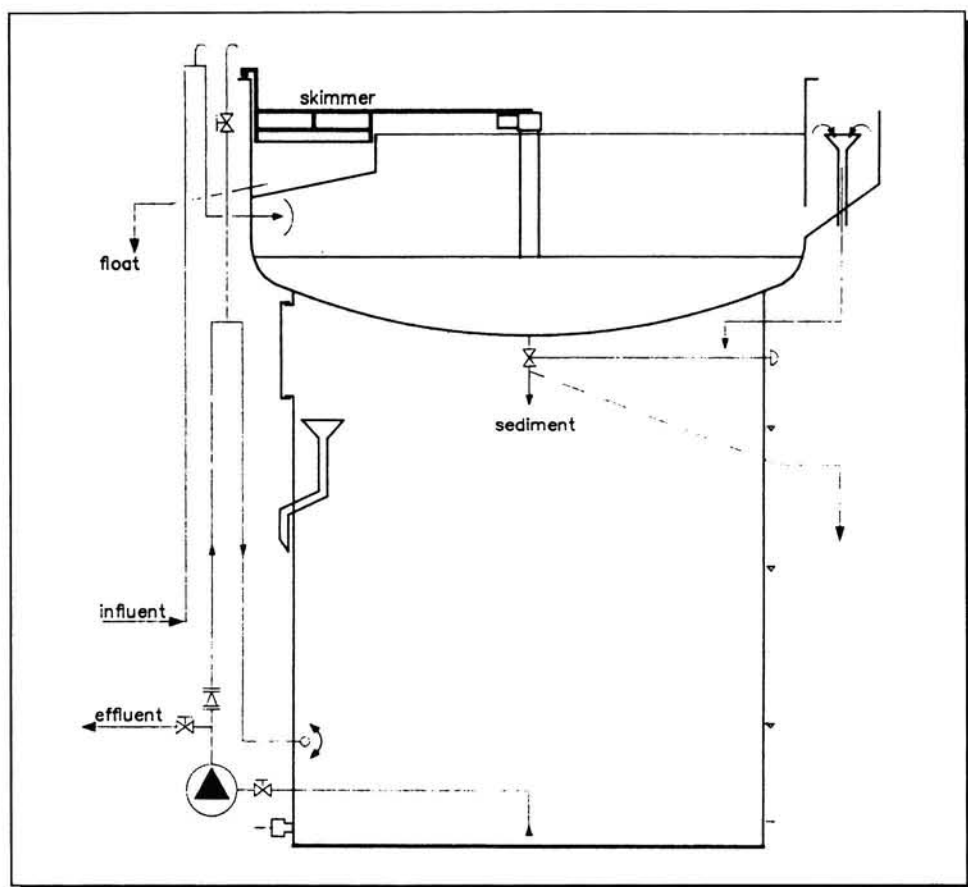


Figure 5: Combinator

Skimmers

Skimmers are used to remove the floating sludge from water. Skimmers are often an integrated part of a waste water treatment installation. There are two principles to remove floating sludge:

1. The sludge can be removed, using scrapers or pipeskimmers. The sludge is wiped off of the water;
2. The sludge can be removed, using the adsorption principle. The sludge sticks to the surface of a conveyor, hose or plate, which moves through the floating sludge. Then the sludge is scraped of the skimmer and collected in a special tank (Figure 6). This method only works if the floating sludge sticks better to the skimmer material than water, for example oil.

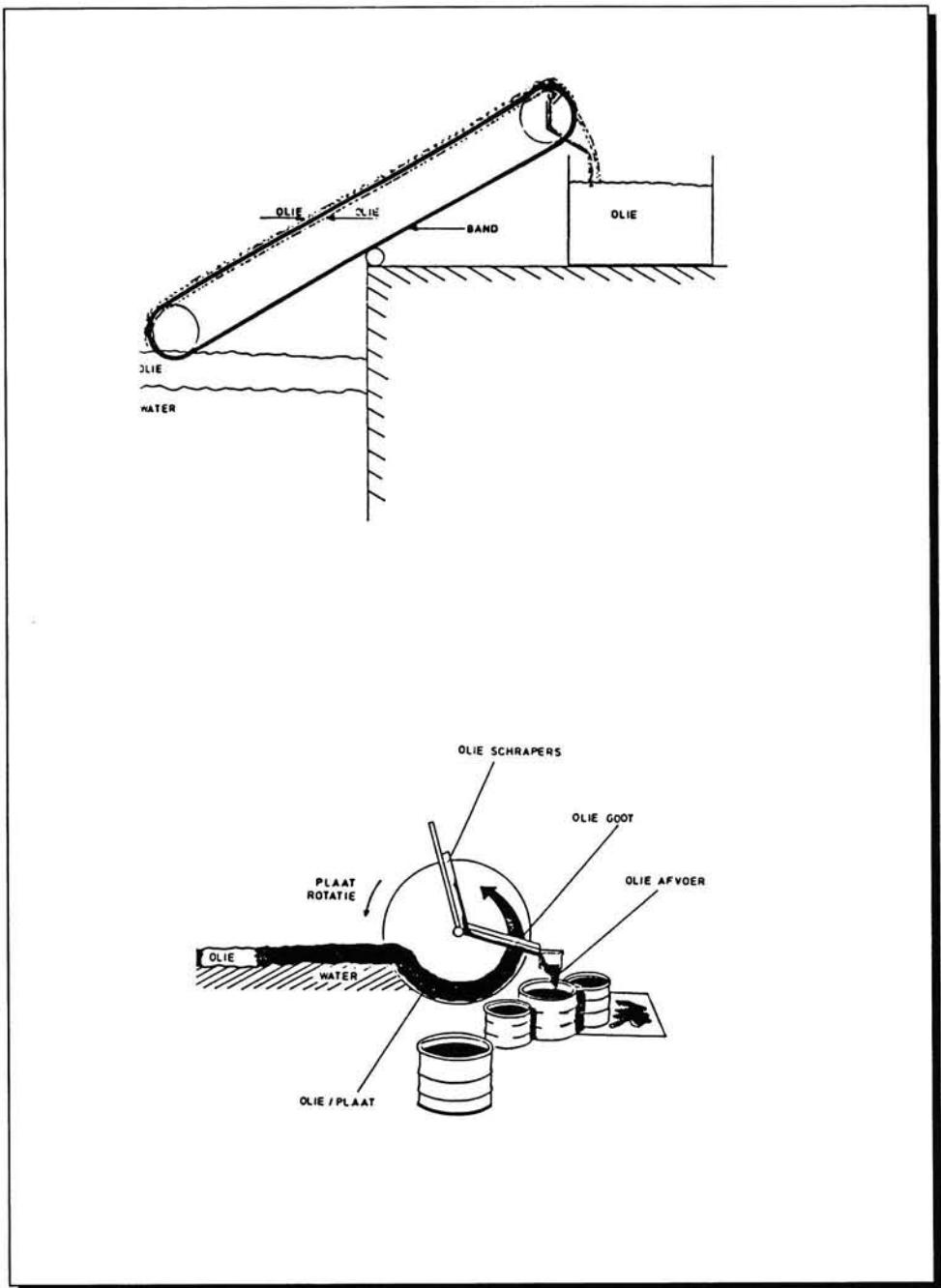


Figure 6: Skimmers

Gravity separation

Stokes has composed a formula which calculates the rising speed of non-dissolved particles in water:

$$v = \frac{1}{18} \frac{(\rho_w - \rho_o)gd^2}{\eta}$$

with:

- ρ = rising speed (m/s)
- d = average diameter of the particles (m)
- g = gravitation acceleration (m/s²)
- ρ_w = density of the water
- ρ_o = density of the particles
- η = viscosity of the water

The formula of Stokes shows that small particles rise, or sink, slower than larger particles. This means that it takes more time to separate small particles from water. The rising speed, together with the rising height, determine the separation return of the installation. If particles need more time to rise, than the time it takes for the water to flow from partition A to partition B (Figure 7), they will not be separated, but will flow with the effluent. For smaller particles the water will have to stay longer in the installation.

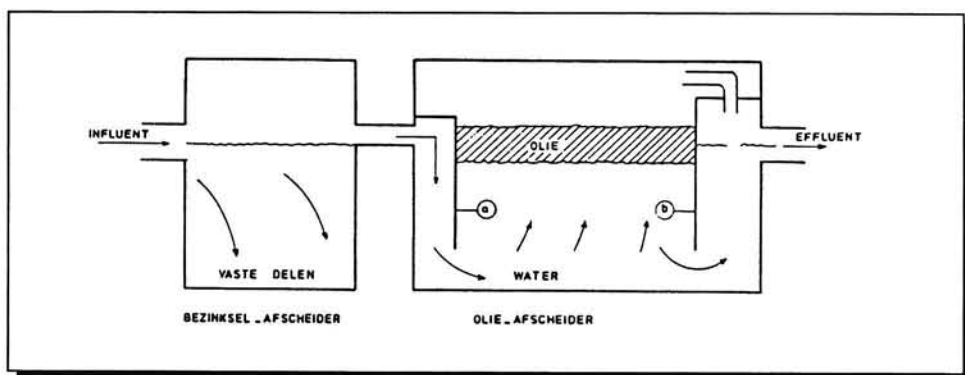


Figure 7: Gravity separation

Sedimentators

Waste water that was treated chemically or biologically contains flocks, which have to be separated from the water. The Sedimentator is a settling tank of the

so-called Dortmund-type. This tank has a hopper shaped bottom which is built with an angle of 60° . The separation is caused by gravity (Figure 8).

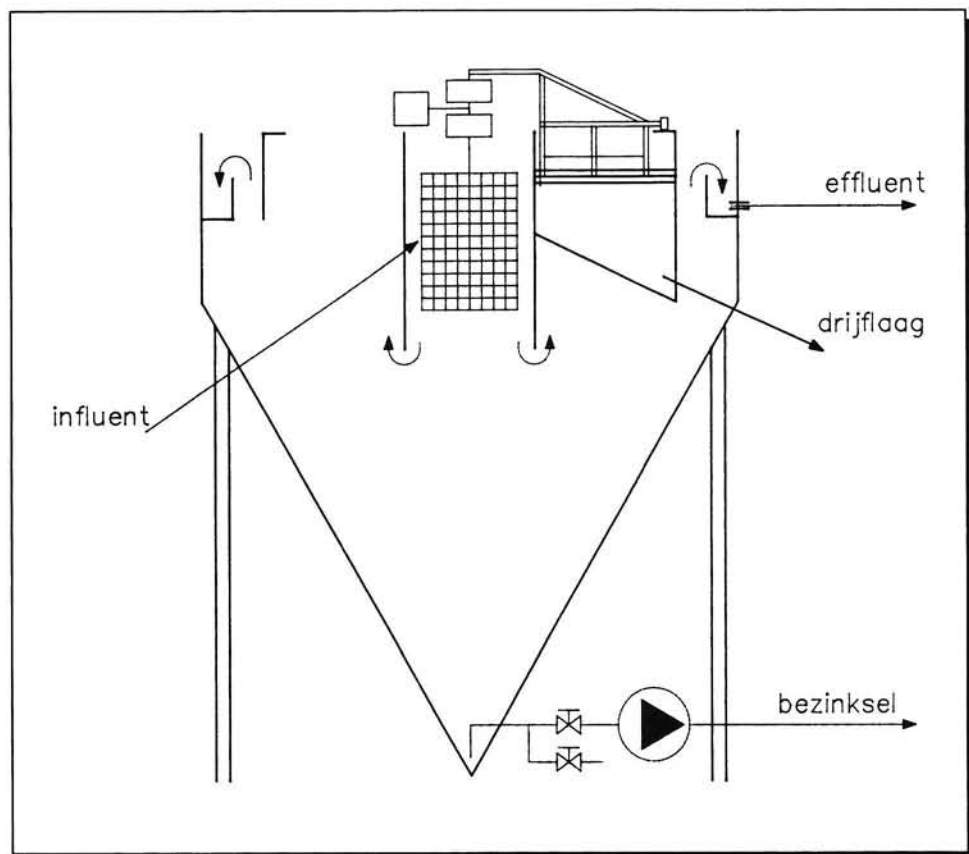


Figure 8: Sedimentator

The influent flows into the inner tank, in which a spatula, which looks like a fence, is turning around very slowly. In this tank a flocculation expedient can be added. Now the water flows down very slowly under the partition of the inner tank. This partition serves as a turning partition. If the water passes the second partition near the edge, it can leave the tank via the overflow. These partitions make sure that the flow is spread over the full width of the tank. They also prevent floating lighter substances from leaving the tank.

Most flocks will sink to the bottom of the hopper. This again causes a layer which has to be removed. The sediment is removed by an adjustable, low speed pump. The sludge of the sedimentator is about 20% of the influent and has a dry substance percentage of about 3% of the weight.

Part III: Slop treatment Onboard; The Seatreat System

A small portion of the flocks will float instead of sink. The sedimentator also has a fully automatic floating sludge remover, which collects the floating sludge in a tank. The floating sludge remover turns around between the inner tank and the second partition. The floating sludge remover and the spatula are driven by the same engine. The spatula turns around 2 times a minute, the remover 0.25.

Plate separator

Plate separators are gravity separators of which the return has been improved by reducing the surface load (Figure 9). The surface load is equal to Q/F , in which "Q" is the Quantity and "F" is the separation area. The load is reduced by placing a number of plates in the separation room. This way the flow is split into a number of smaller flows. The surface load per flow will decrease and particles with small diameters (low rising speed) will be separated.

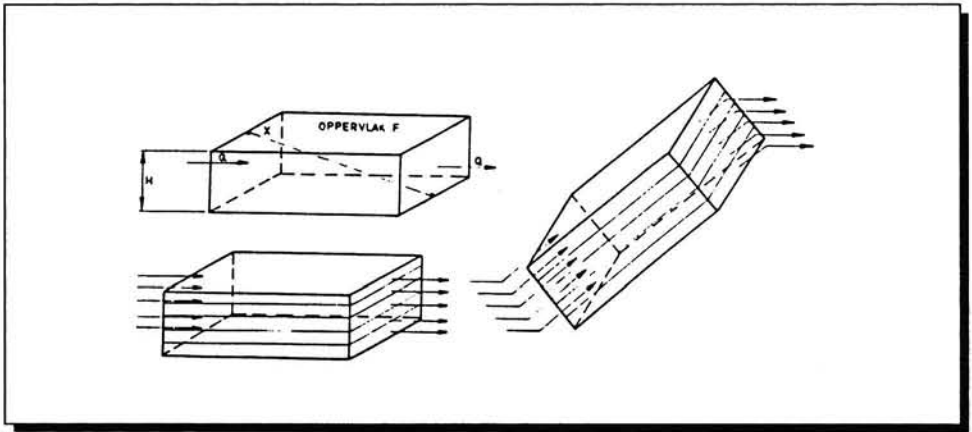


Figure 9: Plate separator

Spin dryers

By using a spin dryer, the acceleration force on a particle, compared to the gravity acceleration force, can be increased considerably. The 'g' in the formula of Stokes is replaced by a bigger value, which means that the time required for a particle to rise, decreases and the separation return increases. Often this equipment is used for separation of oil and water, the oil-water centrifuges.

Coalescence

The effect of the coalescence equipment is based on the phenomenon that large particles rise or descend quicker than small ones. Therefore the equipment is provided with facilities to stimulate the contact between particles, for example

by plates or wire netting. The liquid flows along the surfaces. Small particles will collide with the surfaces and with each other, and will coagulate to bigger flocks.

Coagulation can be stimulated by adding specific chemicals. For the removal of emulsions (non dissolved substances) this is even essential. This is carried out in the Coagulator, described in the following paragraph. An example of coalescence equipment with plates for cleaning the bilge is given in Figure 10.

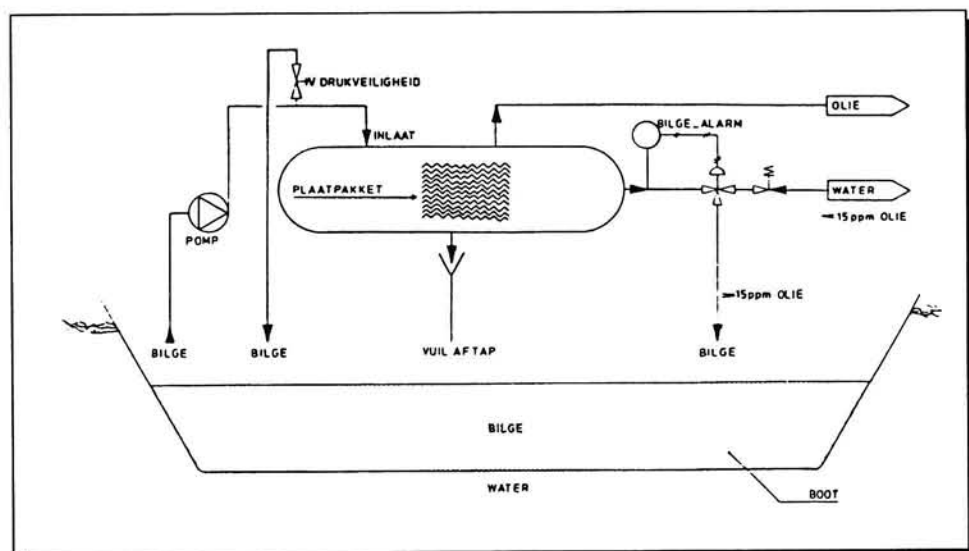


Figure 10: Coalescence

Coagulator

The coagulator is the reactor in which waste water is treated with chemicals. The reactor consists of three compartments (Figure 11). Depending on the next phase, the reactor flow can be continuous.

In the first compartment a coagulation substance is added to the waste water during violent stirring. During the stay in this compartment the emulsions in the water will be broken and the first flocks will originate. Via an overflow, a part of the liquid will flow into the second compartment, where a neutraliser is added. This way the acidity of the waste water, arisen due to the coagulation substance, will become approximately seven (neutral). When the acidity is neutral, flocks stick together and will grow. In this compartment the liquid is stirred so the flocks cannot sink. Via an overflow the waste water flows into the third compartment. This compartment is not stirred. Via the diagonal bottom the chemically treated waste water is pumped away.

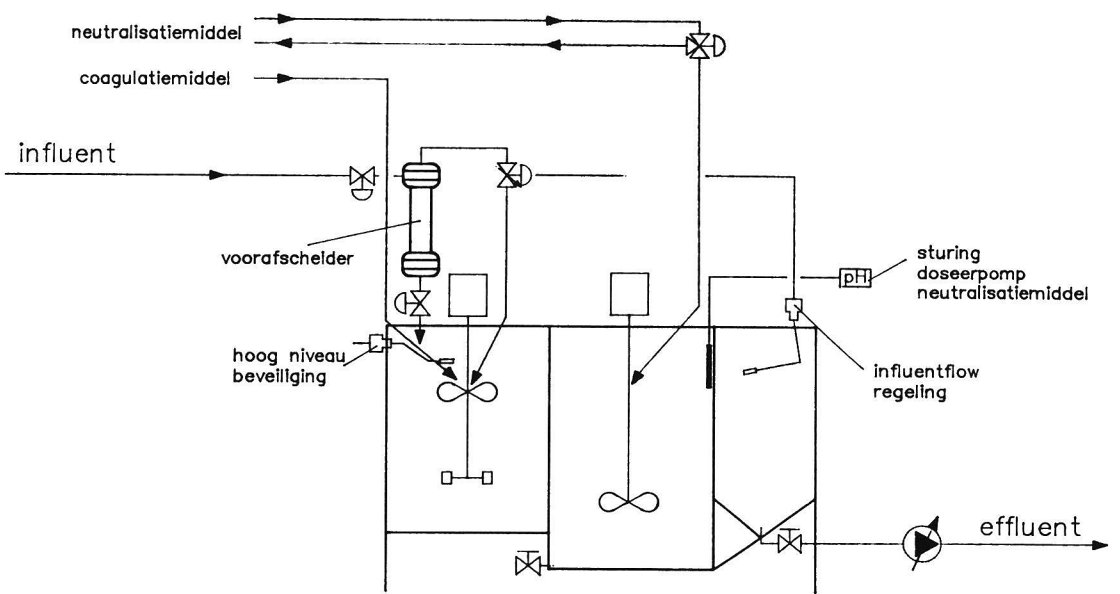


Figure 11: Coagulator

The influent flow is regulated by a pneumatic valve. To prevent obstruction, a pre-separator is placed before this valve. This pre-separator removes large solid particles from the influent.

The amount of coagulation substance, which has to be added, depends on the influent flow. A fixed amount of coagulant per m³ waste water is added. The amount of neutralisation substance, which has to be added, depends on the acidity. The acidity meter in the second compartment measures the acidity of the waste water and regulates a pump.

An adjustable, slow speed pump pumps the effluent further into the system. The reactor is equipped with a high-level security system. When the level becomes too high an input valve is automatically closed. This may happen if the effluent output pump fails. The second compartment is equipped with a drain, which makes it possible to empty the reactor.

Flootation equipment

Often the rising or sinking speed is too low to get an economically profitable separation. To reduce this problem the floatator was developed. The Installation is based on the principle of increasing the rising force of the particles. This is done by attaching the particles to tiny air bubbles. Emulsions and influent with very small particles in it, will have to be treated with the coagulation-flocculation method first (physical/chemical preparation).

There are two methods that are frequently used to produce air bubbles. These methods result in the following systems:

- * Dissolved air flotation (D.A.F.);
- * Induced air floatation (I.A.F.).

Dissolved air flotation

A D.A.F. installation produces microscopical small air bubbles and mixes these with the particles in the suspension, which gives them an upward power. The particles rise to the surface quickly and the floating sludge that originates, can be removed (**Figure 12**).

The air bubbles are produced by putting a part of the cleaned water under pressure, aerating it and returning the it into the dirty water. When the cleaned water flows back into the separator, the low pressure in the separator causes the air to make bubbles. These air bubbles attach themselves to the particles. Instead of putting the recycled flow under pressure, the influent can be put under pressure. The results of these systems however are less constant.

A D.A.F. system can remove about 95 to 97% of the pollution in suspension. The solid substance concentration in the liquid is less than 10 mg/l. The solid substance concentration of the floating sludge varies from 2 to 10%. The capacity of these systems varies from 95 to 2300 liters per minute.

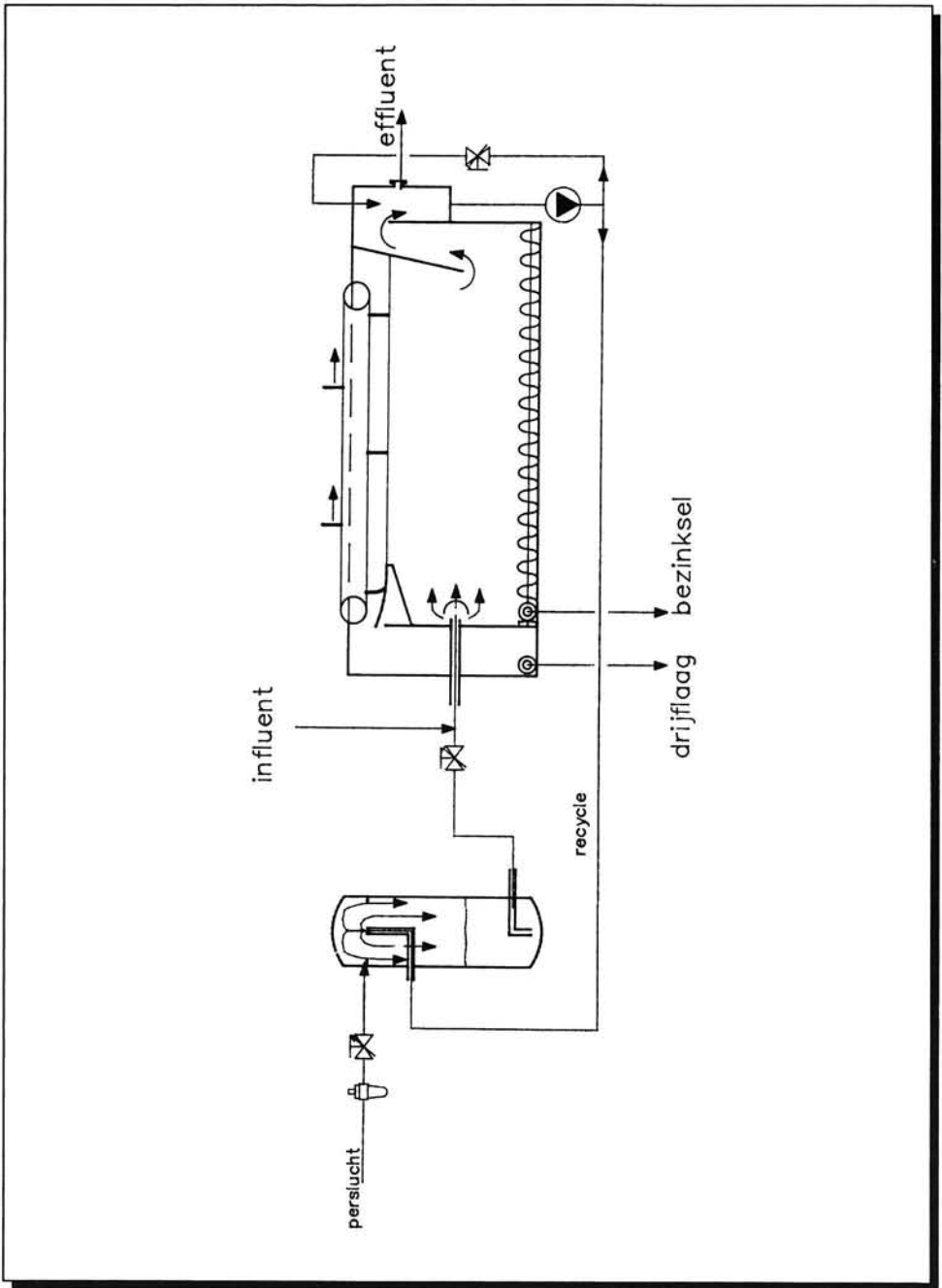


Figure 12: Dissolved air flotation

Induced air flotation

In an I.A.F. installation the air bubbles are caused by a propeller (vortex-mixing) (Figure 13). Research shows that the investment costs of an I.A.F. installation for large capacities ($> 50\text{m}^3/\text{h}$) are lower than for a D.A.F. installation. However if coagulants are required to break an emulsion, generally a D.A.F. system is used, because the sludge production is lower. This means that the sludge disposal costs are lower. Furthermore, the energy cost of an I.A.F. system is much higher than of a D.A.F. system.

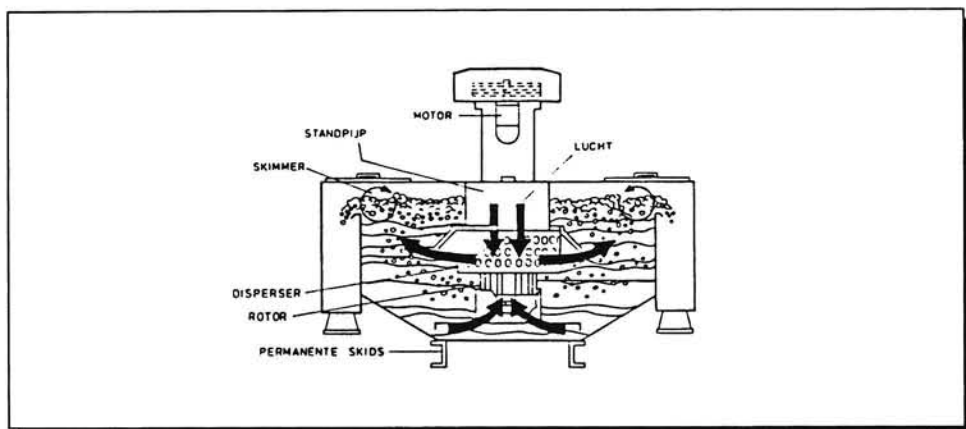


Figure 13: Induced air flotation system

Rotating vacuum precoat filter

The rotating vacuum precoat filter is a filter for separation of particles from liquid. This method can be used to separate the flocks from a coagulation-coculation process from the water.

The filter consists of a tank with a drum in it. A vacuum pump creates an under pressure in the drum. This causes a sucking effect on the surface of the drum. The surface is covered by a very fine wire netting. The drum turns slowly around in the tank.

For an effective filtration the drum has to be covered by a precoat layer. The precoat layer serves as a filtration aid.

Water with precoat flows into the tank. The drum sucks the water through the wire netting and the filtration material accumulates at the outside the drum. Eventually a layer of 10 to 15 centimeters remains on the wire.

Part III: Slop-treatment Onboard; The Seatreat System

After the precoat is attached to the drum, the coagulant can be added. The water is sucked through the precoat layer, and flocks will stick to the outside layer. To ensure that the filter material remains exposed, a knife is placed on the side of the drum. During the rotation the knife cuts a very thin layer of the precoat. This way the part that is polluted by the flocks is removed. Eventually all of the precoat is removed. The precoat and the body-aid (an extra filter aid) determine the exploitation costs. Because the costs are almost proportional to the pollution of the water, this filter is only used for aftercleaning.

Membrane filters

Membrane filtration is a method in which membranes are used for filtering. Membranes are available in many different pore sizes. The extremes are:

- * Hyper filtration. The pores are so small that water molecules can go through it but larger molecules cannot. A less extreme variety of hyper filtration is ultra filtration, in which larger molecules (compared with water) go through the membranes. The principle of this filtration method is given in (Figure 14);
- * Micro filtration. The pores are so small that only large molecules and/or suspended particles are blocked.

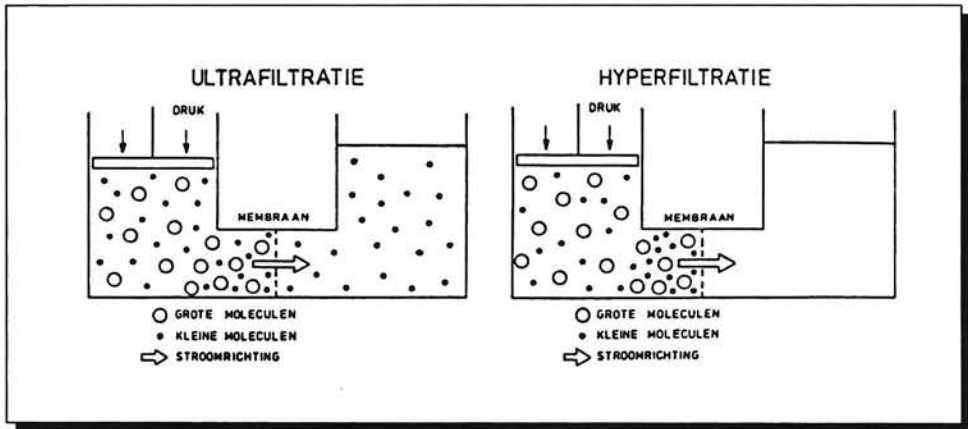


Figure 14: Membrane filters

Compartment filter press

Watery waste substances, with a high level of solid substances, for example the floating layer of a D.A.F., can be treated by a compartment filter press. The influent is pumped, under high pressure, into the compartments of the press. A

large part of the water leaves the compartment through the filter, and the solid substances remain. To improve the capacity of the filter an anorganic filter aid is added.

The compartment filter can reduce a floating sludge to 40 percent. The rest consists of water which often gets further treatment.

Activated carbon filter

After several pre-treatments sometimes the water is still polluted with substances that cannot be removed satisfactory by biological or chemical methods, for example halogenated hydrocarbons. In those circumstances the water is filtered by activated carbon. The activated carbon adsorbs the pollution.

CHAPTER 5: OUTLINE SPECIFICATION FOR A SLOPS TREATMENT SYSTEM ONBOARD

The design of a waste water treatment installation depends on several factors. These factors are:

1. The type of waste water. What are the products in the water and what are their concentrations?
2. The amount of waste water. The capacity of the installation must be large enough to treat all the water;
3. The environmental regulations concerning the degree of treatment;
4. The location of the equipment.

If a treatment installation is placed onboard a ship, the installation is also affected by the movements of the ship. This problem is very important for this study.

THE PRODUCTS

Products that qualify first for onboard treatment are almost all MARPOL A-substances. These substances are not transported very often. However, if they are transported, the costs for delivering slops are so high that it is preferred to do the prewashes onboard the ship. A-products transported by the shipping company under study:

- * acetone cyano hydride;
- * di butyl phtalate;
- * di iso butyl phtalate;
- * ethyl acrylate;
- * butyl benzyl phtalate;
- * di io propyl benzene;
- * α -methyl styrene;
- * vinyl toluene;
- * nonyl phenol;
- * chorotoluene;

Besides these A-product, also some B- and C-products require a prewash. Prewash is required for high viscous or solidifying B-substances and high viscous or solidifying C-substances in the vulnerable areas.

From the cargo record book of the large ship, the most important products have been retrieved. These are the products that have been transported at least three times during a period of two years. (It is assumed that the number of discharges

Part III: Slop-treatment Onboard; The Seatreat System

is equal the number of times the product is transported). With these criteria a list is made (Table IX).

Product	Number of transports	IMO Category
1. acetic acid	23	C
2. propylene glycol	14	III
3. mono ethylene glycol	13	D
4. propylene oxide	12	III
5. polypropylene glycol	11	III
6. ethyl acetate	11	III
7. methylene chloride	11	D
8. phenol	11	B
9. di ethylene glycol	10	III
10. tri chloride ethylene	10	B
11. acetic anhydride	9	C
12. propylpropylene glycol	9	III
13. butyl acetate	8	C
14. formic acid	7	D
15. linear alkyl benzene	7	III
16. acetone	6	III
17. styrene	6	B
18. acrylonitrile	5	B
19. butyl acrylate	5	D
20. propionic acid	5	D
21. chloroethene	4	B
22. di octyl phthalate	4	III
23. iso propyl acetate	4	III
24. methyl acrylate	4	C
25. benzene	3	C
26. cyclohexane	3	C
27. n-paraffine	3	III
28. propylene glycol methyl ether	3	III
29. vinyl acetate monomere	3	C

Table IX: Most important products transported by the large ship

The products in this list are approximately 85% of all products transported by the ship. The products transported by the medium sized and small ship are similar to the products in this list.

As mentioned before, the exact amounts of slops per products are difficult to find out. Water of tanks with remainders of several products and water of separate tanks with different products are discharged together. For the design of a slops treatment installation however, it is important to know the amount of slops per product. A good way to find out is to draw up an average standard

Part III: Slop-treatment Onboard; The Seatreat System

washing procedure of the products. This procedure can be used to divide the total amount of slops over the different products.

Drawing up a standard washing procedure is difficult because often data are not available. Fortunately the shipowner has tank cleaning reports available, over a period of three years.

By examining many reports, an average washing time and temperature for every product is estimated. With these guidelines, combined with a butter production of 13.5 m³/h and a pressure of 8 bar, the mix slops can be divided over their components. The resulting amounts are given in **Table X**.

Product	Transported amounts (m ³)	IMO Category
1. acetic acid	686	C
2. phenol	562	B
3. styrene	242	B
4. polypropylene glycol	277	III
5. mono ethylene glycol	234	D
6. n-paraffine	197	III
7. propylene oxide	179	III
8. linear alkyl benzene	160	III
9. acrylonitrile	159	B
10. benzene	157	C
11. methylene chloride	155	D
12. acetic anhydride	144	C
13. ethyl acetate	142	III
14. dowlanol	128	III
15. butyl acrylate	121	D
16. cyclohexane	113	C
17. methyl acrylate	111	C
18. di ethylene glycol	110	III
19. di octyl phtalate	102	III
20. propylene glycol	97	III
21. pgme	70	III
22. formic acid	65	D
23. butyl acetate	61	C
24. tri-chloor ethylene	57	B
25. propionic acid	57	D
26. vinyl acetate monomere	57	C
27. chlorothene	54	B
28. iso propyl acetate	45	C
29. acetone	41	III

Table X: Slops amounts in the period 10/1990 to 10/1992

Especially B- and C-products are suited for onboard treatment. Regulations for some products will become more strict. However it is not expected that it will become obligatory to deliver prewash of D- and III-products in the near future. Table XI gives a distribution of the discharged slops of the large ship divided by amount.

Category (m ³)	Number of discharges				Share (%)	Cumulative share (%)
	I	II	III	IV		
0-10	11	0	2	1	10.4	10.4
10-20	12	0	10	2	17.8	28.2
20-30	10	2	8	3	17.0	45.2
30-40	7	1	7	4	14.1	59.3
40-50	4	2	2	1	6.7	66.0
50-75	9	3	10	9	23.0	89.0
75-100	1	1	1	7	7.3	96.3
100-125	0	2	0	2	3.0	99.3
> 125	0	1	0	0	0.7	100.0
Total	54	12	40	29	100	

I): slops of one product, 1991

II): slops mixes, 1991

III): slops of one product, 1992

IV): slops mixes, 1992

Table XI: Distribution of the number of discharges

CONCENTRATIONS AND ENVIRONMENTAL REGULATIONS

To get an impression of the (average) concentration of dry substance in the slops the watertest is used. A watertest is an obligatory test of the cargo tanks on dischargeability. Annex II gives, per category of substance, the maximum amount of remainders that is allowed to be left in the tank, after it has been unloaded. A watertest is used to check if the tanks can be unloaded (stripped) sufficiently, to satisfy the demands.

The maximum amounts per tank and connecting pipes are:

- * A-product not applicable, always prewash;
- * B-product 0.1 m³ (if no prewash demanded);
- * C-product 0.3 m³ (if no prewash demanded);
- * D-product no maximum;
- * III-product no maximum.

Part III: Slop-treatment Onboard; The Seatreat System

The results of the watertest of the large ship are given in Table XII.

Tanknumber	Strip amount (l)	strip time (min)
1 Starboard	40	2
2 Portside	85	2
3 Starboard	85	4
4 Portside	45	2
5 Starboard	60	2
6 Starboard	50	2
7 Portside	40	2
slops tank SB	40	2
Average	55	

Table XII: Watertest results

The basic environmental requirements, which result from Annex II, are a guideline for the cleanliness of the effluent. The requirements are as follows:

- A-product: 0.1 %, 0.05% in vulnerable areas,
- B-product: 1 ppm in the wake
- C-product: 10 ppm in the wake
- D-product: discharges mixed with water with a ratio of 1 on 10
- III-product: none

MOVEMENTS OF THE SHIP

For the design of the installation it is necessary to know the movements and accelerations of the ship at the location of the installation. To find these values the computer program SEAWAY, developed by ir J.M.M Journée of the Delft University of Technology, is used. The input of the program comprises the main dimensions, frame plan, center of gravity, length and height of the bilge-keel and a wave spectrum. The program is run with the following values:

- * Loading condition: Full ($\rho = 0.933 \text{ t/m}^3$) and 100% stores (no slops);
- * Speed: 15, 11.25 and 7.5 knots;
- * Wave directions 0° , 45° , 90° , 135° and 180° .

Movements, speeds and accelerations are calculated for two locations. These are possible locations for the installation. The positions of these locations are:

Part III: Sloptreatment Onboard; The Seatreat System

	Location 1	Location 2
Distance from afterperpendicular:	24.13 m	50.95 m
Horizontal distance to the side (PS):	0.00 m	6.00 m
Height above base:	9.70 m	9.70 m

Location one is located just before the accommodation, location two behind the manifold, 6 meters to portside from the center of the ship (Figure 15).

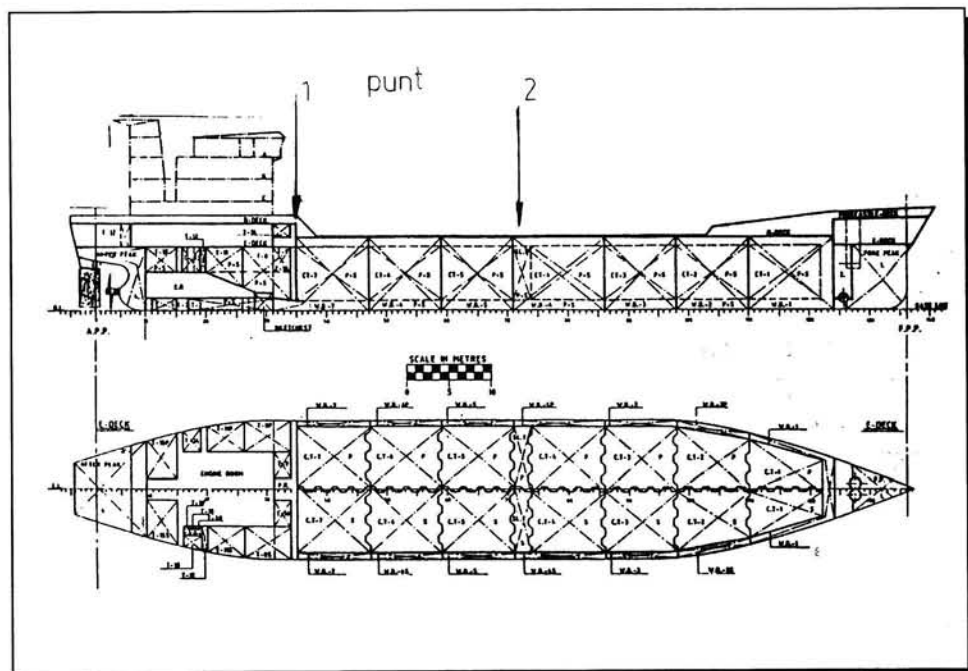


Figure 15: Possible locations of the installation

The computer program gives for each combination of speed, wave direction, significant amplitude and average heave (z), sway (y), surge (x), roll (ϕ), pitch (θ) and yaw (ψ) periods, a Bretschneider wave spectrum. The movements are illustrated by Figure 16. Figure 17 gives an example of a Bretschneider wave spectrum.

The average value of the highest 1/3 part of a spectrum is also called Significant Value. The significant wave height is symbolized by $H_{1/3}$ and the period by T_1 .

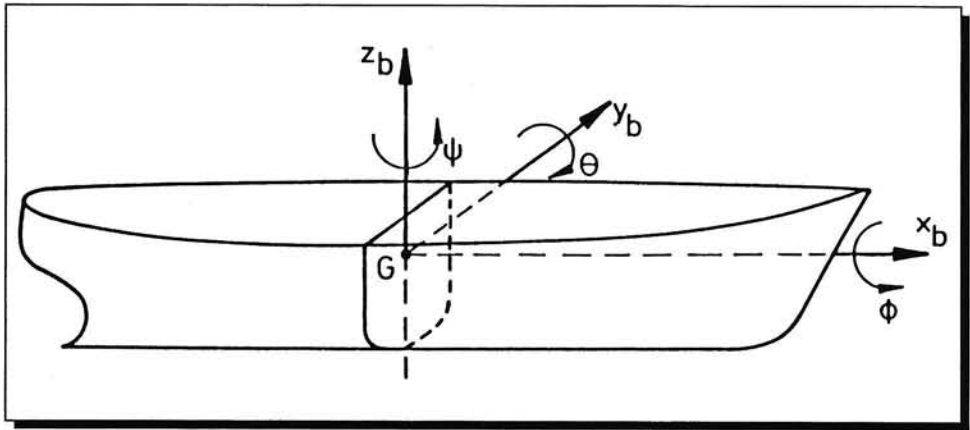


Figure 16: Movements

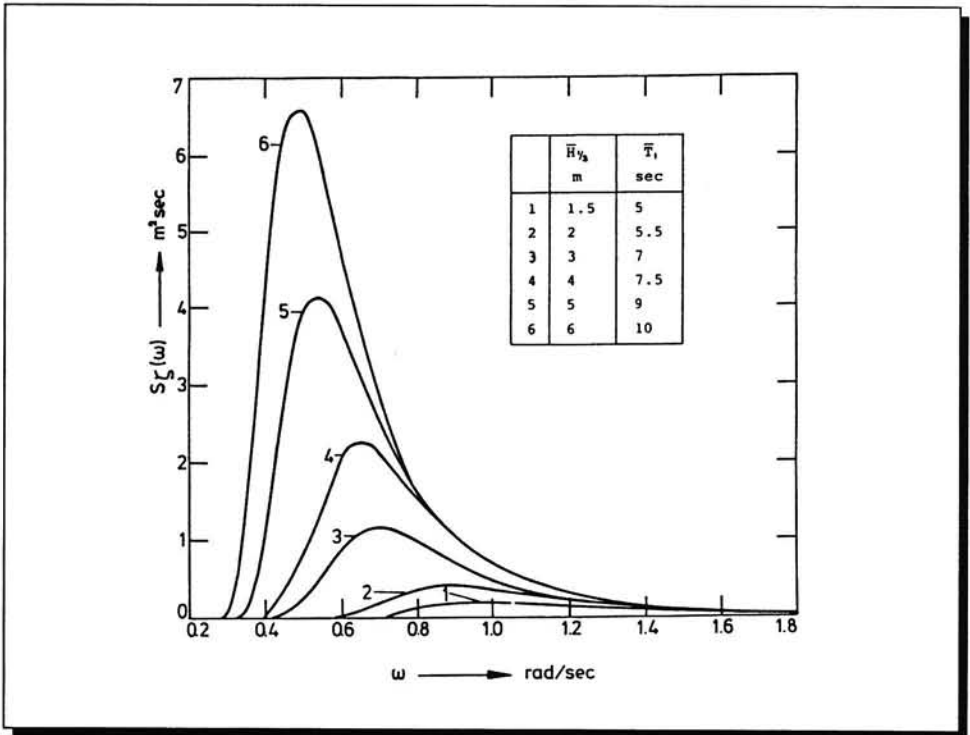


Figure 17: Bretschneider wave spectrum

According to Hogben and Lumd (Ocean Wave Statistics 1967) the probability of meeting a wave in the northern part of the Atlantic Ocean with a height less

than 4 meters is about 90%. Table XIII gives a summary of the output of SEAWAY, for a significant wave height of 4.90 meter.

Significant rolling angle(°):

Wave direction (°)/ Speed (knots)	0	45	90	135	180
15.00	0	3.92	13.72	5.32	0
11.25	0	10.73	13.97	6.33	0
7.50	0	11.08	14.29	7.78	0

Roll period:

Wave direction (°)/ Speed (knots)	0	45	90	135	180
15.00	6.28	15.30	10.62	10.15	10.41
11.25	6.28	11.27	10.62	10.32	10.31
7.50	6.28	11.13	10.63	10.51	10.54

Table XIII: Summary SEAWAY output, roll

For this example the most extreme situation occurs when waves come at right angles (90°) and the ships speed of 7.5 knots. In this situation the ship has a significant roll angle of 14°30' and a period of 10.63 seconds. These figures can be evaluated using Figure 18. This figure gives a cross section of the large ship. It shows the angle in which the waterplane touches the main deck.

Generally the captain or first mate will avoid extreme roll angles, by changing course or reducing power. The program shows that reducing power (reducing speed) hardly affects the roll angle for waves that come at right angles. Generally the roll angle becomes even bigger. Reducing speed does give a reduction of movements.

Table XIV gives an overview of the accelerations in x, y and z direction. Table XV gives an overview of the extreme acceleration values.

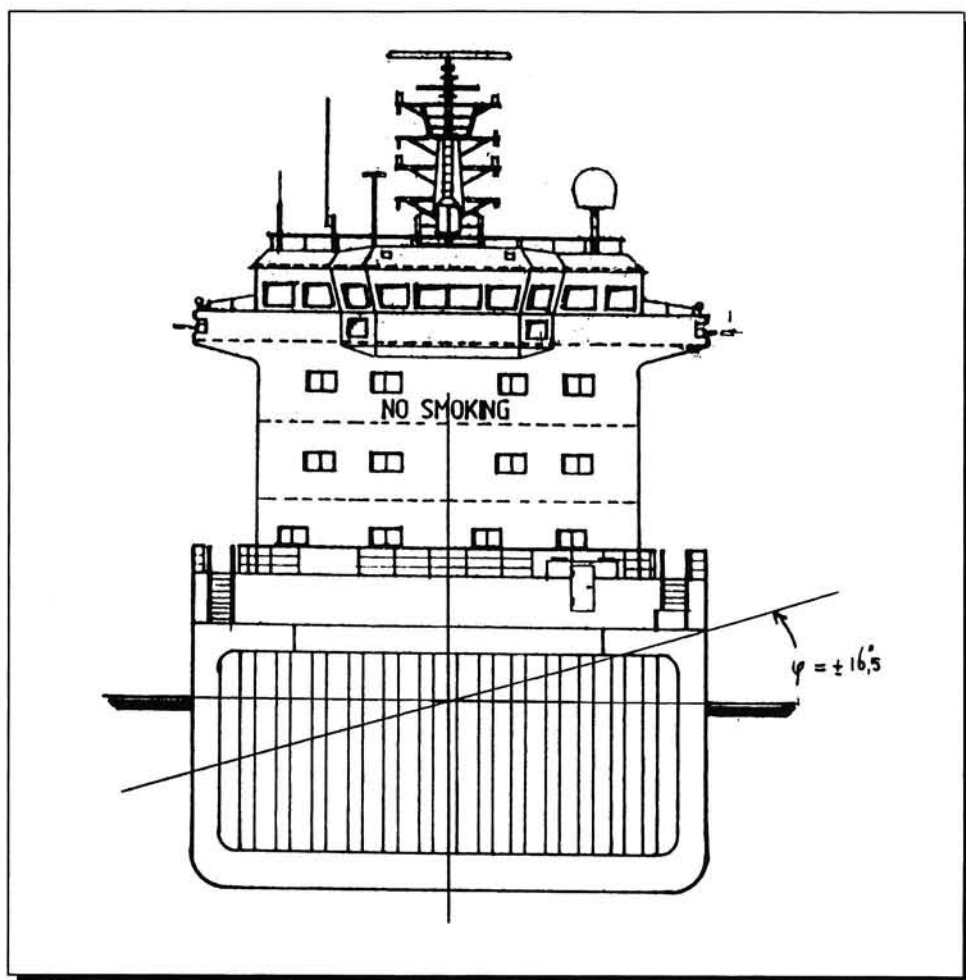


Figure 18: Cross section chemicaltanker

Location 1

Speed/ Angle	15 knots			11.25 knots			7.5 knots		
	x	y	z	x	y	z	x	y	z
0°	0.12 22.5	0.00 6.28	0.14 20.4	0.14 15.4	0.00 6.28	0.23 16.3	0.17 12.1	0.00 6.28	0.37 13.0
45°	0.13 14.6	0.44 15.4	0.28 15.5	0.15 11.8	1.87 11.0	0.40 13.1	0.21 9.87	2.17 10.8	0.57 10.8
90°	0.13 6.19	3.09 9.46	1.38 7.51	0.09 6.25	3.13 9.48	1.36 7.54	0.06 6.37	3.18 9.50	1.34 7.56
135°	0.93 5.76	1.51 7.75	2.48 6.14	0.85 6.05	1.63 8.43	2.01 6.43	0.75 6.39	1.82 9.13	1.59 6.87
180°	1.07 5.83	0.00 8.15	2.47 6.01	0.97 6.18	0.00 8.63	1.88 6.34	0.83 6.60	0.00 9.47	1.39 6.90

Location 2

Speed/ Angle	15 knots			11.25 knots			7.5 knots		
	x	y	z	x	y	z	x	y	z
0°	0.12 22.5	0.00 6.28	0.14 20.4	0.14 15.4	0.00 6.28	0.23 16.7	0.17 12.1	0.00 6.28	0.25 13.9
45°	0.08 14.9	0.52 15.2	0.27 15.6	0.11 12.0	1.94 11.0	0.49 12.1	0.18 10.0	2.00 10.9	0.45 12.0
90°	0.13 6.26	3.12 9.39	1.14 7.51	0.09 6.35	3.17 9.41	1.16 7.56	0.06 6.50	3.22 9.44	1.17 7.59
135°	1.03 5.75	1.39 8.71	2.02 6.53	0.94 6.04	1.55 9.22	1.69 6.81	0.84 6.37	1.76 9.74	1.34 7.18
180°	1.07 5.83	0.00 9.23	2.03 6.42	0.97 6.18	0.00 9.45	1.59 6.73	0.83 6.60	0.00 10.0	1.15 7.16

The first line for every angle gives the significant amplitude of the acceleration, the second line gives the average period

Table XIV: Acceleration in x, y, and z direction on location 1 and 2 (m/s²)

Part III: Sloptreatment Onboard; The Seatreat System

	Speed (kn)	Wave dir. (°)	Acceleration (m/s ²)	Period (sec.)
Location 1, x	15.0	180	1.07	5.83
y	7.5	90	3.18	9.5
z	15.0	135	2.48	6.14
Location 2, x	15.0	180	1.07	5.83
y	7.5	90	3.22	9.44
z	15.0	135	2.03	6.42

Table XV: Most extreme accelerations

CHAPTER 6: CHEMICAL TANKER DESIGN CONSTRAINTS

This chapter discusses the technical aspects which affect installing a waste water treatment installation onboard a large chemical tanker.

THE PROCESS

On basis of the data from the previous chapter, a treatment installation was designed by Encon of Rotterdam which can treat most of the slops. A schematic representation of the treatment process is given in **Figure 19**. The equipment is based on a chemical-physical process.

The slops treatment comprises the following phases:

1. The slops are pumped from the buffertank to the reactor.
2. In the reactor the waste water is treated with non toxic chemicals. First a coagulant is added, while the water is stirred violently. This neutralises the colloidal particles and causes the primary flocks. The coagulant is iron chloride.
3. Then the acid mix is neutralised by lime milk. If the acidity is neutral (7) the flocks grow to the secondary flocks.
4. In the third compartment of the reactor a flocculant is added. This flocculant stimulates the process of (3). Stirring prevents the secondary flocks from sinking.
5. After the reactor phase, the process goes on with the sludge removal. In a spin dryer the secondary flocks are separated from the water. This phase is characteristic for slops treatment at sea. Separation methods based on natural gravity only, cannot be used on a ship in motion.
6. The spin dryer causes two output flows: the treated water and the concentrated waste. The ratio between the volumes is 97% water and 3% waste. The waste is collected in a container and delivered in port for incinerating.
Depending on the demands for the discharge and the concentration of chemicals, the water is filtered. Sand filters decrease the amount of flocks to a minimum.
7. Parallel to the waterflow, there is an activated carbon filter. The carbon molecules adsorb the organic substances. It is not possible to let the water flow through the filters without pretreatment, for the filters would be blocked.

The filters are used to extract substances that are hardly sensitive to the chemical process. The most important ones are chlorides.

8. Before the water leaves the plant, the amount of water and the concentration of toxic substances in the water is measured. This gives the possibility to check if everything is carried out according to the regulations. If the water does not comply with the environmental regulations, it is treated again, otherwise it can be discharged at sea.

BUFFERTANKS

Type of treatment

Because of its limited capacity, the treatment installation of the ship is not able to treat the output of the washing machines immediately. Therefore, it is necessary to have buffer capacity.

The dimensions of a buffertank for the installation depend on:

- * The amount of slops produced by one prewash;
- * The amount of slops that should be treated immediately;
- * The maximum space the buffertanks may occupy.

The minimum capacity of a single buffertank depends on the average largest amount of slops of one wash. The absolute largest amount of the slops is not really important, as long as this amount is significantly bigger than the average. For example, the tank can be big enough to contain 80% of all slops volumes. It is assumed that the tank is empty at the start of the washing, so all slops of previous washes have been treated. **Table XI** shows the required tank capacity required for storing as a function of the percentage of discharges.

Because it often happens that tanks with slops of different products are washed simultaneously, the wash water will often contain more than one product. There are two principle possibilities of storing the wash water:

1. If the products are compatible, they can be stored together in one tank. This method is similar to the current situation. This restricts the number of slops tanks. A disadvantage of this method is that sometimes mixtures are more difficult to treat than separate products.
2. All wash water is collected in separate tanks, so the water is only polluted by one product. Only if mixing specific products has special advantages for the treatment, they will be stored together.

Starting point for the treatment of the waste water is that slops are treated as quick as possible.

Part III: Slop-treatment Onboard; The Seatreat System

Though it is the objective to keep the number of buffertanks limited, the treatment process must be as effective and efficient as possible. This decreases the operational costs of the installation and restricts the amount of slops that has to be delivered in port. Therefore, option 2 is most suited.

Theoretically the number of buffertanks for option 2 is equal to the number of cargo tanks. Every cargo tank may contain a different product and every tank may be unloaded and washed simultaneously. Then the ship needs 16 buffertanks. (This is equal to the number of cargo tanks including the number of slopstanks, which in the future will be used for cargo).

However, the cargo record books show that the maximum number of different slops in the last two years, produced by washing on the same date, was seven. Therefore the number of buffertanks can be reduced to seven.

It is not necessary to use the installation after every wash. It can be attractive to use the machine less frequently, for example for saving energy, chemicals and maintenance. However this may mean that the buffer capacity and number of buffe tanks must be bigger, due to compatibility problems.

Bigger buffer capacity should be prevented, as the loss of deadweight and cargo capacity must be as low as possible.

Concluding, batch treatment of the slops appears the best method. This way the adding and selection of coagulant and flocculation substance can be controlled best. Adding different slops to the buffertank, while the installation is working, will change the influent of the flocculation unit. This way optimisation of flock forming will be disturbed. Equipment as the combinator can cope with the fluctuation of influent, but this is based on techniques that cannot be used at a moving ship.

Type of buffertank

To restrict the required number of modifications to the ship and to enable placement of the installation on existing ships, tankcontainers are used as buffertanks. The volume of the tanks in a TEU-frame varies from 11 m³ to 28 m³. A standard volume of 25 m³ is used. The tanks are made of stainless steel.

Another possibility is the division of the present slopstanks into several smaller tanks. The big disadvantage of this alternative is the loss of cargo capacity, for this means that the slopstanks cannot be used for cargo. Investment costs for modifying the slopstanks seem smaller than buying tankcontainers. However, for every tank a pump is required and the cleaning of box-shaped tanks is more difficult than the cleaning of cylindrical tankcontainers.

Number of buffertanks

The number of tankcontainers depends on the:

- a. Average number of different types of slops per wash;
- b. Mixability of the products;
- c. Treatability of the slops-mixes;
- d. Volume of the slops;
- e. Reliability of the installation; what time is the installation unavailable due to bad weather?
- f. Time between storing and treatment;
- g. The flexibility required by the shipowner.

a. Number of different slops types during one wash

The number of different product slops per discharge over a two year period is given in **Table XVI**:

Number of products	Number of discharges	Percentage (%)
1	58	58
2	19	20
3	9	9
4	4	8
5	3	3
6	5	3
7-11	2	3

Table XVI: The number of different products slops per discharge

This overview shows that discharges with seven different products or more, are very rare. Therefore, a maximum of six different products is assumed. This assumption implicates that only six buffertanks are required, to keep the slops separated, this in contrast to the earlier mentioned number of seven.

b. and c. Mixability and treatability of the slops

This aspect has been examined, but is not discussed any further. The consequence of a better treatability of some mixes is that some buffertanks have to be connected. With three connected tanks, the mix advantage for most products is used sufficiently.

d. Volume of the slops

Slops volume has been discussed earlier. Below a summary is given of the most important factors for the slops production:

- * The product. The characteristics of the product cause a specific way of washing. The washing method depends on:
 - The environment temperature;
 - The next product in the tank;
 - The person who is responsible for the wash;
 - The demands of the cargo owner.
- * The number of washing machines per tank;
- * The type of washing machine;
- * The number of tanks;
- * The water pressure.

For the large ship the average washing time per tank is 35 minutes. The average slops production is 8 m³ per tank.

The reliability of the installation

The installation can be used under almost any circumstance. Only in extreme situations (e.g., a roll more than 20°) the installation cannot be used. This is a very important aspect for the shipowner when making the fleet instructions. This is also important for the number of buffertanks. If for example, practice shows that the installation cannot be used during 30% of the time, it is probable that extra buffertanks are required.

For any installation capacity it can be calculated how much time it takes to treat 6 full tank containers. Time required for cleaning the tanks has also to be accounted for.

f. Other factors that determine the time between washing and treatment.

The time between washing and treatment depends very much on factor (e). However there are several other factors that do not depend on the installation but also affect this time:

- * The time between two successive washes. If the period between unloading, washing, loading, unloading and washing again is short, it may happen that there are new slops produced before the previous ones have been treated;
- * Insufficient supply of coagulant or flocculant;
- * The tanks for the slops are full, therefore the installation cannot accept new slops;
- * The port authorities may forbid treatment during port stays.

Part III: Slop treatment Onboard; The Seatreat System

Therefore, the shipowner may decide to place buffertanks onboard the ship. There is a probability that new slops are produced while the buffertanks are full. Then there are two possibilities to handle the slops:

- * The classified slops are delivered at the shore reception facility;
- * Empty cargo tanks can be used for temporary storage of slops. In this situation it is hard to prevent mixing of slops. This possibility should only be used if the buffertanks are totally full or if the products in the buffertanks should not be mixed with the new slops.

Recirculation

Easily settling substances can sink in the tankcontainer. This way it can block the valve or pump. To prevent this, recirculation may be used. The wash water is circulated via pipes alongside the tanks. The idea is shown in Figure 20. This figure also shows that three of the six containers are connected. This way, different slops can be treated as one.

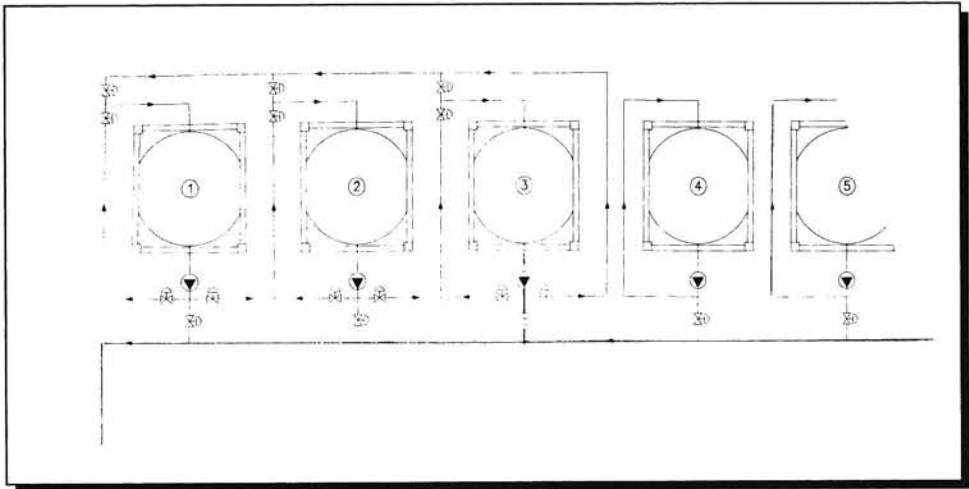


Figure 20: Recirculation

OTHER STORAGE CAPACITY

Besides the buffertanks for storage of the slops, other tank capacity is required for the temporary storage of the treated water and for storage of the sludge that has to be delivered in port.

Part III: Slop-treatment Onboard; The Seatreat System

Cleaned water

Most port authorities do not have special regulations, besides those of MARPOL. If MARPOL permits the use the installation in port, the port authorities will probably also approve. The treated water however, is often not clean enough to be discharged in port, so it should be stored temporarily in tanks.

A separate tank for storage of cleaned water is required when all buffertanks are full. This can be an extra tank container or a cargo tank. As shown before, only in 5% of all situations all tanks are used. Therefore, often one or more buffertanks are available. Consequently, it is decided that an extra tank for cleaned water is not necessary.

When the ship is at sea, the water can be discharged immediately, which means that no temporary storage is required.

Sludge

After the treatment of waste water, sludge remains. This sludge consists of the treated products, chemicals and water. Waste water contains approximately 30 kg sludge per m³.

On a total slops volume of 3000 m³ a year, this gives only 90 tons of sludge, which is 1050 kg (35 m³ water) per cleaning. Sludge has to be stored onboard and must be delivered in port for further treatment.

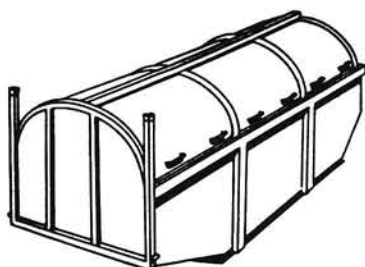
The storage-unit must be located within the cargo area of the ship. It is the ambition to have sufficient sludge storage capacity in order to limit the number of calls at the shore reception facilities.

Sludge flows by a pipe into the sludge container, which could be shaped as shown in **Figure 21**. The container is made of conventional steel. Concentrated chemical sludge will hardly erode the steel. The volume of the container is selected on the basis of the expected slops volume. The size of the container affects its location on the ship; a standard twenty feet container (TEU) will be sufficient. This container has to be remove approximately 5 times a year.

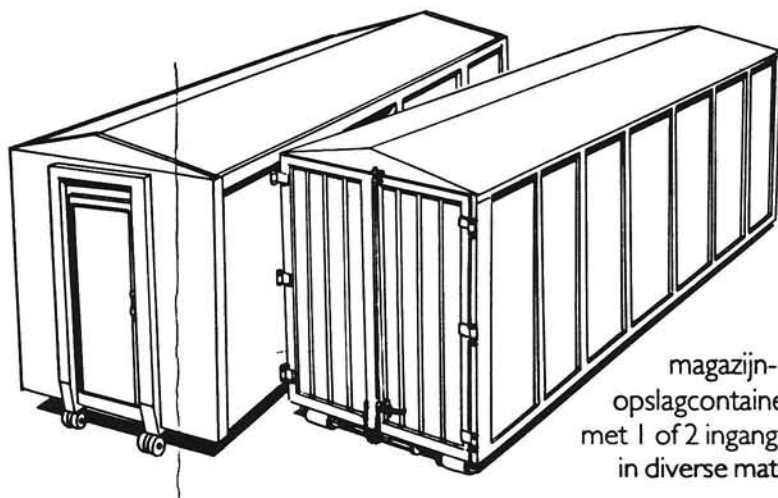
LOCATION OF THE INSTALLATION

To determine the location of the installation on deck, the following requirements have to be considered:

1. Regulations: The installation must be located within the cargo area.
2. Shipowner demands: The installation should not limit the view from the bridge, cargo control room or captains' cabin.
3. Building costs:
 - Modifications of the current deck layout must be limited
 - Cargo handling should not be hindered



gesloten container, inhoud: 4 - 30 m³
laadvermogen



magazijn- of
opslagcontainers
met 1 of 2 ingangen
in diverse maten

Figure 21: Sludge containers

Part III: Sloptreatment Onboard; The Seatreat System

- Pipes must be short
- Movements and accelerations of the installations must be acceptable
- Vibration level must be acceptable.

Regulations

This paragraph discusses some specific parts of the IBC-code in more detail. The IBC-code defines the *cargo area* as follows:

"Cargo area is that part of the ship that contains cargo tanks, slops tanks, cargo pump-rooms including pump-rooms, cofferdams, ballast or void spaces adjacent to cargo tanks or slops tanks and also deck areas throughout the entire length and breadth of the part of the ship over the abovementioned spaces."

IBC - 3.2.3:

"Entrances, air inlets and openings to accommodation, service and machinery spaces and control stations should not face the cargo area. They should be located on the end bulkhead not facing the cargo area and/or the outboard side of the superstructure of deckhouse at a distance of at least 4% of the Length of the ship but not less than 3 m from the end of the superstructure of deckhouse facing the cargo area. This distance, however, need not exceed 5 m."

A dangerous zone plan has been made according to regulations from the IBC-code and Lloyd's. The IBC regulations are:

IBC 8.2.2.1

"The heights of vent outlets should not be less than 4 m above the weather deck or above the fore and aft gangway if fitted within 4 m of the gangway."

IBC 8.2.2.2

"The vent height may be reduced to 3 m above the deck or fore and aft gangway, as applicable, provided high-velocity vent valves of a type approved by the Administration directing the vapour-air mixture upwards in an unimpeded jet with an exit velocity of at least 30 m/s are fitted."

IBC 8.2.2.3

"The vent outlets should also be arranged at a distance of at least 10 m from the nearest air intake or openings to accommodation service and machinery spaces and ignition sources." IBC 15.12.1.3 prescribes that the distance for noxious products must be at least 15 m.

IBC 10.2.3.5

"Zones on open deck, or semi-enclosed spaces on open deck within 3 m of any cargo tank outlet, gas or vapour outlet,..." are considered dangerous locations. This includes "all ballast tanks and cofferdams within the cargo tank block, to the full width of the ship, plus 3 m fore and aft and up to a height of 2.4 m above the deck."

In the dangerous zone plan for the ship, the dangerous zone is enlarged to 4.5 m. This is caused due to the special demands for the transport of carbon disulfide, diethyl ether and propylene oxide. The height of 2.4 m must be enlarged to 4.5 m (Lloyds Register 10.4 (A)). Similarly, the 3 m in the horizontal direction must be enlarged to 4.5 m. This requirement has hardly any influence, because the dangerous zones are mainly located within the zones of the gas-outlets.

The dangerous zone of the gas or vapour outlets of the tank container is equal to a globe with a radius of 4.5 m. This zone must be within the cargo zone. The installation must satisfy the regulations of electric equipment in the dangerous zone, IBC chapter 10.

Shipowner requirements

The view from the bridge should always comprise the seaway and the other ships. This results in a maximum view line of 1.5 times the length of the ship in front of the ship. Because the installation should be located in the cargo zone, there are no problems for the view backwards and sideways. The cargo control room requires view on the manifold and a large part of the deck. The restriction of the view from the captain's cabin may cause problems for the captain often watches the activities from his cabin.

The installation may not hinder loading/unloading, ventilation, washing and inspection of the cargo tanks. This means that containers may not block, valves, tank and butter heads and others. This means that the containers must be placed at least two meters above the deck.

Building costs

The containers cannot be placed on the deck without adjustments to the systems on it. These adjustments have to be limited. To limit the length of the pipes, the containers should be located near the manifold. Short pipes reduce the building and maintenance costs.

The accelerations and movements of the center of gravity are found by the computer program SEAWAY. The pitch turning point of the ship is located on the center of gravity of the loadline, in a specific cargo condition. For a draught of 6.2 meter, the turning point for this ship is located 46.3 m from the after

Part III: Sloptreatment Onboard; The Seatreat System

perpendicular, which is 2.45 m behind midship. If the ship is not fully loaded, this location will be a little farther to the front. The containers should be located near the turning point.

There are no exact data available about the vibrations distribution over the length of the ship. It is assumed that the probability for vibrations gets bigger if the location is nearer to the back of the ship.

If one takes all the mentioned aspects into account, there are two locations that are optimal for the containers:

1. Between the back cofferdam and the first gas-outlets:

- * The containers should be located high to prevent view restrictions;
- * Only small modifications of the deck layout are required: turning around the deck crane;
- * No hindrance of cargo handling;
- * Near the manifold;
- * Near the pitch turning point.

2. Between the manifold and the second gas-outlets:

- * No view restrictions;
- * Possibly no modifications of the deck layout;
- * No hindrance of cargo handling;
- * Near the manifold;
- * Near the pitch turning point;
- * Good level of vibrations.

First location

There are some objects that may obstruct the containers. The first object is the hatch coaming that leads to the ballast pump room and inert gas room. This hatch coaming is located on the raised D-deck, in front of the accommodation. The height of the coaming is 560 mm and the length is 810 mm. When the hatch is open, the height is 1370 mm above the D-deck.

The second object is the cargo tank ventilator, which is also located on the D-deck, in front of the accommodation. The height of the fan is 1650 mm above the D-deck.

The accessibility of the safety and eye shower must remain good. These are attached to the front of the accommodation. The showers must be reliable and should not freeze in the winter. Long pipes from the machine room to the shower increase the probability of freezing.

Part III: Sloptreatment Onboard; The Seatreat System

To prevent hindrance by the crane in the out of service position, it must be turned 180° when it is fixed. It should be no problem if the crane is above the manifold. The crane can still reach the front of the accommodation on the D-deck.

Other objects that may obstruct the containers are:

- * Ventilator inlet: the height of this inlet is 1650 mm;
- * The space with oxygen bottles which must remain accessible. The height is 1950 mm and the depth is 375 mm;
- * Control room: the height is 1655 mm;
- * Cargo pumps: the height of the pumps and the electric engines is 2285 mm.

Because the view of the cargo control room should not be hindered, the containers must be placed on a minimum elevation of 1.65 m above the deck. This elevation is measured from the D-deck. Because the D-deck is 1.60 above the main deck, the containers must be located on 3.25 m above the main deck. This is far above the cargo pumps. Because the containers are filled and gas-freed from the topside, they should not be placed on each other.

Because the pipes should be short, the containers must be placed as close to the manifold as possible. This is restricted by the first gas-outlet. To minimize the number of adjustments, the showers and the oxygen space are placed against the accommodation. Therefore only two containers can be placed behind each other.

Second location

The second possible location of the containers, is before the manifold. The crew must be able to walk over the manifold and the view may not be hindered. The two largest obstacles are: a platform with two fire extinguishers and the second gas-outlet. The gas-outlet should not be covered with containers.

Between the platform and the gas-outlets there is a gap with a length of 13 m. Here two twenty foot containers can be placed behind each other. The containers will be placed on a height of 3.25 m from the main deck. They cannot be placed lower, because the fire extinguishers must be able to extinguish in front of the platform. Higher is not necessary and would hinder the view. Twist locks can attach the containers to the deck.

EXPANSION OF THE MANIFOLD

It must be possible to connect any cargo tank to any buffertank. Different slops must have the possibility to be pumped into the buffertanks without mixing. Therefore, the manifold should be expanded.

Part III: Slop-treatment Onboard; The Seatreat System

Six butters can be in service simultaneously. If the wash concerns only one product, the maximum number of connections per buffertank is six. If each of the six butters produces different slops, then it must be possible to reach every buffertank separately. Because the average production per tank is 8 m^3 and the contents of a tank container is 25 m^3 the number of connections per buffertank is decreased to three. This reduces the building costs.

The expansion of the manifold is based on the following consideration. The cargo tanks of the ship can be considered as a shore installation with sixteen storage tanks. Those tanks can each contain the same product, but can also contain up to sixteen different products. The buffertanks are considered as a ship with cargo tanks. Pumping slops into the buffertanks is considered as loading a ship.

The shore installation has six loadlines which means that six different cargoes can be loaded simultaneously. The junction point between the cargo tanks and the buffertanks will look very much like the present manifold for six tanks. **Figure 22** shows the 'slops manifold'.

Six pipes run from the slops manifold to the main manifold (port side). At the end of every pipe there are three or six connections, which can connect the separate cargo tanks with the containers by hoses. During washing, the cargo pumps pump the slops into the appropriate buffertank.

Next to the buffertanks and the installation, a small manifold must be made to control the supply of the treatment installation. Because the installation will treat only one type of slops at a time, it is possible to work with one pump and one main pipe.

Because fixed pipes and valves are extensive and require large investments, hoses are used. Because buffertanks are supplied with different slops simultaneously, it is not possible to use only one central main pipe. Slops should not be mixed. In the extreme situation that six butters are working simultaneously, six different slops will be produced. Pipes must run from 16 cargotanks to 6 buffer tanks ($6 \cdot 16$ is 96 pipes and valves). Therefore, hoses are more suited.

According to the classification societies (Lloyd's and Det Norske Veritas) the use of hoses is permitted. The maximum length of the hoses is approximately 5 meters. The hoses must be tested for burst pressure, which is related to the cargo pump capacities.

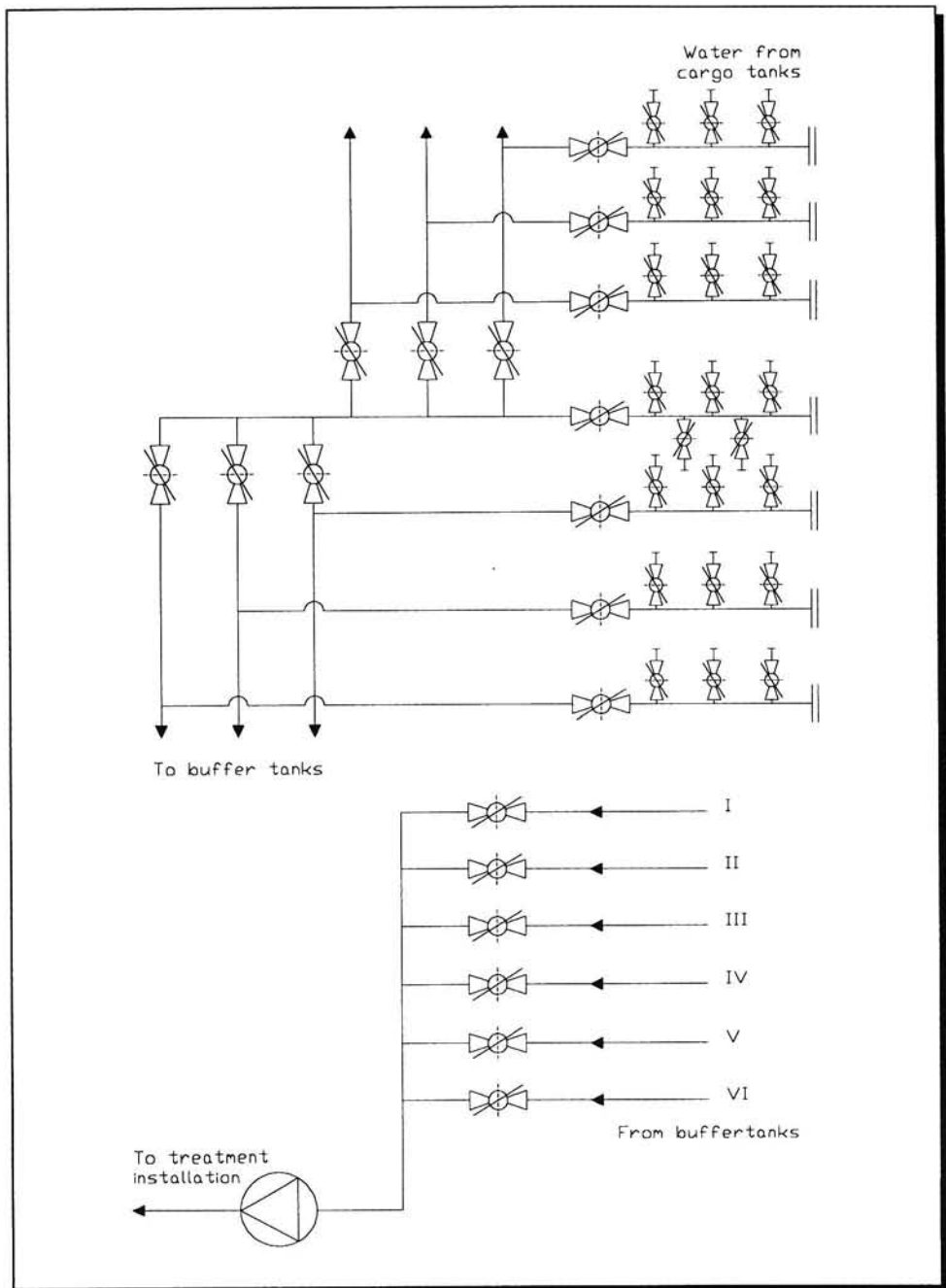


Figure 22: Slop manifold

Part III: Slop-treatment Onboard; The Seatreat System

Fast-coupling systems are not permitted. Nut-bolt connections are more time consuming, but cannot be avoided. The connections between the hoses and the flanges must be located above a leakage bin. This means an expansion of the leakage bin or an extra bend in the pipes to the buffer tanks (Figure 23) is required.

CONSTRUCTION

Container deck

To support the containers, it is necessary to build a small deck. It is sufficient to put struts under the corner fittings of the containers. The weight of the containers and the support construction will be carried by the main deck. The weight forces on the deck construction are dispersed by webframes and girders. The locations of the connections behind the installation are shown in Figure 24. The container support construction can be built in two ways:

- * Frame construction (Figure 25);
- * Bracket construction. (Figure 26).

Pipe system

There are three pipe systems that require an expansion. These are:

- * Wash water supply system;
Figure 27 and Figure 28 show the supply pipes near the containers. Stainless steel pipes with a diameter of 75 mm and a thickness of 2.5 mm are used. The estimated length of the pipes is 145 m.
- * Heating system of the tank containers;
The present tank heating system is expanded to the tank containers. The containers are connected to this system by hoses.
- * Fire extinguishing system around the installation;
Figure 29 shows the sprinkler system around the containers. This system requires 30 meters of pipes with a diameter of 38 mm and 36 nozzles.

Electrical installation

The installation is controlled from the cargo control room. An on line monitor system is installed, which shows the temperature of the buffertanks.

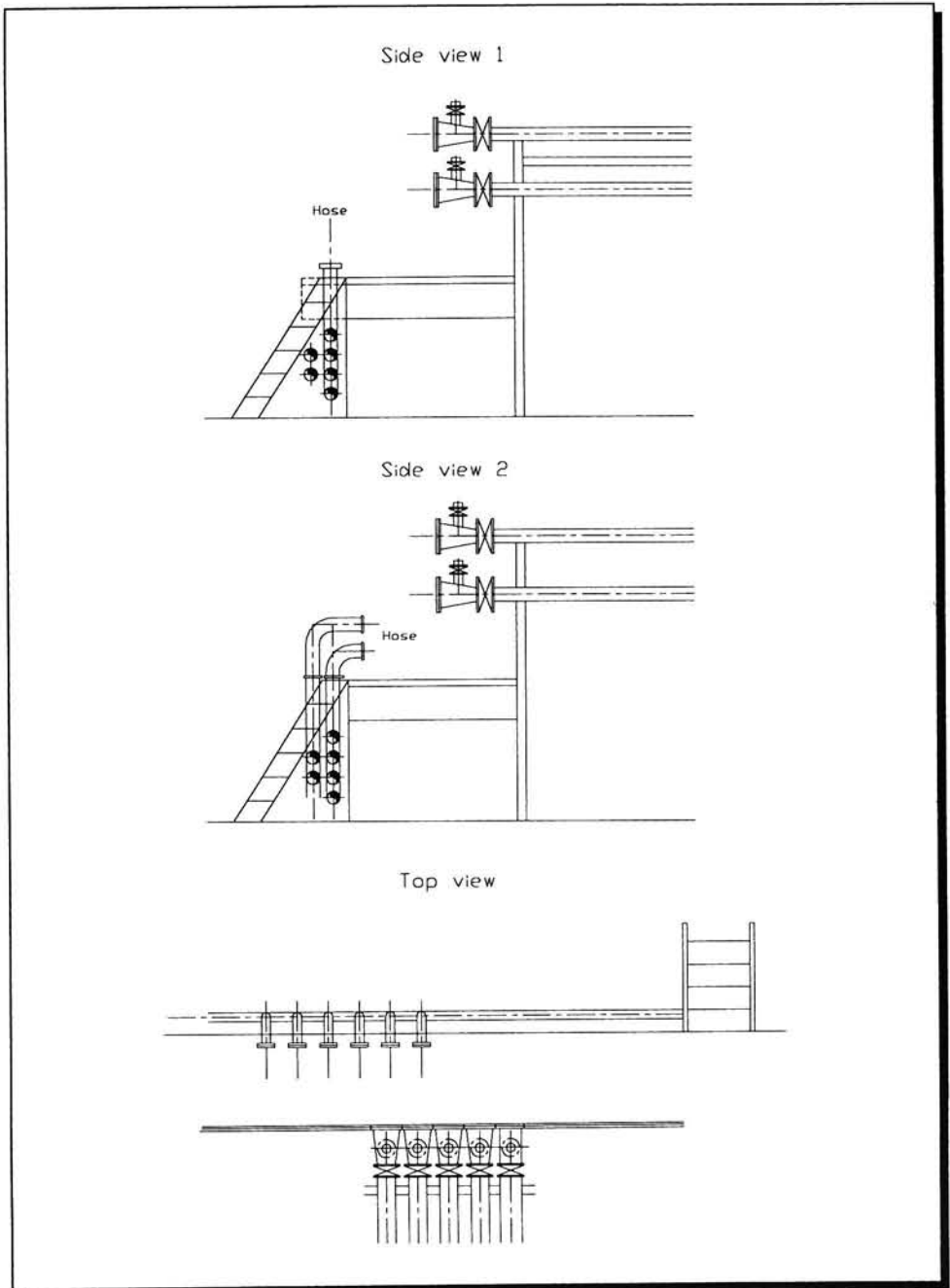


Figure 23: Connection to the manifold

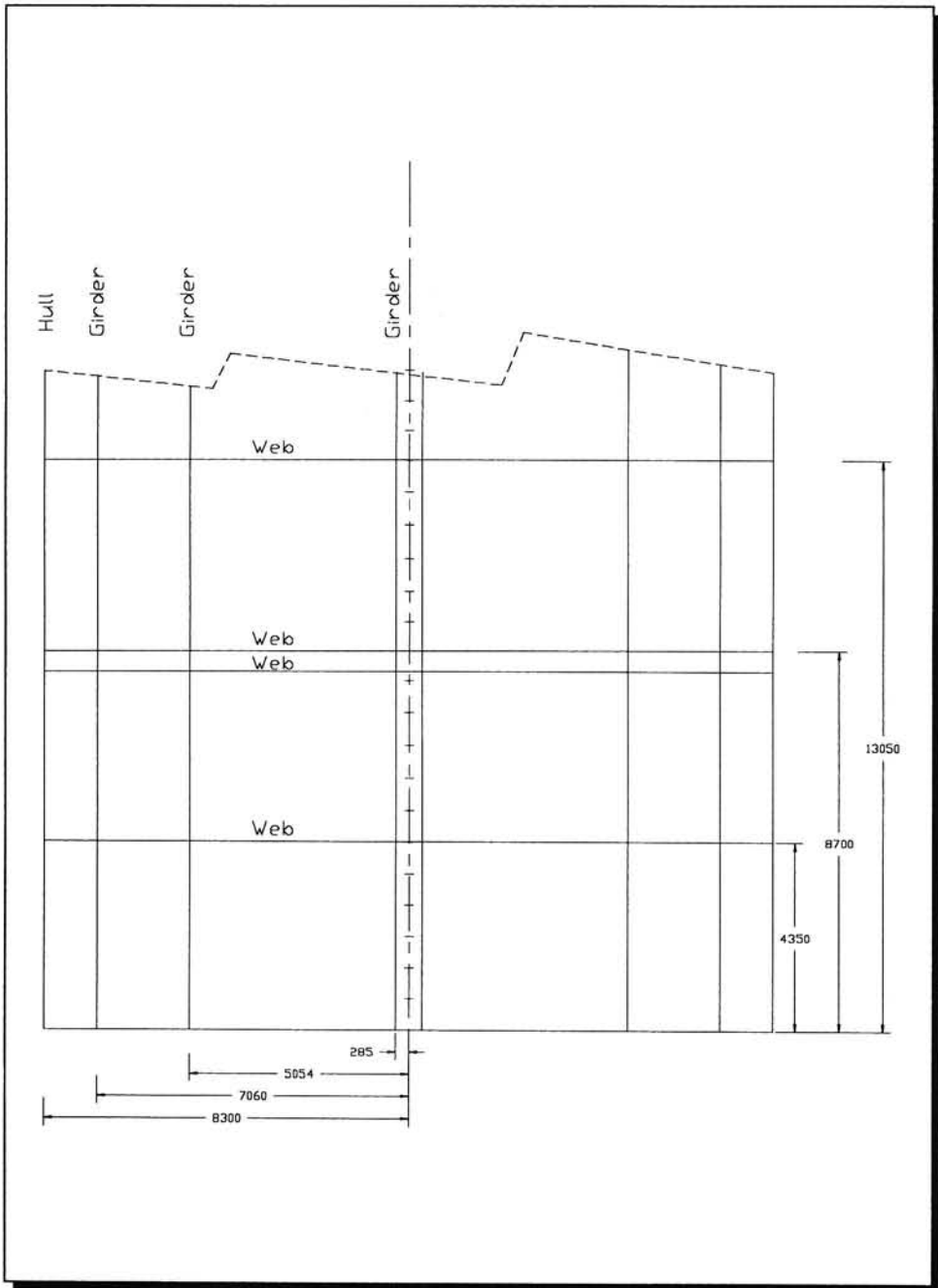


Figure 24: Connections

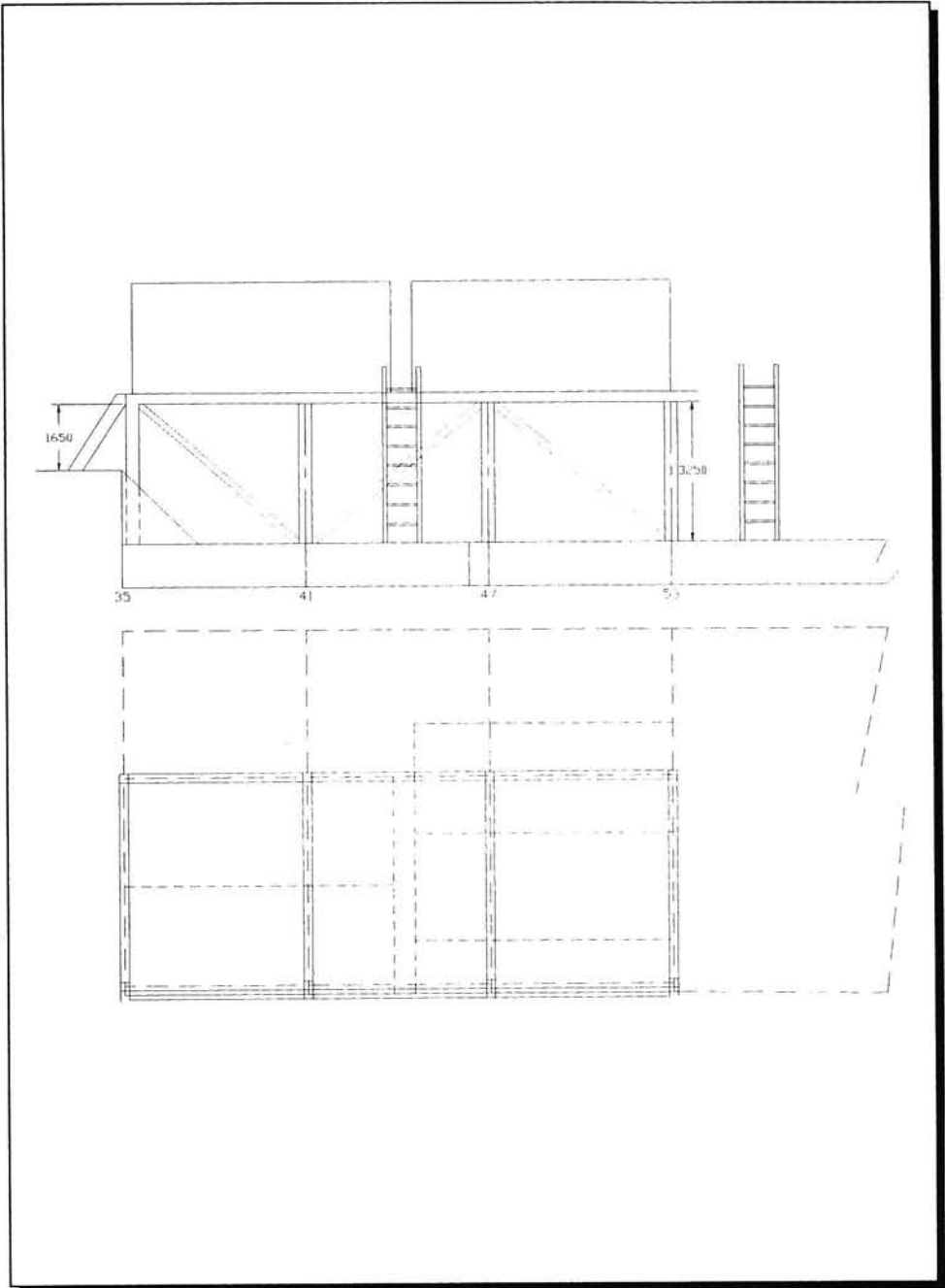


Figure 25: Frame deck construction

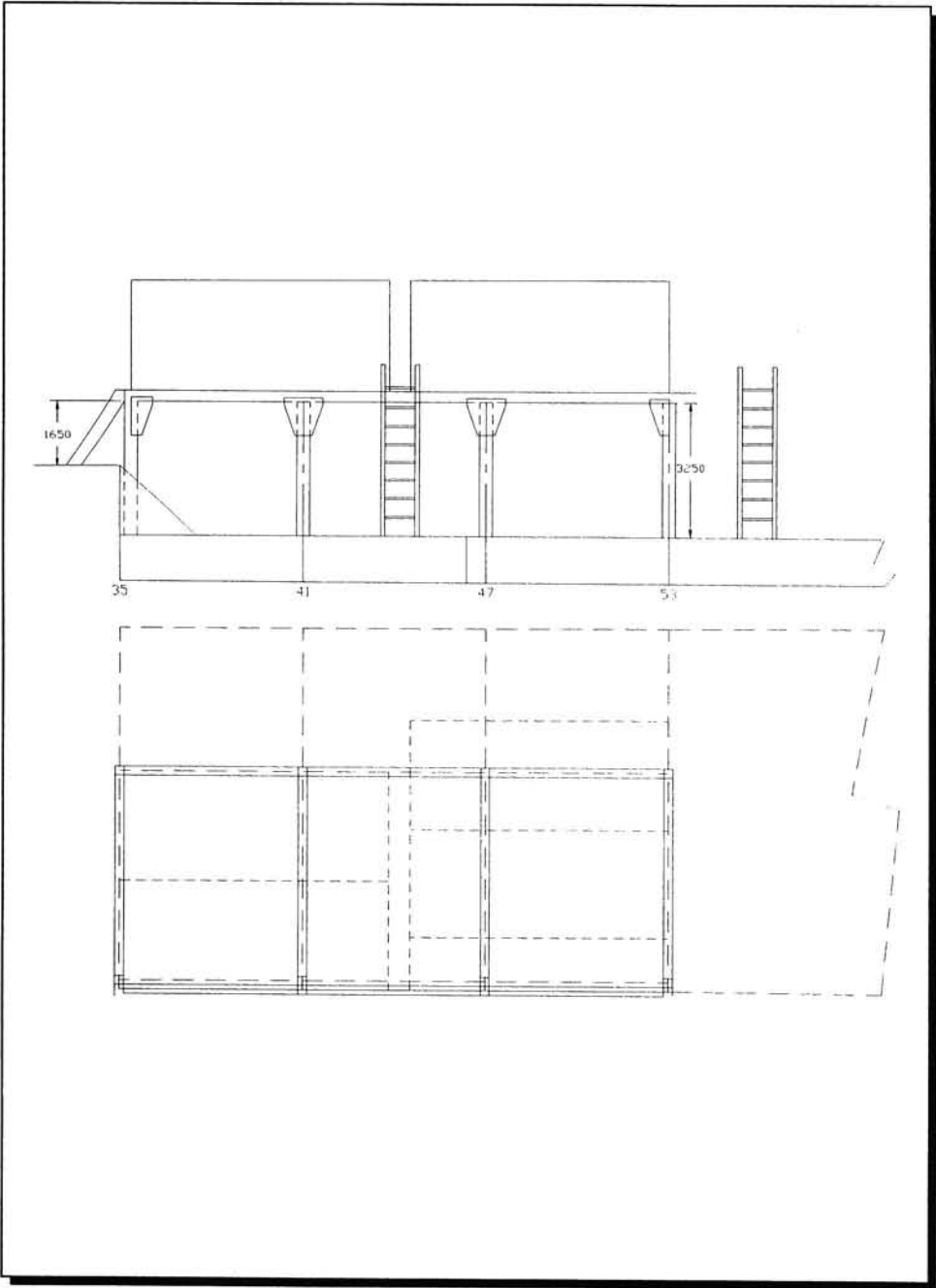


Figure 26: Bracket deck construction

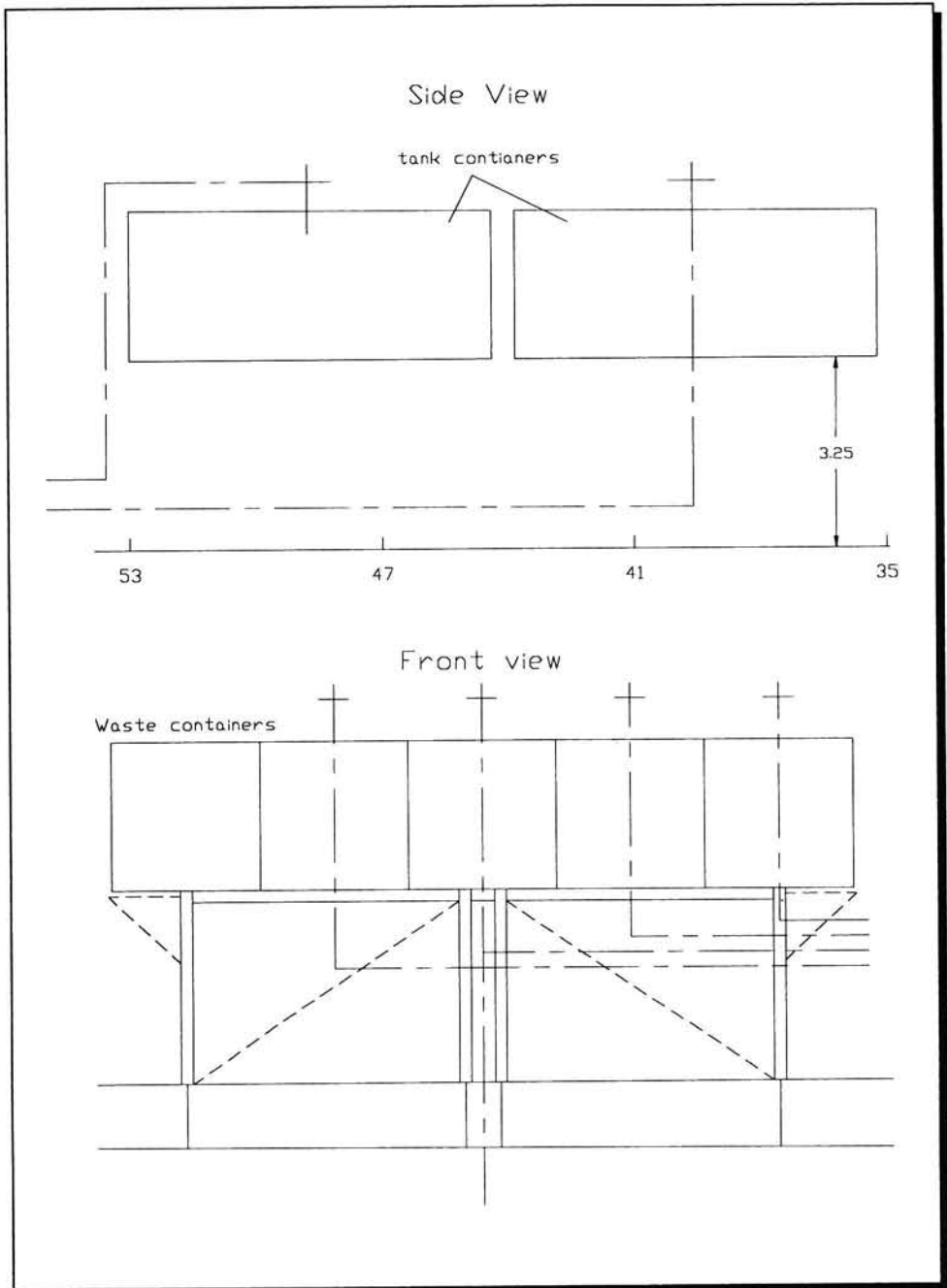


Figure 27: Tank supply system (1)

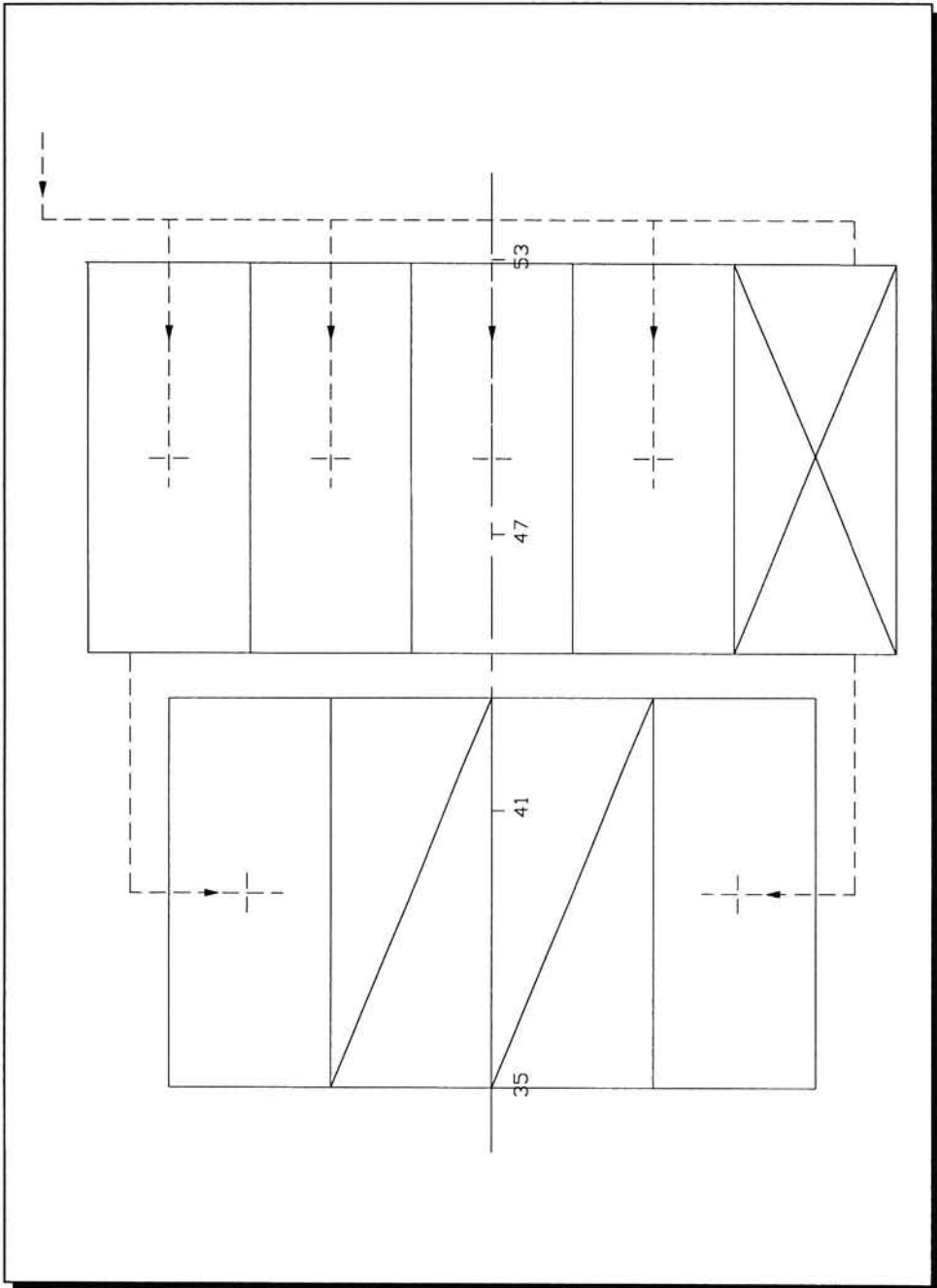


Figure 28: Tank supply system (2)

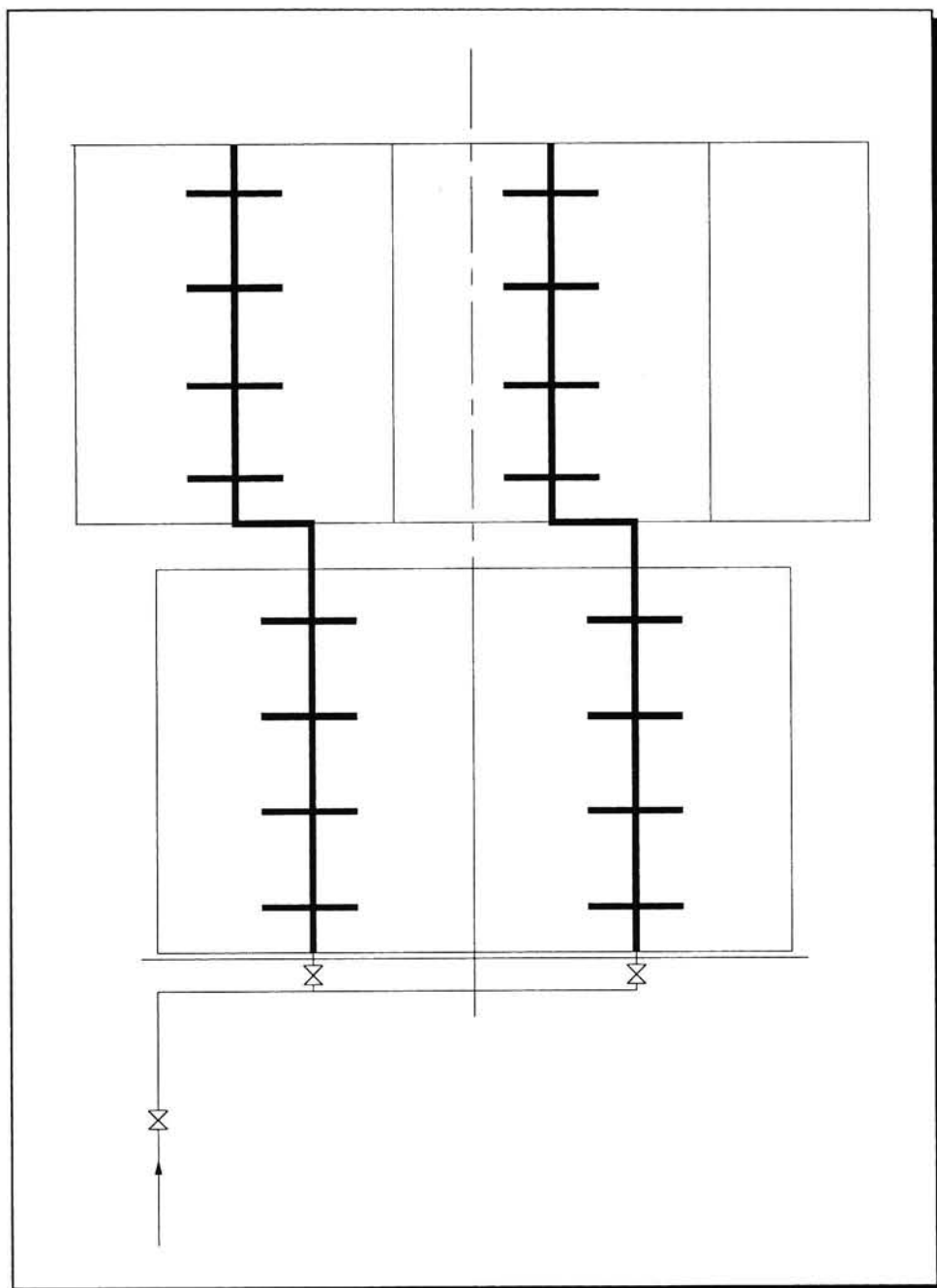


Figure 29: Sprinkler system

WEIGHT AND CENTER OF GRAVITY

Weight

The maximum total weight of the installation is 218 ton, which is divided in:

- * Six tankcontainers with a weight of 4,500 kg each and a contents of 25,000 kg maximum each ($\rho_{\text{average}} = 1.0 \text{ t/m}^3$);
- * The Seatreat slops treatment installation in two box containers, with a total weight of 17,000 kg;
- * One waste container with a weight of 1,500 kg and maximum contents of 10,000 kg;
- * Pipes and valves: 5,100 kg;
- * Deck support construction: 3,807 kg;
- * plates under the installation: 2,800 kg.

Center of gravity

The horizontal position of the center of gravity of the containers, measured from the after perpendicular, for each location is:

1. 32.3 m before the after perpendicular, when the slops treatment containers are placed after the stack and the waste container in the front row, extremely starboard.
2. 67.1 m before the after perpendicular.

The center of gravity of the extra steel is considered to be the same as the one of the containers.

The vertical position of the center of gravity of the containers is 13.2 m above the base. The center of gravity of the extra steel is estimated to be 2 meters above the main deck, which is 10.7 m above the base.

STABILITY AND TRIM

The stability of the ship with the installation is checked for the least stable situation of the original ship. This situation is:

- * Fully loaded, specific weight of the cargo $\rho = 0.70 \text{ t/m}^3$;
- * 50% stores;
- * Empty slops tanks.

The new vertical position of the center of gravity is 5.6 m above the base and the new metacenter height is 1.38 m. This means the ship is stable.

Often buffertanks are not completely filled. Then free liquid surfaces will reduce the stability. The reduction is only 5.8 mm and can therefore be neglected.

The trim of the ship, calculated for the maximum weight of the installation is 0.52 m backward for location 1 and 0.61 m forward for location 2. Forward trim can have negative effects on the straight line stability. Therefore, for trim location 1 is preferred.

ENERGY REQUIREMENTS

Because some products must be heated, the buffertank are equipped with a heating system. There are two possibilities to heat the system; electrical and steam or hot water. The cargo tanks of the ship are heated by hot water. It is assumed that 12 kW per container is required for heating a tank to 80°C. This means that the maximum energy consumption is 72 kW. The energy consumption of the treatment installation is 10 kWh/m³.

Electrical heating

The advantage of electrical heaters is its simple construction. There are hardly any pipes required. However, there are many disadvantages:

- * Electrical heaters are very sensitive to disturbances. Especially at sea the reliability is low. Water can penetrate the isolation and may burn the coils. If the heating would work continuously, its reliability would be bigger. However, this is not possible, for not all products can be heated. Also, because of the effect on the energy consumption, this option is not interesting.
- * Temperature changes are relatively big. Deviations up to 8°C may occur.
- * The price of second-hand tankcontainers with electrical heating equipment is almost twice as high as the price of containers with hot water heating equipment.

Hot water

There are little disadvantages of hot water heating. The advantages are:

- * Hot water heating is reliable and the heater does not have to work continuously;
- * The temperature is almost constant;
- * The containers are cheaper;
- * The heating can be connected to the cargo tank heating system or possibly to the cooling water system of the main engine.

Part III: Slop-treatment Onboard; The Seatreat System

Because of these advantages, the hot water heating system is chosen. The power for the heating system is supplied by a thermic boiler. A heat exchanger heats the water, which flows through shafts in the tank hull and bottom.

To heat the products in all cargo tanks (14 tanks) to a temperature of 70°C and in the slops tanks (2 tanks) to 45°C, a power of 72.5 kW is required. The extra cost for the treatment installation is NLG 0.027 per kWh, which is NLG 0.27 per m³.

CHAPTER 7: ECONOMIC EVALUATION

In this chapter an economic evaluation of the system is made. The profitability of the system is the most important aspect for the shipowner.

The amount of slops that has been delivered in port voluntarily, has not increased the last few years. The costs for the delivery of the slops are still the most important factor. Environmental protection still has little influence on the delivery behavior.

GEOGRAPHICAL LOCATIONS**Shore reception facilities**

Not every port has a shore reception facility. IMO listed the ports in the world with these facilities. This list is not complete for not all countries cooperate. Countries in Europe that cooperate are Germany, Italy and the Netherlands:

Germany:

	<u>Type</u>	<u>Category</u>
Bremen	Tanktruck	B, C
Bremerhafen	Tanktruck	B, C
Emden	Terminal	A, B, C
Hamburg	Terminal	A, B, C
Leer	Tank truck	A, B, C
Nordenham	Terminal	C

Italy:

	<u>Type</u>	<u>Category</u>
Catania	Terminal	A, B, C
Livorno	Tanktruck	B, C
Port Torres	Terminal	A, B, C
Sarroch	Terminal	B
Venezia	Terminal	A, B, C

The Netherlands:

	<u>Type</u>	<u>Category</u>
Amsterdam	Terminal	A, B, C
Rotterdam	Terminal	A, B, C
Vlissingen	Terminal	A, B, C
Delfzijl	Terminal	A, B, C
Dordrecht	Terminal	A, B, C
Moerdijk	Terminal	A, B, C
Terneuzen	Terminal	A, B, C

Part III: Slop-treatment Onboard; The Seatreat System

Other important ports with shore reception facilities are:

- * Antwerpen;
- * Huelva;
- * Barreiro (Lissabon).

In other ports it is not possible to deliver slops, unless by using a tank truck, which has to be arranged by an agent. This type of reception facilities is not reliable.

Figure 30 shows the ports with a shore reception facility in Western Europe. It shows that the number of ports with this facility is small. Due to the limited facilities it may be difficult to deliver slops. Therefore, the chemical tanker has to keep much wash water onboard.

Incineration installations

Information about ports with incineration facilities is scarce. The number of ports is very limited. The following overview gives some of the ports:

- * Rotterdam;
- * Le Havre, facilities in Rouen and Gronfreville;
- * Fos, facilities in Rognac (25 km of Fos/Lavère);
- * Genua.

Because the sludge in the containers is only delivered a few times a year (2 to 5 times), it is no problem that there are only a few incineration facilities.

Economic factors

For an economic evaluation of the slops treatment system (seatreat), the following aspects are important.

Potential benefits are:

- * No costs for delivering slops;
- * Decrease of the port time concerning:
 - Waiting times due to analyses;
 - Waiting times for slops ship/truck;
 - Unloading time;
 - Time required for filling in papers.
- * Extra cargo capacity.

The possible drawbacks are:

- * Investments for slops treatment installation

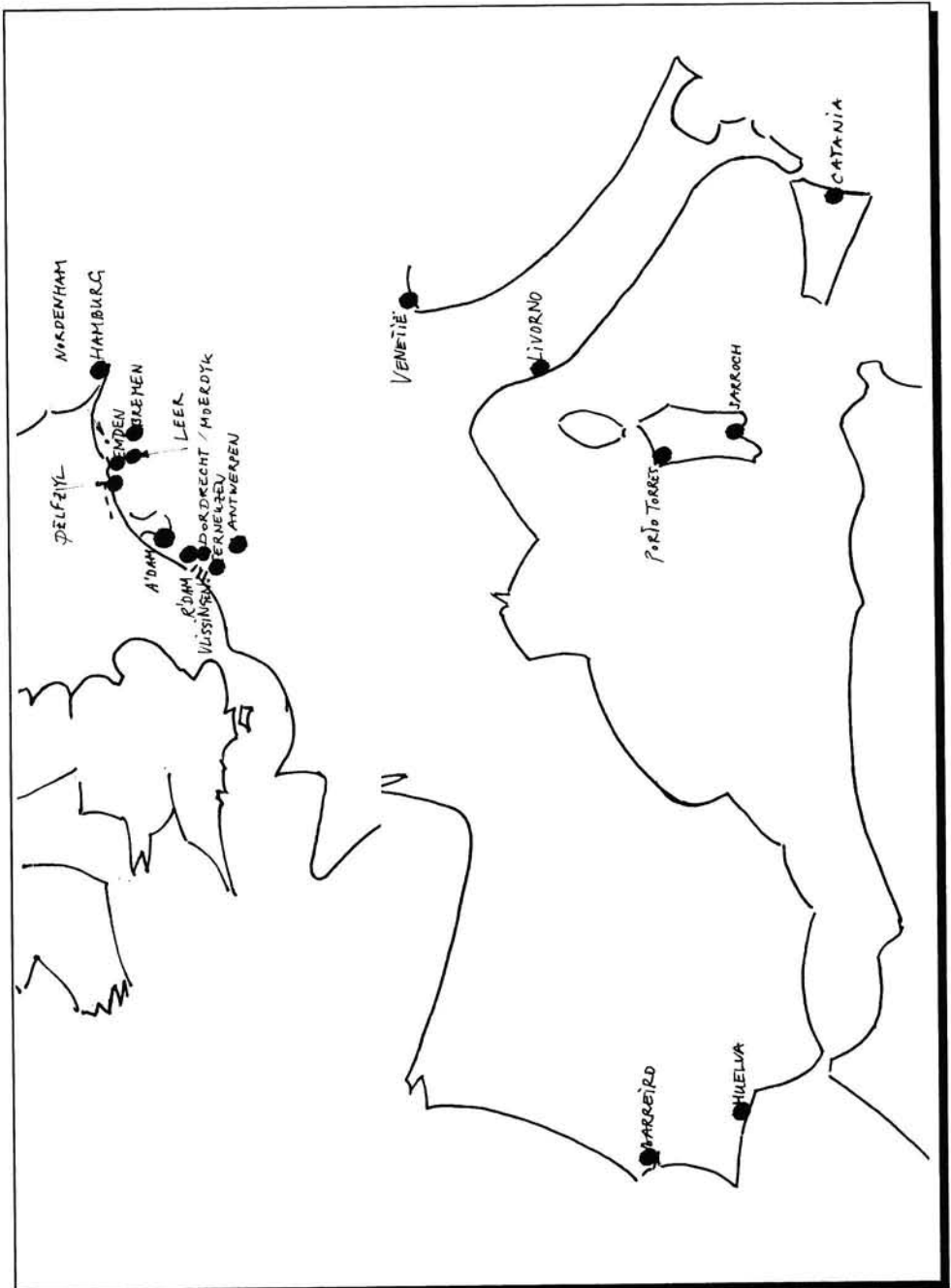


Figure 30: Ports with shore reception facilities

Part III: Slop-treatment Onboard; The Seatreat System

- * Operational costs, like:
 - Chemicals;
 - Energy;
 - Activated carbon;
 - Waste treatment;
 - Tank heating;
 - Container handling costs.
- * Investments for modifications of the ship;
- * Deadweight reduction due to the weight of the slops treatment installation.

SLOPS DELIVERY

95% of all delivered slops (in Rotterdam) are collected by a slops ship. Only for complicated washes, or if a tanker is not able to wash its own tanks, the ship will moor at the quay at the shore reception facilities. In other countries slops often are collected by tanktrucks.

It appears that in reality sailing times, for sailing to the reception facilities, hardly ever occur. Dock dues, costs for the shore crew and moving costs are not relevant. These costs are comprised in the costs for the slops ship/truck, and the slops tariffs. On the other hand, waiting times for analyses, waiting times for the slops ship and the time required for unloading of slops, are important.

If the amount of slops is very large, it can be profitable to let the ship deliver the slops at the reception facility itself. This depends on the amount of slops and the size of the ship. Slops ships have a maximum capacity of up to 3000 ton. If the amount is bigger than the capacity of the slop ship, it is economically interesting to moor the ship at the slops reception facilities.

furthermore, large slops amounts have to be transported in chartered ships. These ships should be returned clean, which means there will be extra slops for which the shipowner has to pay.

Table XVII gives an overview of the basic prices for delivering slops, in relation to the chemical oxygen demand. The given prices are indicative. For specific products other prices may apply. For example, phenol slops cost NLG 705/ m³.

An overview of slops prices for the A-products, transported by the shipowner, is given in **Table XVIII**. Prices of NLG 50 per m³ are based on a maximum chemical oxygen consumption of 3000 mg/l. Above this value a surcharge of NLG 4 per 1000 ppm has to be paid.

Part III: Slop-treatment Onboard; The Seatreat System

Chemical oxygen demand per ppm:

to	400	NLG	4.00	per m ³
	500		7.50	
	600		8.50	
	700		9.50	
	800		11.00	
	900		12.50	
	1000		14.00	
	2000		32.00	
	3000		48.00	
over	3000		48,00	+ NLG 4.50 extra per 1000 ppm cod

These prices include analysis costs. (1)

Costs for slops ship:	NLG 250 per hour, in overtime 25% extra
Analysis costs:	NLG 350 zie (1)
Costs for customs documents:	NLG 225

Table XVII: Prices for delivering slops in Rotterdam

Product	Tariff (NLG/ m ³)
Acetone cyano hydride	700
Di butyl phtalate	50
Di is butyl phtalate	50
Ethyl acrylate	700
Butyl benzyl phtalate	50
Di iso propyl benzene	50
α -methol styrene	50
Nonyl pheno (synperonic	50 - 700
Chlorotoluene	700
Decyl acrylate	700

Table XVIII: Slops costs of A-products

The average maximum concentration in the prewash water is 16,000 mg/l. With **Table XVII**, the average general slops tariff is NLG 107. With **Table XVIII**, the average tariff of the NLG 50 products, is $50 + (16,000 - 3,000) * 4 = \text{NLG } 102$. The average tariffs for A-products are NLG 375.

In the future, the average slops tariffs decrease as the amount of less dangerous substances will increase. These substances are part of the group with an average tariff of NLG 104. The low prices of the extra slops decrease the average.

Part III: Slop-treatment Onboard; The Seatreat System

The costs calculation of the slops treatment installation is based on decreasing tariffs as a function of the delivered amount of slops. Till a slops volume of 1110 m³, the shape of the function is based on a linear decreasing function, then the slops tariff is assumed to be constant at NLG 104. This results in the following equations:

$$Tariff_{avg} = 0.252x + 389 \text{ for } 0 \leq x \leq 1110$$

and:

$$tariff_{avg} = 104 \text{ for } x > 1110$$

A graphical representation of this function is shown in Figure 31.

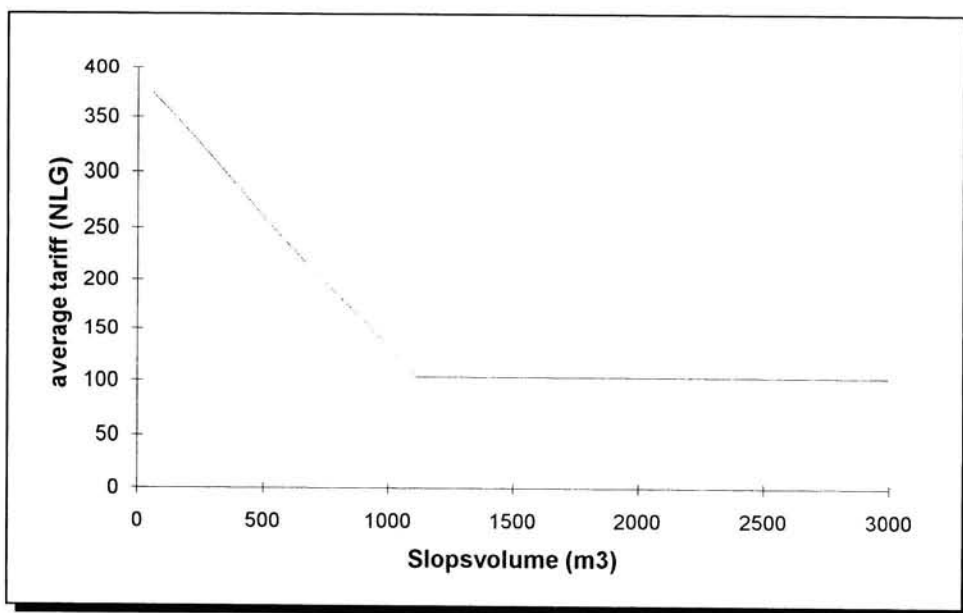


Figure 31: Course of the slops costs function

ROUNDTrips

To check for the capacity of the installation, it is necessary to consider the travel times of the ship. In principle, it must be possible to treat the slops between every unloading port and the next port. If it appears that this often is not possible, then the capacity of the installation should increase.

Part III: Slop-treatment Onboard; The Seatreat System

An analysis of the trips in the period 1/92 to 6/93 (1.5 years) results in the values given in **Table XIX**. This leads to the following figures (hours):

Average travel time:	767.4	hours
Average port time:	271.8	hours
Average sailing time:	495.7	hours
Average port time per port:	2.8	hours
Average number of ports per trip:	11.4	hours
Number of port calls per year:	122	
Average number of trips per year:	10.7	
Average sea time per year:	5283	hours
Average port time per year:	2897	hours
Total time in service	8181	hours
Assumed number of service days:	340	days
Port time ratio (%)	35	%

Roundtrip	T _{sailing} (hours)	T _{port} (hours)	T _{total} (hours)	Number of ports	T _{port avg.} (hours)
1.	397.49	265.41	662.90	11	24.13
2.	497.91	297.08	794.99	10	29.71
3.	447.85	162.26	610.11	7	23.18
4.	616.85	231.93	848.78	11	21.08
5.	360.76	127.56	488.34	8	15.95
6.	484.98	431.50	916.48	19	22.71
7.	374.37	214.08	588.45	11	19.46
8.	600.67	343.75	944.42	16	21.48
9.	530.15	252.17	782.32	13	19.40
10.	418.01	266.82	684.83	10	26.68
11.	515.56	250.26	765.82	10	25.03
12.	546.31	224.58	770.89	12	18.72
13.	440.36	363.25	803.61	12	30.27
14.	582.65	398.92	981.57	12	33.24
15.	585.69	282.92	868.61	8	35.37
16.	530.75	235.91	766.66	13	18.15
	7,930.36	4,348.42	12,278.78	183	384.56

Table XIX: Trip overviews

Table XIX gives an average port time per port of 23.76 hours. **Table XX** shows the port times for the most important ports. Selection criterion for the ports in this table, is that the ship visited this port at least 4 times during 1.5 years.

Port	Country	Loading/ unloading	Port time (hours)	Calls	Total (hours)
Antwerpen	B	unloading	30.69	19	583.11
Livorno	I	unloading	15.05	14	210.70
Salt end	UK	loading	33.32	13	433.16
Terneuzen	NL	loading	27.91	13	362.83
Tarragona	E	unloading	22.16	12	265.92
Stade	D	loading	15.03	11	165.33
Genua	I	unloading	19.60	10	196.00
Huelva	E	loading	18.74	10	187.40
Fos	F	loading	31.03	9	279.27
Tees	UK	both	31.77	9	285.93
Rotterdam	NL	both	22.40	8	179.20
Oristano	I	unloading	13.57	6	81.42
Lavéra	F	loading	17.80	5	89.00
Swansea	UK	loading	16.80	5	84.00
Barreiro	P	unloading	14.39	4	57.56
Immingham	UK	unloading	26.85	4	107.40
				152	3568.23

Table XX: Port times

This table gives an average port time of 23.50 hours per port. This means that the average port time of the most important ports is equal to the average port time of all ports.

AVERAGE SAILING TIME BETWEEN TWO PORTS

The average time at sea between two port calls is 38.16 hours. The time between unloading and the next (un)loading is 61.92 hours. This means there are 62 hours available to treat the slops. With a capacity of 5 m³/h, this results in a maximum volume of 310 m³. The average slops amount is 35 m³, which takes only 7 hours to be treated. Therefore, the capacity does not have to be adjusted. Figure 32 shows a standard trip on the map of Europe.

UTILIZATION LEVEL

For an estimate of possible loss of income, due to the utilization of cargo capacity by slops, it is necessary to know the average utilization level of the ship. Table XXI gives the utilization level of some ships. These figures are based on the third quarter of 1992.

The column "payload" gives the "loaded sailing time" * "transported weight" per trip. The column "cap. factor" gives the multiplication of the "loaded sailing

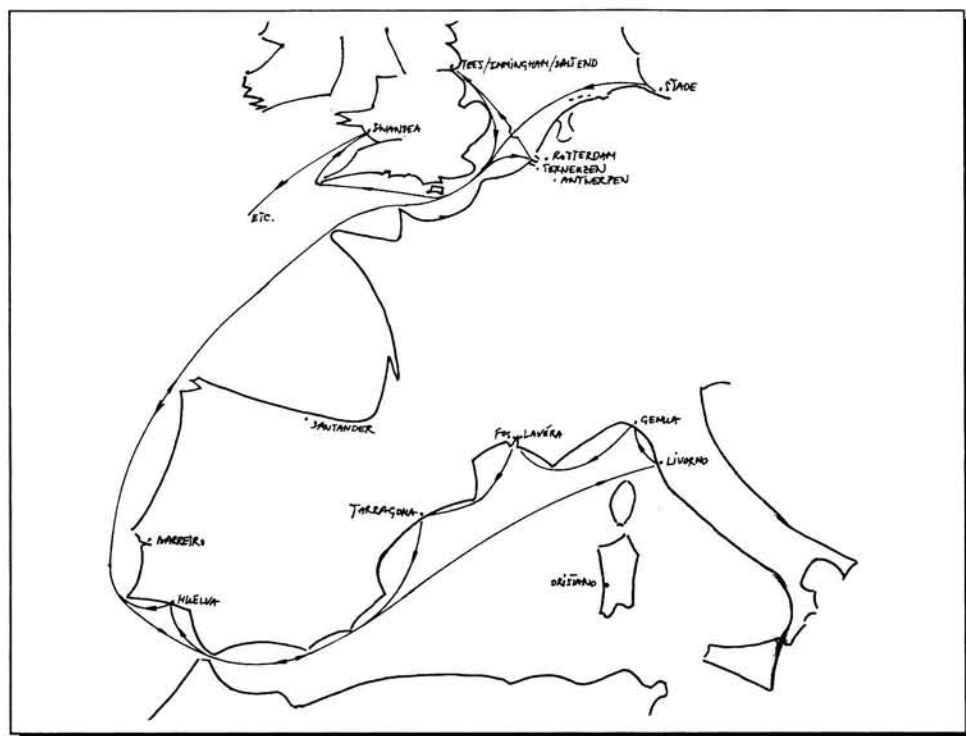


Figure 32: Standard roundtrip

Nr.	Sailing time (hr)	Loading (hr)	Ballasting (hr)	Payload (ton.hr)	Dead-weight (ton)	Cap. factor (ton.hr)	Perc. (%)
1.	764	595	169	1183076	2350	1398250	84.61
2.	852	573	279	1181603	2500	1432500	82.49
3.	850	676	174	1242779	2500	1690000	73.54
4.	1320	1123	197	3264943	4000	4492000	72.68
	3786		819	6872401	11350	9102750	76.25

Table XXI: Average utilization level

time" * "deadweight". Finally, the utilization level (last column) is calculated by dividing the "payload" by the "cap. factor".

Table XXII gives the utilization levels over 1991 and three quarters of 1992. The average utilization level of all quarters is 76.50 %

Year	Quarter	Utilization level
1991	1	78.33
1991	2	81.53
1991	3	72.64
1991	4	74.19
1992	1	74.36
1992	2	78.19
1992	3	76.25

Table XXII: Utilization level

FREIGHT RATES AND DAILY REVENUES

It is impossible to give an average freight rate for the transport of a specific product. This rate depends on the route, possible return cargo and the world economy. Therefore, is it not possible to find average freight rates for the products that are most important for the calculation of the loss of income due to the loss of deadweight.

INVESTMENTS AND COSTS

Slops treatment installation

The costs for the slops treatment installation are calculated as follows:

Assumptions

Interest:	9%		
Economical life time:	10 years	(so two units for the life time of a ship)	
Maintenance:	4%	of the investments	
Number of washed tanks:	375	per year	
Treated slops amount:	3000 m ³	per year	
Investments installation:	NLG	600,000	
Energy consumption:	NLG	0.15 /kWh	(10 kWh/m ^w slops)
Iron chloride consumption:	NLG	50 /100 kg	(2 kg/m ³)
Lime consumption:	NLG	395 /ton	(1.2 kg/m ³)
Activated carbon consumption:	NLG	4,500 /ton	(1 kg/m ³)
Solid waste disposal:	NLG	600 /ton	(30 kg/m ³)

Part III: Slop treatment Onboard; The Seatreat System

Indirect costs

Depreciation:	NLG	60,000
Interest:	NLG	24,000
Maintenance:	NLG	<u>27,000</u>
	NLG	111,000

Direct costs, based on 3000 m³ slops

Electricity:	NLG	4,500
Iron chloride:	NLG	3,000
Lime:	NLG	1,422
Activated carbon:	NLG	13,500
Waste treatment:	NLG	<u>54,000</u>
	NLG	76,422

Total costs per year:	NLG	<u>187,422</u>
-----------------------	-----	----------------

Ship modifications

Some modifications of the ship are required before the installation can work. These modifications are:

- * Purchase of second-hand tank container;
Tank containers, with a capacity of 25 m³ and heating capacity of 80°C, cost between NLG 10,000 and NLG 15,000.
- * Pipe systems;
Three pipe systems have to be expanded or added:
 - Supply system for wash water,
The pipe length is 145 m. Material and assembly costs of stainless steel pipes is approximately NLG 300 per m;
 - The containers are connected to the present tank heating system. Everything together costs NLG 8,000;
 - The price of the fire extinguishing installation is approximately NLG 12,000.
- * Valves;
For the wash water supply system the following valves are required:

- 3 + 1 per supply pipe	24
- 1 + 6 for the main pipe	7
- 1 for every cross over	6
- 1 after every buffer tank	<u>6</u>
	43

Valves with a diameter of 75 mm cost NLG 1,500 each;

Part III: Slop-treatment Onboard; The Seatreat System

- * Pump;
The installation is supplied by a stainless steel pump, with a capacity of 5 to 10 m³/h. The price is NLG 15,000.

- * Container deck;
The price of the container deck including labour hours, is estimated according to the experience of the shipowner and shipyard. It depends on whether an extra strengthening of the deck is required. The costs estimate is based on a frame construction:
 - NLG 10,000 without extra strengthening
 - NLG 25,000 with extra strengthening

- * Ventilation bend;
The costs for moving the bend in the tank ventilation pipe are approximately NLG 1,000.

- * Electrical installation;
The installation must be controlled from the cargo control room. Furthermore, an on line monitoring system is required. The costs are:
 - Level measuring system: NLG 5,000 per container;
 - Temperature measuring system: NLG 800 per container.

- * Hoses;
Hoses of 75 mm wide and 5 m long, required from the manifold, cost NLG 1,500 each.

Overview

6 tank containers, NLG 12,500:	NLG	75,000
145 m water pipes, NLG 300 per meter:	NLG	43,500
Hot water pipes:	NLG	8,000
Extinguishing system:	NLG	12,000
43 valves, NLG 1,500 each:	NLG	64,500
Pump:	NLG	15,000
Container deck:	NLG	17,500
Modification of ventilation pipe:	NLG	1,000
Electric installation, NLG 5,800 per container:	NLG	34,800
6 hoses, NLG 1,500 each:	NLG	<u>9,000</u>
Total investment for the modifications:	NLG	280,300

Interest:	9%
Economical life time:	10 years
Maintenance:	2% of the investments

Indirect modification costs

Part III: Slop-treatment Onboard; The Seatreat System

Depreciation:	NLG	28,030
Interest:	NLG	12,614
Maintenance:	NLG	<u>5,606</u>
Total costs per year:	NLG	46,250

Tank heating

Assumptions

Extra consumption of the boiler:	194 kg/24 hours
Fuel price IFO:	NLG 127,80 per ton
Capacity slops treatment installation:	5 m ³ /h
Average slops amount per wash:	35 m ³
Average tank heating time:	7 hours

	<u>1991</u>	<u>1992</u>
Number of washes:	53	75
Number of washed tanks:	308	401
Average number of tanks per washes:	5.8	5.3
Number of hot washes:	93	189
Percentage of hot washes(%):	30.1	47.3

The average percentage of hot washes is 38.75%. Combined with one wash per unloading port, the number of hot washes per year is 25. If it is assumed that when products are washed hot, the buffer tanks have to be heated, the tank heating system of the buffer tanks is used 25 times a year.

With the capacity of the slops treatment installation, the average slops production per tank and the average number of tanks per wash, the average service time of the treatment installation is 7 hours per hot wash.

The minimum costs per year, due to the heating of the buffertanks can be represented with the following function:

$$\frac{y}{3000} * \frac{a * b * (7+x)}{c} = \frac{y}{3000} * \frac{25 * 24.8 * (7+x)}{24}$$

with:

- y = Amount of slops to be treated
- a = Number of hot washes
- b = Fuel price
- c = Number of hours in one day
- x = Number of hours over 7 hours that the slops are in the tanks

With x = 0 and y = 3000, the cost for tank heating is NLG 180.83 per years. These costs are neglectable, compared with the other costs.

Part III: Slop treatment Onboard; The Seatreat System

Loss of deadweight

The maximum weight of the installation is 218 tons. This means that in principle the ship can carry 218 tons less cargo, than without the installation. However, because generally the buffertanks are not completely filled, the real deadweight loss is less. The following overview gives a summary of the weights:

Fixed weight

6 tank containers, 4.5 ton each:	27,000 kg
Slops treatment containers:	20,000 kg
Waste container:	1,500 kg
Pipes:	5,075 kg
Deck construction:	3,807 kg
Plates:	<u>2,800 kg</u>
Total weight	60,182 kg

The fixed income loss due to a reduction of cargo capacity of 61 tons is:

$$W_{fixed} * o * p * d = 61 * 0.77 * 5.12 * 340 = f81,765.00 \text{ per year}$$

with:

- W = Weight
- o = Utilization level
- p = Rate per ton per day
- d = Number of days in service

Variable weight

Besides the fixed weight extra weight must be added, to represent the variable weight of the slops in the tank containers and the waste.

The total slops amount is assumed to be 3000 m³ per year. In 1991 the number of washes was 53. The number of port calls was 122. This means that in 43.4 percent the tanks were washed after unloading. In 1992, this percentage was 61.7. The average is 52.5%.

On this basis, the time the wash water is onboard, cleaned or not cleaned, is calculated. Based on washing after 52.5 % of the port calls, and a washing time of 7 hours, the wash water is onboard 448.4 hours or 18.7 days. The loss of income based on an average slops production of 35 m³ is:

$$35 \times 0.77 \times 18.7 \times 5.12 = f2,580,00$$

This result is valid for the treatment of all slops. If in reality the amounts are less, then the costs are also less.

The solid waste container should be emptied when there is 10 tons of waste in it. Therefore, the average amount of sludge in this container is 5 tons. The loss of income is:

$$5 \times 0.77 \times 340 \times 5.12 = f6,702.00$$

Total costs per year

Summarizing, the total costs per year are:

* Indirect costs	NLG	239,015
* Direct costs:	NLG	<u>85,884</u>
Total costs:	NLG	324,899

These costs are based on a slops amount of 3000 m³, which means that all slops are treated by the installation. It is not probable that this will really happen.

BENEFITS

The advantages of a slops treatment installation are:

- * Smaller amount of slops that should be delivered in port;
- * Shorter port times:
 - No waiting times due to analyses of slops or for the slops ship;
 - No loading time of the slops ship.
- * Extra cargo space, because slops do not have to be stored until they can be discharged outside vulnerable areas or delivered in port;
- * Greater flexibility in accepting cargo.

Slops amount reduction

The primary advantage of the slops treatment installation is the independency of shore reception facilities. The slops treatment idea originated because of the lack of slops reception infrastructure and the tariffs. It regularly happens that the profit of one trip disappears because of the costs for delivery and treatment of the classified slops. This is a situation that shipowners do not want. Although the costs of the slops are generally payed by the shipper, it is assumed that costs saved by the onboard treatment will be payed back by higher freight rates.

Part III: Slop treatment Onboard; The Seatreat System

If a slops treatment installation is used, the ship does not deliver any wash water in port anymore. Only a small amount of waste must be incinerated.

Port time reduction

Because a ship with a slops treatment installation almost never delivers any slops in port, port times will reduce. Under the present regulations the reduction of the port times is small. However, when regulations become more strict and more slops must be delivered, port times will increase, and the advantages will increase.

Because of lack of information about the time the ship spends in port, waiting for analyses, waiting for the slops ship and the unloading of the slops, calculations are made with a range of port time reductions. The number of ports in which the port time decreases, is estimated by dividing the amount of slops to be treated by the total slops amount of a year (3000 m³) multiplied by the number of calls per year. The port time reduction is calculated according to the following formula:

$$R_{\Delta T_{port}} = \left(\left(\frac{x}{3000} \right) * 122 \right) * \frac{y}{24} * z$$

with:

- x = Amount of slops to be delivered in port
- y = Port time reduction (hours)
- z = Daily time charter revenues of the ship

Estimate of the port time reduction:

- * Waiting time for the analyses results ± 2 hours
- * Waiting time for slops ship or tank truck ± 1 hour
- * Unloading prewash ± 0.5 hours

Extra cargo capacity

Because of the buffer tanks on the deck of the ship, the slops and cargo tanks are not necessary anymore for storage of slops. To calculate the advantages, the following data are required:

- * How often and how long is cargo capacity used for slops?
- * Up to what percentage can the space be used?
- * What are the daily revenues of the ship?

The slops tanks of the ship are equipped as normal cargo tanks. The tanks are called slops tanks, but in reality they can be considered as cargo tanks. The cargo report book gives information about the utilization of the tanks by waste

Part III: Slop-treatment Onboard; The Seatreat System

water. Combined with the average utilization level and the daily proceeds, the extra income per year can be calculated.

Year 1991

In 1991 there were 53 washes, of which 38 times the water was directly discharged and 15 times via a tank. The following tanks were used for the storage of slops:

Tank	Number of days used	Volume (m ³)	Multiplication
SSL	7.5	104.6	780.0
PSL	0.5	104.6	52.3
CS1	2.0	199.0	398.0
CP2	1.0	318.0	318.0
CS3	3.5	397.7	1,392.0
CP3	1.0	399.2	399.2
CS5	2.5	415.9	1,039.8
CP6	1.5	416.9	623.9
CS6	1.5	414.3	621.5
CS7	0.5	389.5	194.8
	21.5		5819.3

The utilization level is 98.5%, so in 1991 the amount*day which was occupied by the slops is 5732.0 m³.day. Combined with an average density of the cargo of 0.937 t/m³ and an utilization level of 77%, the slops utilization was 4135.6 ton day.

With an average ton price of NLG 5.12 per ton per day, the loss of income is NLG 21,174 per year.

Year 1992

In 1992 there were 75 washes, of which 52 times the water was discharged directly and 23 times via a tank. The following tanks were used for the storage of slops:

Part III: Slop-treatment Onboard; The Seatreat System

Tank	Number of days used	Volume (m ³)	Multiplication
SSL	9.0	104.6	941.4
PSL	19.0	104.6	1987.4
CS1	8.0	199.0	1592.0
CP2	1.0	316.4	316.4
CS3	3.0	197.7	1193.1
CP3	4.0	399.2	1596.8
CS4	1.0	414.3	414.3
CS6	11.0	415.9	4574.9
CS7	6.5	387.9	2521.4
	62.5		15137.7

The utilization level is 98.5%, so in 1992 the amount*day that was occupied by the slops is 14910.6 m³.day. Combined with an average cargo density of 0.937 t/m³ and an utilization level of 77% the slops utilization was 10757.8 ton.day.

With an average ton price of NLG 5.12 per ton per day, the loss of income is NLG 55,080 per year.

The conclusion is that with the slops treatment installation the ship can earn an extra NLG 40,000 because of the extra cargo capacity.

Flexibility

If the shipowner can offer a fixed (low) tariff to the shipper for the slops treatment, he may also be prepared to transport other goods, for which in the past the slops costs were high. It is very difficult to quantify this factor.

CALCULATIONS AND CONCLUSIONS

The results of the previous paragraphs are combined in a spreadsheet. By varying several parameters, it is possible to find the yearly costs for the treatment system, for several expected situations.

The most important factors that are varied, are the slops volume and the expected port time reduction.

Table XXIII gives an overview of the slops costs per cubic meter in relation to the slops amount per year and the port time reduction. **Figure 33** gives a graphical representation of these data.

Figure 34 shows, for a port time reduction of four hours, the costs and profits in relation to the treated amount of slops. This figure clearly shows that the break-even point of the installation for this port time reduction, is approximately 600 m³.

Reduction	100 m ³	200 m ³	300 m ³	400 m ³	600 m ³	800 m ³	1000 m ³	1200 m ³
3 hours	1665	640	314	165	40	3	0	-2
4 hours	1632	607	282	132	7	-30	-32	-34
5 hours	1599	574	249	99	-26	-63	-65	-67
6 hours	1567	541	216	66	058	-96	-98	-100

Table XXIII: Slops costs per year (NLG)

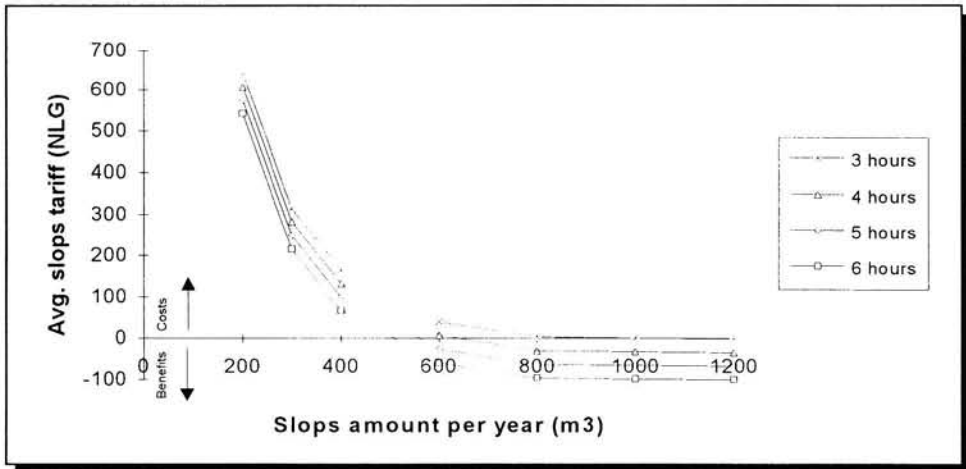


Figure 33: Slops tariffs reduction in relation to port time reduction

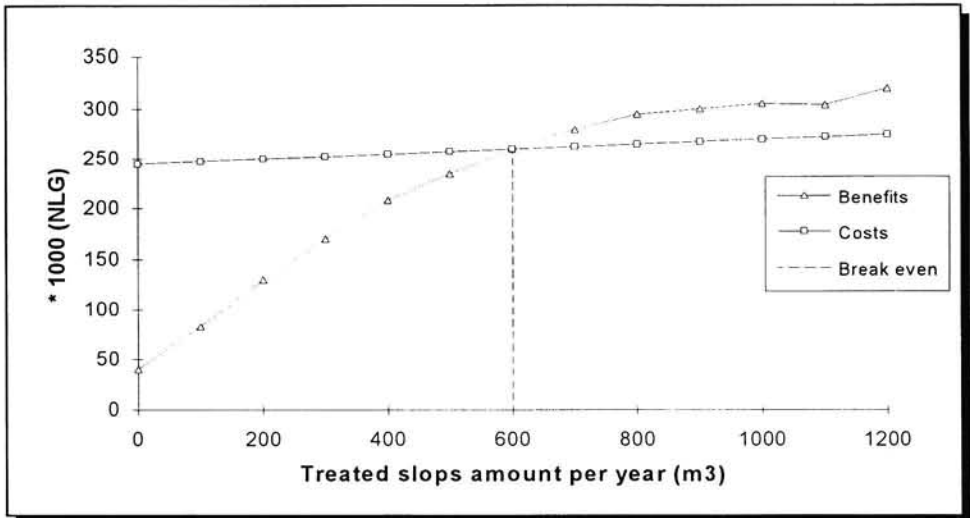


Figure 34: Costs versus profits, 4 hours port time reduction

EVALUATION AND RECOMMENDATIONS

Besides economic advantages, the system also contributes to a cleaner marine environment. The ideal environmental situation is given by Figure 35. All of the waste water is treated by the installation, so nothing is discharged at sea anymore. In reality this is not possible.

The shipowner/captain has to face several options when slops are produced. These options are shown in Figure 36.

As shown in Figure 19, the cleaned waste water flow is measured and sampled. All cleaned water has to be measured and sampled to find the ppm level. These values are registered by a computer. The crew does not have the possibility to change the values.

Because there is a relation between the amount of discharged water and the amount of remaining waste, it can be checked whether the waste water is treated well.

It is not necessary to keep the sludge of the different slops separated. The total amount of waste has to correspond with the amount of water that was discharged.

The relations between the amount of cleaned water and the waste, varies per product and per ship. The check is carried out according to the following principles:

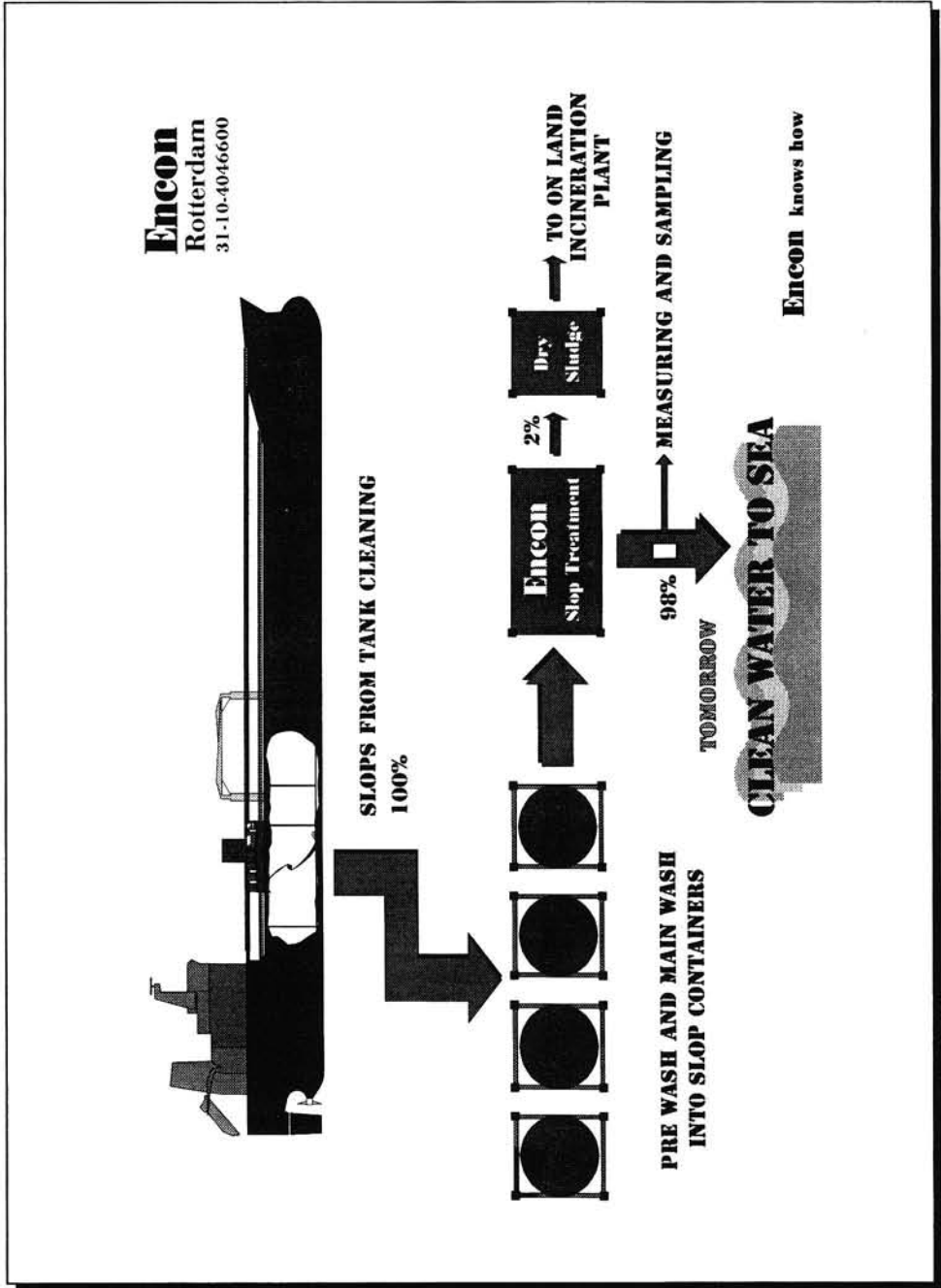


Figure 35: Ideal environmental solution

Part III: Slop-treatment Onboard; The Seatreat System

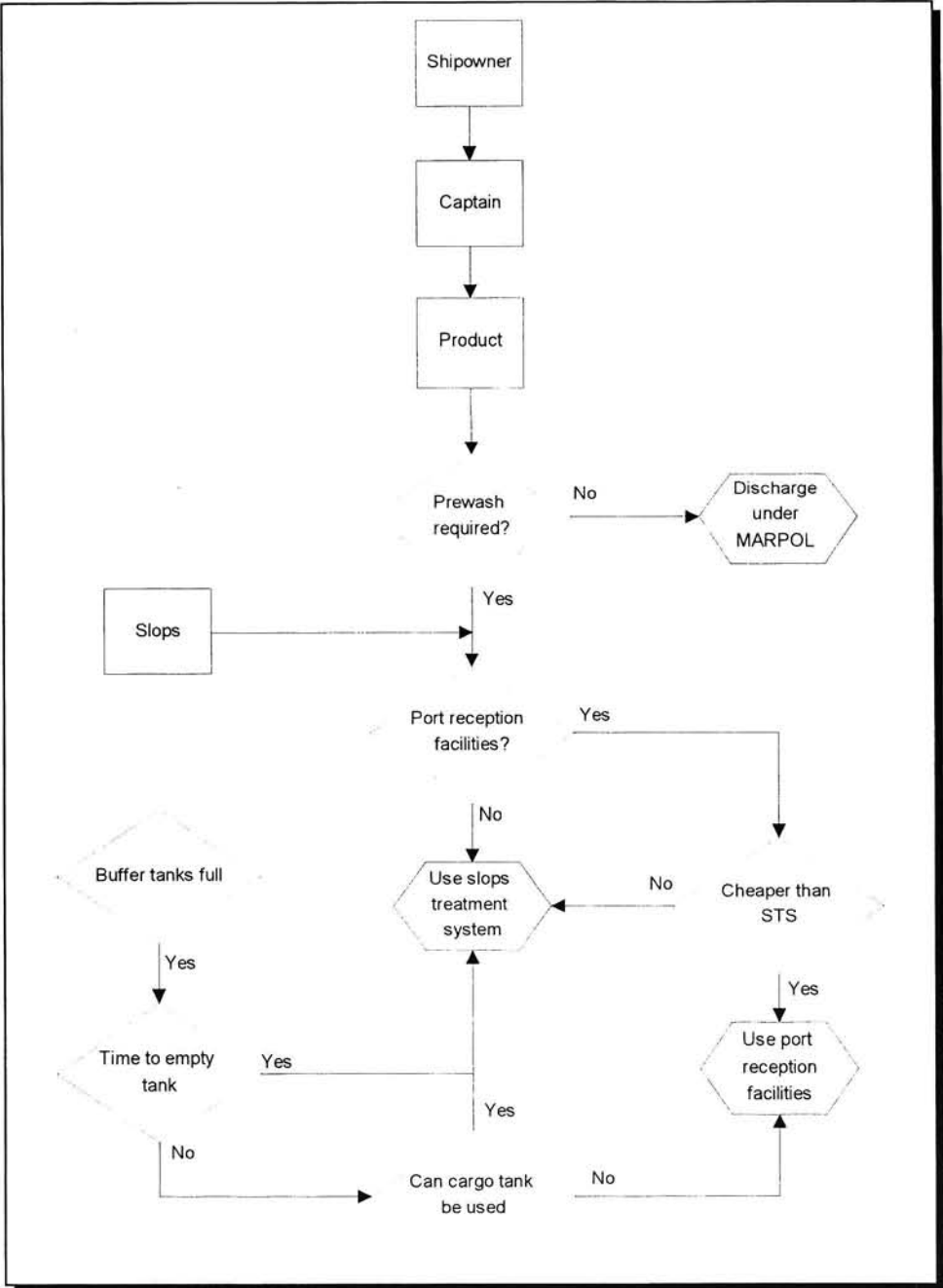


Figure 36: Option flow diagram

Part III: Slop-treatment Onboard; The Seatreat System

- * Counter on zero;
- * Treatment of the prewash;
- * Computer registers the amount of discharged water;
- * A prescribed relation determines the amount of sludge that has to be present on the ship.

The check can be carried out when the container with sludge is unloaded for further treatment.

The only way to get around the law is discharging the prewash directly into the sea, without treatment. However, it is possible to estimate the amount of sludge onboard. It has to correspond with the transported cargo, which is noted in the cargo record book. The system is well-secured but it can always be tempered with.

Recommendations

When the shipowner decides to use the slops treatment installation, he should pay attention to the following aspects:

- * The monitoring system for recording the amount of delivered prewash, which will be obligatory in the near future;
- * Calculation of the break-even points for other ships. Meanwhile a lobby for the potential acceptance of the Seatreat system should start at IMO's MEPC;
- * When the amount of delivered slops approaches the break-even point, the slops treatment installations can be placed onboard the ships;
- * In the test period the operational costs of the system can be compared with the other ships without slops treatment installation;
- * If after the test period the treatment system appears cheaper than the conventional delivery method, slops treatment installations can be placed on all ships.

As a sequence of this study the following aspects can be examined:

- * Analysis of the port times; in this study calculations are made based on port time reductions. These calculations were based on limited information. Better information about the reduction of port times should provide a better foundation for the economic calculations;
- * Study of the increase of flexibility of cargo types, for a ship with a slops treatment system;
- * Further design of technical details.

PART IV - SEA-RIVER CHEMICALTANKER

Table of Contents

CHAPTER 1:	SEA-RIVER LANES INFRASTRUCTURE	290
CHAPTER 2:	SEA-RIVER SHIPS	295
CHAPTER 3:	INTRA-EUROPEAN CHEMICAL TRADES	301
CHAPTER 4:	TRANSPORT ALTERNATIVES	303
CHAPTER 5:	SEA-RIVER CHEMICALTANKER	306
CHAPTER 6:	EVALUATION OF TRANSPORT COSTS	311
CHAPTER 7:	HOW TO IMPROVE THE COMPETITIVENESS?	315
CHAPTER 8:	INNOVATION: THE CYLINDERTANKTYPE CHEMICAL- TANKER	317

PART IV - SEA-RIVER CHEMICALTANKER

Within Europe, a large volume of specialty chemicals is distributed by tanktrucks, tankcontainers and to a lesser extent, by railtankcars. These relatively small parcels, varying in size from 25 - 150 tons, are not really suitable for the seaborne chemicaltanker trades. The major reason being that the tankcapacities of a chemicaltanker are often too large, while the sea-going vessels cannot directly load or discharge at the factory's premises because of their inland location.

A way to eliminate both constraints is the development of a sea-river chemicaltanker, with many small, independent tanks. The cylindertanktype is chosen for its ease of construction and its ease of cleaning.

The example in this **Part IV** is based on a study by MERC, Rotterdam, in which ir. R. Heijliger participated as part of his masterthesis project. The case-study which describes the potential of a sea-river chemicaltanker on the route Rhine - United Kingdom, is preceded by some chapters on the sea-river ships development and its potential in Europe, and concluded with some remarks on the cylindertanktype chemicaltanker.

CHAPTER 1: SEA-RIVER LANES INFRASTRUCTURE

The maritime equivalent of a road or rail, is the sealane. A part of the European sealanes are formed by the seas that surround the countries; another part is formed by the connecting navigable rivers and canals. Seagoing vessels are in general not designed for the navigation on rivers, because of air (bridges) and water draught restrictions. The old small coastal ships of 500 gross tons were able to navigate the sea as well as on most of the rivers. However, the dis-economy of scale eroded their competitive advantage overtime. For this reason a new class of sea-river vessels was developed around 1970, characterized by a larger carrying capacity (deadweight-dwt) and a very shallow water and air draught.

These vessels are able to transport cargo via the sealanes into the river/canals system, without additional transshipment, which reduces costs substantially and improves the competitive position vis-à-vis other modes, such as road and rail. The development of this ship type is briefly discussed in the next paragraph.

Figure 1 shows the sea-river lanes infrastructure in Europe.

Within Western Europe, the major sea-river routes are related to the River Rhine system; in Eastern Europe, the Russian riversystem, connecting the Baltic, via the Volga to the Black Sea and Caspian Sea is an even more important domain of sea-river ships and a potential new corridor between the Baltic Sea and the Mediterranean.

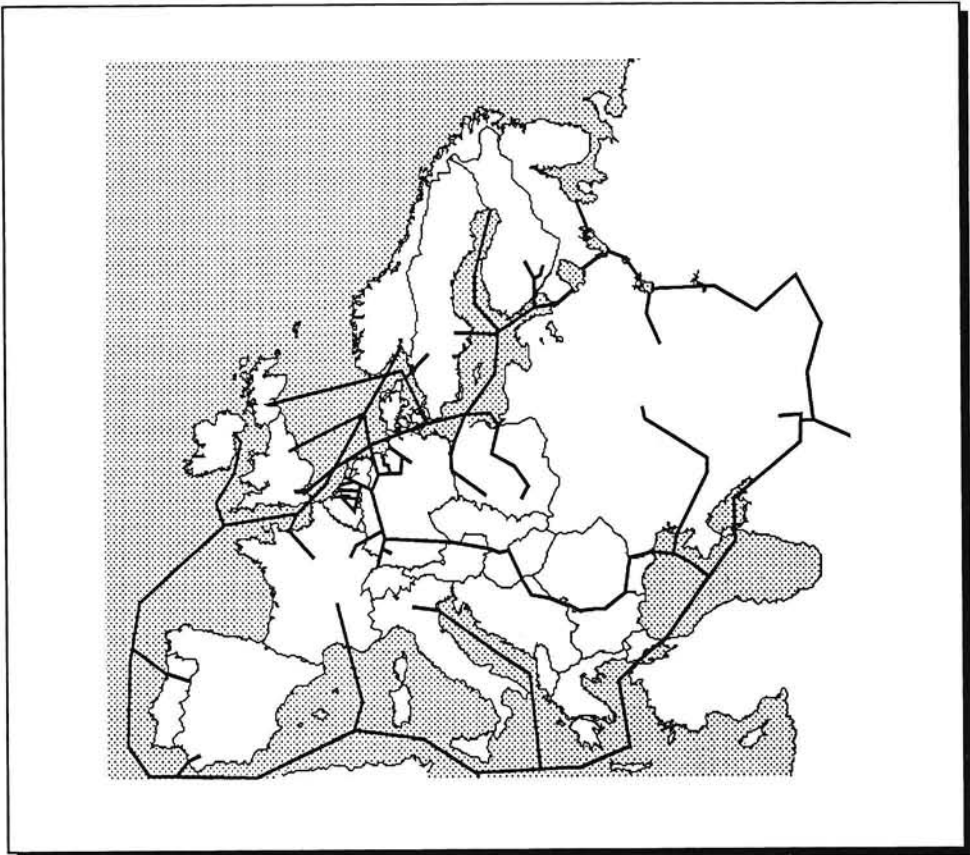


Figure 1: Sealane infrastructure

The recent changes in Eastern Europe have led to an overwhelming influx of these Russian vessels into the West-European trades; desperately trying to earn precious foreign exchange at any cost, thereby disrupting the already delicate balance in the freight market.

The limits posed on the design of sea-river-vessels in Western Europe are determined by the limitations of the major rivers and canals, such as the river Seine (air draught 8.7m), the Albert Canal in Belgium (air draught 6.4m, waterdraught 3.40m), the rives Rhine and Elbe, etc.

For this case-study the River Rhine navigational limitations are discussed, as they form the performance indicators of the vessel design.

Figure 2 shows the Rhine and the connecting rivers. The distance from Basel to Rotterdam is approximately 1.000 km. Table I shows the classification of canals and rivers in Europe by main dimensions.

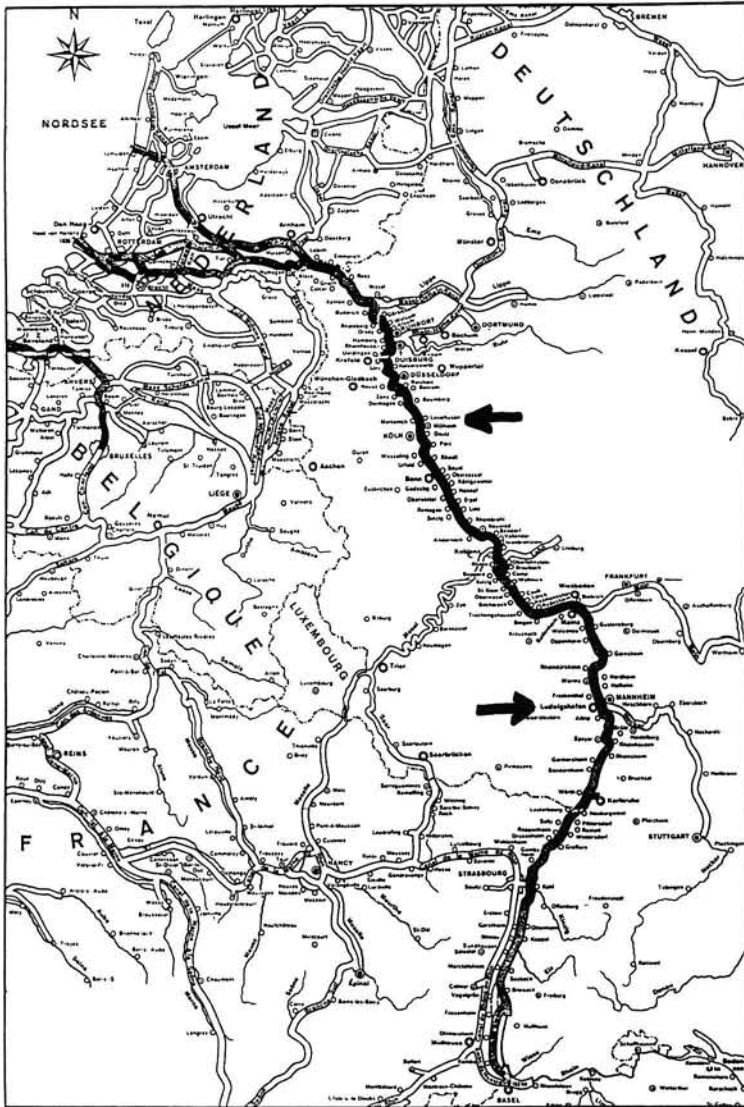


Figure 2: Rhine and connecting rivers








Type des voies navigables Type of inland waterways	Classes de voies navigables Classes of navigable waterways	Autopropulsés et chalands Motor vessels and barges				Convois poussés Pushed convoys				Hauteur minimale sous les ponts Minimum height under bridges		
		Type de bateau: caractéristiques générales Type of vessel: general characteristics				Type de convoi: caractéristiques générales Type of convoy: general characteristics						
		Dénomination Designation	Longueur Length	Largeur Beam	Tranf d'eau Draught	Tonnage Tonnage	Longueur Length	Largeur Beam	Tranf d'eau Draught		Tonnage Tonnage	
	m	m	m	T	m	m	m	T	m			
D'INTÉRÊT RÉGIONAL OF REGIONAL IMPORTANCE A l'Est de l'Ebe To East of Ebe	I	Pânche Barge	38.50	5.05	1.80 - 2.20	250 - 400					4.00	
	II	Xast - Campinot Campina - Barge	50 - 55	6.60	2.50	400 - 650					4.00 - 5.00	
	III	Gustav Koenigs	67 - 80	8.20	2.50	650 - 1000					4.00 - 5.00	
	I	Grosse Finow	41	4.70	1.40	180					3.00	
	II	Barka Motorowa 500	57	7.50 - 9.00	1.60	500 - 630					3.00	
	III		67 - 70	8.20 - 9.00	1.60 - 2.00	470 - 700		118 - 132	6.230 - 9.00	1.60 - 2.00	1000 - 1200	4.00
D'INTÉRÊT RÉGIONAL OF INTERNATIONAL IMPORTANCE	IV	Johann Weiker	80 - 85	9.50	2.50	1000 - 1500		85	9.50	2.50 - 2.80	1250 - 1450	5.25 ou/br 7.00
	Va	Grands Rhénans Large Rhine Vessels	95 - 110	11.40	2.50 - 2.80	1500 - 3000		95 - 110	11.40	2.50 - 4.50	1600 - 3000	5.25 ou/br 7.00 ou/br 9.10
	Vb							172 - 185	11.40	2.50 - 4.50	3200 -	
	Via							95 - 110	22.80	2.50 - 4.50	3200 - 6000	7.00 ou/br 9.10
	Vb		140	15.00	3.90			185 - 195	22.80	2.50 - 4.50	6400 - 12000	7.00 ou/br 9.10
	Vc							270 - 280 193 - 200	22.80	2.50 - 4.50	9600 - 18000 9600 - 18000	9.10
	VII							285 195	33.00 34.20	2.50 - 4.50	14500 - 27000	9.10

Table I: ECMT/CEMT Classification

There are four design parameter limitations for ships on the Rhine, relating to regulations (speed, length, width) and air and water draught. The speed of the vessels on the Rhine is, measured in relation to the speed over land:

- * Speed up stream : 10 km/hr;
- * Down stream : 17 km/hr.

The maximum length of a selfpropelled ship is 140m, a pusher convoy has maximum dimensions of:

- * Max.length : 185 m;
- * Max. width : 22.8 m.

Although, exemption is given to 6 barge convoys that are even longer. The air draught on the Rhine is limited to 10m up to the city of Strassbourg, although, extreme high water on the Rhine may reduce this substantially and sometimes make sailing on the river impossible for short periods of time.

Part IV: Sea-river Chemicaltanker

Beyond Strassbourg, on the arteries Neckar and Main, the air draught is limited to approx. 6.5m.

The most difficult and important design parameter, water draught, depends on the annual run-off of melt water from snow in the Alps and rain that fall in the catchment basin of the Rhine. This may fluctuate from day to day, month to month and year to year.

The Rhine is divided into six draught-sections: the measurement of each section is based on the so-called Etiage Equivalent (E.E.), being the draught which is the minimum draught over the last 20 years.

Most of the commercial river traffic has its as origin or destination in the region around Ludwigshafen. The maximum allowable draught on this stretch of the river Rhine is statistically as follows:

- * Less than 55% of the year max. draught 3.30 m;
- * Less than 65% of the year max. draught 2.90 m;
- * Less than 73% of the year max. draught 2.70 m;
- * Less than 78% of the year max. draught 2.60 m.

CHAPTER 2: SEA-RIVER SHIPS

The sea-river ships concept grew out of the traditional European coastal ships. **Figure 3** shows in brief the change in design from 1880-1960. The 70's and 80's saw a rapid growth in the size of these vessels as **Figure 4** illustrates, especially spurred by Dutch and Russian owners.

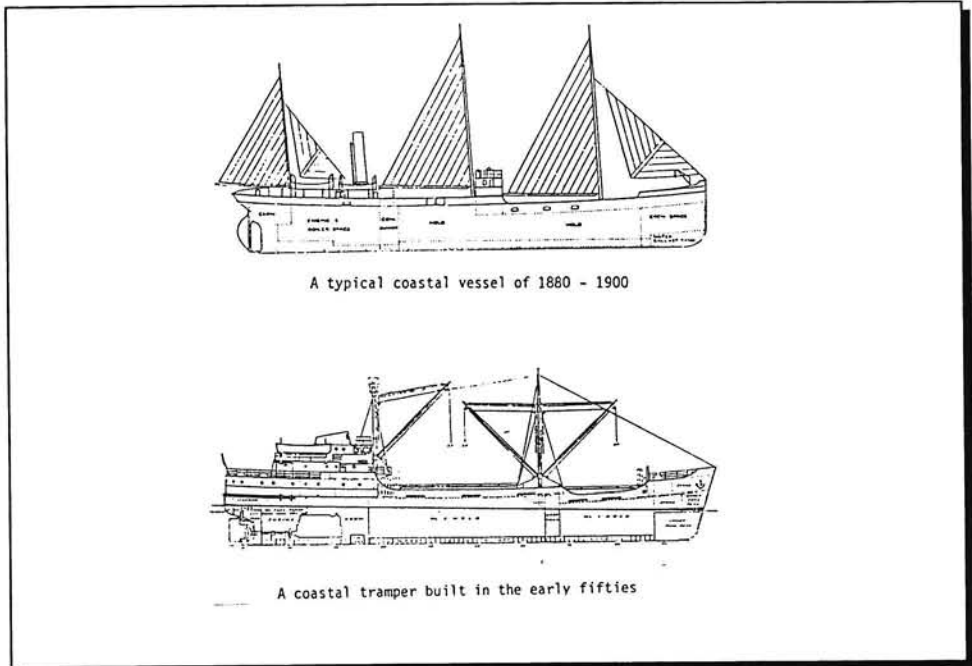


Figure 3: Design change 1880 -1960

As from 1973 the purpose-built sea-river vessels appeared in the West-European transportsystem. **Figure 5** shows some typical examples. These ships are characterized by a limited or shallow draught of 3 m, and a retractable bridge system.

They form the replacement of the traditional small 500 gross tons coastal ships and they have filled a void. By their nature they are able to access small riversystems or ports and now play a vital role in providing many factories with a very low cost transport option. The growth of the sea-river fleet is clearly demonstrated by **Figure 6** and **Figure 7**. The fleet consists of an impressive

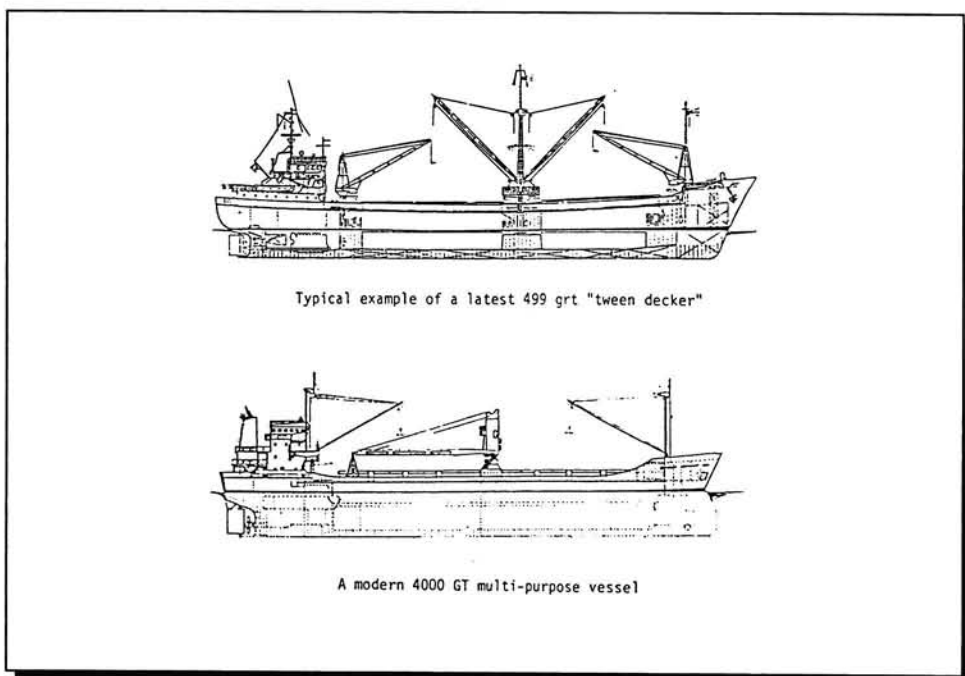


Figure 4: Growth in shipsize

1100 ships, half owned by West European owners and half owned by Russian owners.

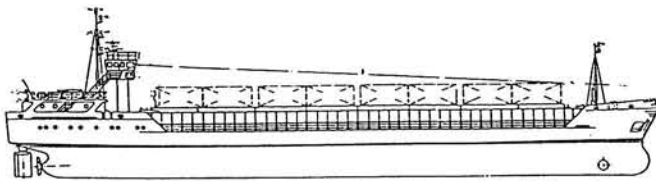
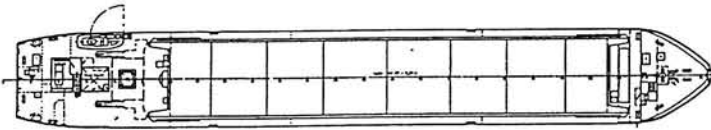
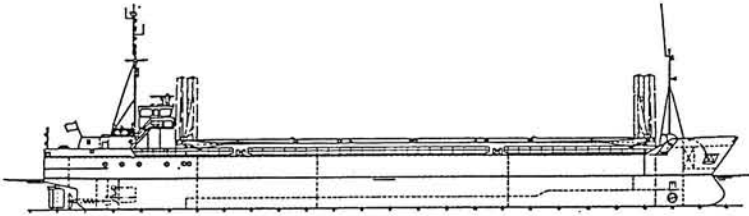
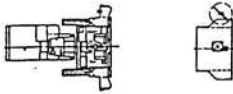
These ships play an important role in the seaborne transport of goods. Their transport production in tonmiles can be approximated as follows: the ships sail on average 60% of the year at sea (speed 10 knots/hr) and spent 40% in port. They carry on average 1500 tons and sail 20% of the seatime in ballast. The tonmile production per annum is thus: $1100 \text{ ships} \times 360 \text{ days} \times 60\% \text{ at sea} \times 80\% \text{ (excl. ballast)} \times 1500 \text{ tons} \times 10 \text{ knots} \times 24 \text{ hrs} = 68.4 \text{ billion tonmiles}$.

Shipowners, shipbrokers, shipbuilders and naval architects are constantly improving the sea-river ships, by adding features or new concepts. An interesting development is the replacement of the traditional propellor-rudder by waterjet propulsion (Figure 8). This allows for manoeuvrability of the ship in extremely undeeep waters (1 meter!). Shallow draught sea-river chemical gas tankers successfully operate now for several years as well as IMO-3 type product tankers.

An important development was the sea-river container and roll-on/roll-off design. These ships all impact the modal split. For example, the containers are carried to and from the UK directly into the German riverport of Duisburg. Thus eliminating the transshipment and road (or barge) haulage between Rotterdam and Duisburg.

General Arrangement

Built by Hermann Sürken at Papenburg Ems, the 1,572 dwt Rhenus may be considered typical of Rhine Sea tonnage. The squared holds, wing tanks and large double bottom tanks enable the ship to be ballasted deeply. The telescopic bridge lowers to permit a 5.5 m air draught.



A general arrangement plan of the SAAR EMDEN, originally launched as the Rysum at Rosslau in 1991. The vessel was designed and constructed by the abh Ingenieur-Technik GmbH, Emden, for Werner Bockstiegel KG., Emden.

Figure 5: Typical example sea-river vessels

Part IV: Sea-river Chemicaltanker

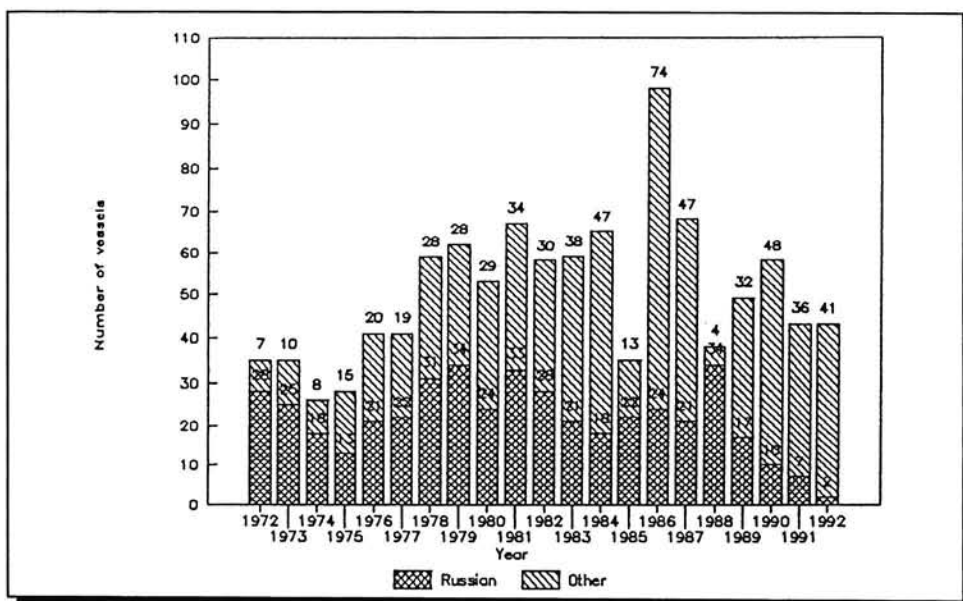


Figure 6: Sea river vessel fleet

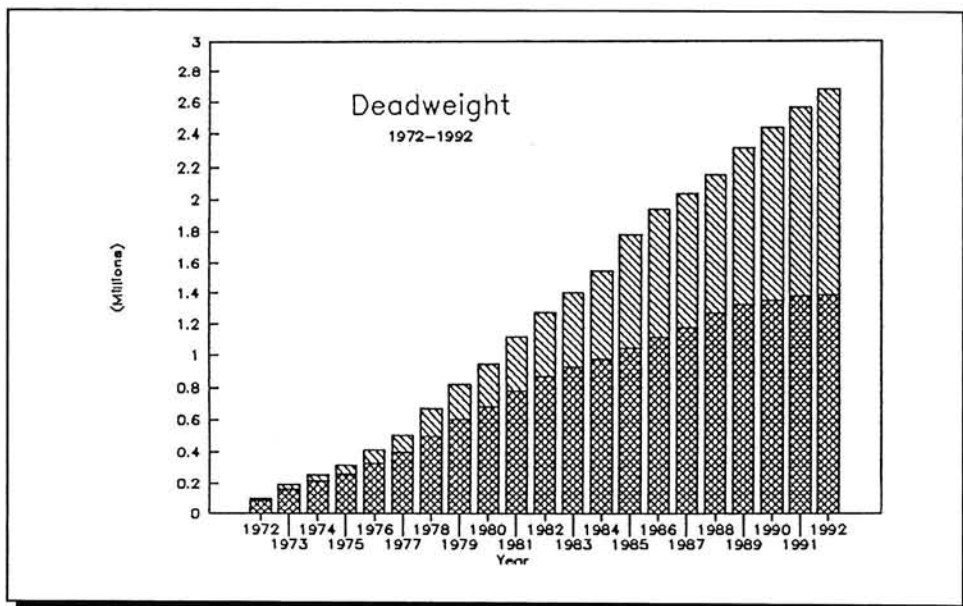
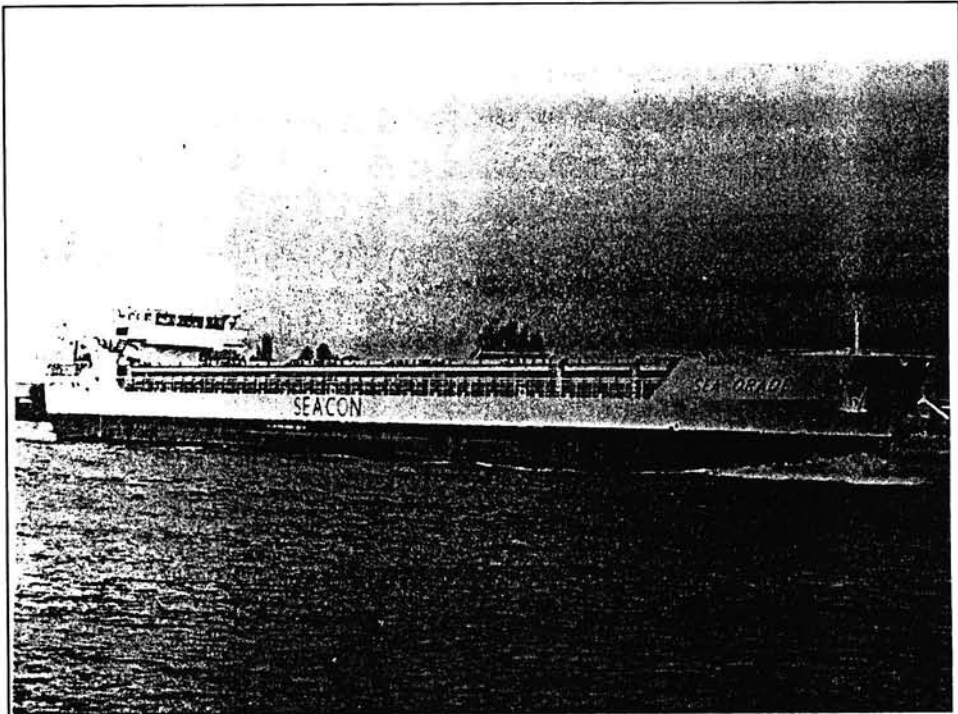
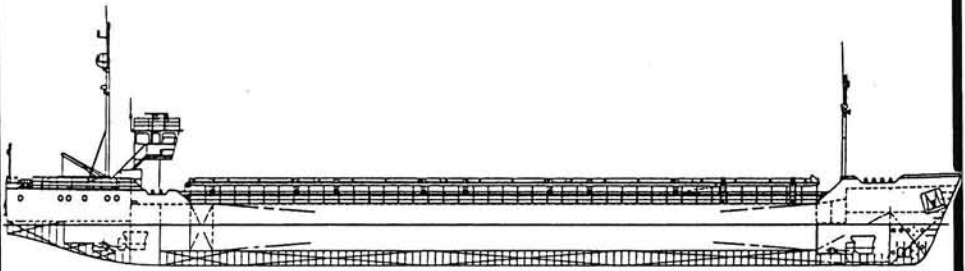


Figure 7: Deadweight sea-river vessel fleet



The SEA ORADE heads up the River Waal. The vessel is from the Bayerische Schiffbau at Erlenbach-am-Main. She is on time charter to Seacon Ltd., London. Photo: Jaap de Ward.



Frank Dahl of Drochtersen is the owner of the Sea Orade.

Figure 8: Waterjet propulsion

Part IV: Sea-river Chemicaltanker

Innovation in sea-river ships in the transport of steel coils or paper reels(newsprint) saves, because of the direct shipment, a considerable amount of scarce energy resources.

The figures below illustrate the energy consumption per tonkilometer of the different modes.

mega-joules per tonkilometer	
road	0.7-1.2
rail	0.6
coaster	0.25 (3000 dwt, 10 knots)

In order to illustrate the potential of technological innovation the transport of chemicals between the UK and Germany is taken as an example.

The basic question hereby is:

Can technological innovation in sea-river shipdesign make this form of transport competitive and may this impact the modal split in this important Corridor?

In the remainder of this Part IV, the chemical trade, modes of transport, design of a sea-river small parcel chemicaltanker, and the economics will be discussed.

CHAPTER 3: INTRA-EUROPEAN CHEMICAL TRADES

The statistics on chemical trades in Europe are fragmented and not consistent. An approximation of the total volume can be found in specialized studies, out of which the following numbers have been taken. Chemicals can be classified in several ways. This study is concerned only with intermediates (specialties) that are shipped in relatively small quantities, contrary to the bulk chemicals like benzene, toluene, xylene, methanol.

The specialty chemical constitute a group of 600 different products, of which almost 400 are internationally shipped in sufficient quantities in order to use a ship. The value of the specialty chemicals is high, often more than \$ 1.000 per ton. The higher the value, the smaller the parcel quantity. Bulk products are shipped in parcels of 2000-4000 tons; the specialties always below 500 tons and the very expensive below 200 ton.

Small parcels of 25 tons are shipped in tankcontainers or tankrailcars. Smaller quantities are shipped in drums, and are not relevant to this study. The Intra-European chemical trade flows amount to 22 million tons in 1988, of which 15 bulk chemicals constitute 80%, and 15 other primaire products another 10%. The 22 million tons can be subdivided into 11.1 mln international shipments, 3.5 mln transshipment and 7.4 mln national (cabotage).

The 600, specialties represent only 10% of the total volume, or 2.2 million ton. Of these 600 specialties, 250 can be considered as bulk because of their parcel size and 140 are allocated to tankcontainers/tankrailcars. The quantities of the other chemicals is negligible in parcel size. Producers and users of specialty chemicals are BASF, Bayer, Hoechst, Hüls in Germany, Akzo and DSM in the Netherlands, and ICI and many others in the UK. The chemical trade between Germany, the Benelux and the UK amounts to approx. 1 million tons.

Chemicaltankers vary in size from 1.000 to 50.000 ton deadweight. Ships upto 3.000 dwt are used in shortsea operations, while the category above 3.000-6.000 dwt, connects the major shortsea trading areas: the Baltic, the Atlantic, the Mediterrenean. The worldfleet of chemicaltankers consist of around 1.000 ships, **Table II** shows the number of ships per deadweight size class.

Part IV: Sea-river Chemicaltanker

January 1st, 1992		Ships of 300 grt/gt and over										
Summer draught (in m)	dwt - size class										T O T A L	
	< = 2499	2500 -4999	5000 -7499	7500 -9999	10000 -14999	15000 -19999	20000 -22499	22500 -24999	25000 -29999	30000 -39999		> = 40000
unknown	26	1	-	1	-	-	-	-	-	1	-	29
2.50 - 2.99	23	-	-	-	-	-	-	-	-	-	-	23
3.00 - 3.49	37	-	-	-	-	-	-	-	-	-	-	37
3.50 - 3.99	133	1	-	-	-	-	-	-	-	-	-	134
4.00 - 4.49	212	3	-	-	-	-	-	-	-	-	-	215
4.50 - 4.99	84	2	-	-	-	-	-	-	-	-	-	86
5.00 - 5.49	32	63	-	1	-	-	-	-	-	-	-	96
5.50 - 5.99	-	57	-	-	-	-	-	-	-	-	-	57
6.00 - 6.49	-	43	19	-	-	-	-	-	-	-	-	62
6.50 - 6.99	-	11	26	6	-	-	-	-	-	-	-	43
7.00 - 7.49	-	-	31	21	-	-	-	-	-	-	-	52
7.50 - 7.99	-	-	5	15	3	-	-	-	-	-	-	23
8.00 - 8.49	-	-	1	2	7	-	-	-	-	-	-	10
8.50 - 8.99	-	-	-	-	13	5	-	-	-	-	-	18
9.00 - 9.49	-	-	-	2	5	9	1	2	-	1	-	20
9.50 - 9.99	-	-	-	-	-	3	-	12	10	1	-	26
10.00 - 10.49	-	-	-	-	-	1	2	7	1	5	-	16
10.50 - 10.99	-	-	-	-	-	-	1	4	7	10	-	22
11.00 - 11.49	-	-	-	-	-	-	-	1	19	21	2	43
11.50 - 11.99	-	-	-	-	-	-	-	-	-	15	1	16
> = 12.00	-	-	-	-	-	-	-	-	1	-	2	3
T O T A L	547	181	82	48	28	18	4	26	38	54	5	1031

Table II: Ships per deadweight size class

CHAPTER 4: TRANSPORT ALTERNATIVES

In this case-study the economics of a shallow draught chemical tanker will be evaluated. For comparison's sake an existing transport route is taken: Ludwigshafen via Leverkusen on the Rhine in Germany via Rotterdam to the chemical industry on the Thames in the UK and back. The total roundtrip-time, based on 5 days sailing on the river and at sea, and 2 days in port, is 7 days.

Figure 9 shows this direct alternative with the sea-river chemicaltanker; the other alternatives, as they exist today, are ranked according to the number of handlings of the cargo unit. The sea-river tanker alternative represents the minimum number of handlings of three: the cargo is pumped into the ship at the chemical plant, shipped by sea and discharged at the other plant. The transport alternatives are not only ranked on the basis of the number of handlings, but also in the transit time and the cost. The more a cargo is handled or transhipped, the more can go wrong, so quality in general is more likely to be achieved with a minimum number of manipulations of the cargo.

The second criterion is the frequency of the service and parcelsize. A sea-river vessel makes a roundtrip every week, which equates to a frequency of once a week and the minimum quantity is 100 tons per commodity, due to the tankconfiguration. Other modes, such as tankcontainers offer the possibility of daily shipments of 25 tons. This is an important variable for the comparison of the 9 transport alternatives.

The third criterion is the transittime; tankcontainers, using ferries for the channel crossing, have a transit time of less than two days, which compares favourably with the 3.-3.5 days of the sea-river vessel. The fourth criterion is the transport cost per ton.

In the following paragraph the first three criteria for evaluation will be discussed:

1. Number of handlings and parts in the chain;
2. Frequency of service;
3. Transit time will be discussed.

Shippers who wish to transport chemicals to and from Germany and the Thames/UK have a lot of options as shown in **Figure 9**. This means that the Corridor is highly developed and competitive. The alternatives are described below.

1. A river chemicaltanker transports the chemicals from the plant on the Rhine to Rotterdam where it is transhipped into a tankstorage terminal;

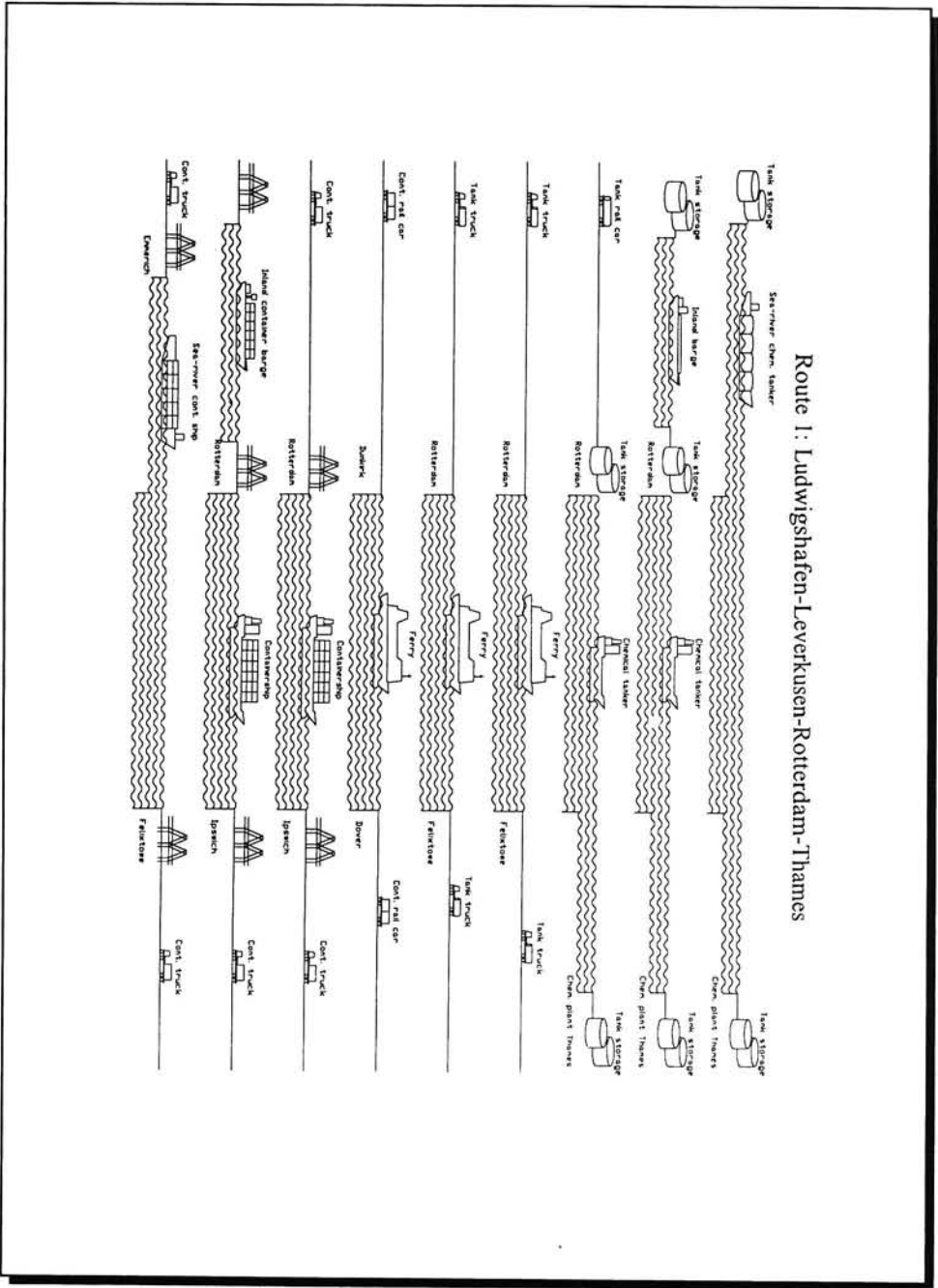


Figure 9: Sea-river tanker alternative

From there it is pumped into a shortsea chemicaltanker and after the short trip over the Northsea, the product is pumped into a tankstorage again.

The product is transhipped 4 times and the system uses apart from the tankstorage at the chemical plants, one tankterminal, a river barge and a seagoing tanker.

2. In stead of using a rivertanker, a railtankcar is used. The rest is identical as 1).
3. The next three options all make use of the (freight) ferry's that offer several sailings a day out of Calais-Zeebrugge, Oostend, Flushing, Rotterdam and Scheveningen.
These options all make use of the tankcontainer (25 tons). The only difference between the three options is the transport mode of the tankcontainer: manned truck-chasis, unmanned chassis (on ship), double container on railcar. The product is transhipped only two times, and the container stays on one chassis/railcar, but uses a ferry.
4. The last three transport alternatives use the containerships as a means of transport. The tankcontainer can be trucked from Germany to the container terminal in Rotterdam or it can be trucked to a container terminal on the Rhine. From here it can either make use of a riverbarge to bring it to Rotterdam or a sea-river container ship. This last option is not always available as there are presently few direct services emanating from the Rhine ports (Duisburg) to destinations in the UK.

Competition

From this picture it becomes clear that the shipper of specialty chemicals has many alternatives and that the Corridor UK-Benelux/Germany is well developed. Shortsea operators like R.M.S., Cast and Geest Line offer direct containerservices from Germany to some ports in the UK. Ro-ro services are offered by Norfolk Line from Scheveningen, P&O Ferries/Stena Line and Northsea Ferries from Rotterdam, Olau Line from Flushing, etc.

Integrated chemical transport companies like Gebr. Broere of Dordrecht, offer chemical barge transport, storage and seatransport to plants of the shippers/consignee's or to their own terminals for onward distribution.

A new door-to-door service is thus faced with a lot of infighting to capture a marketshare. The existing competitors will not let newcomers take away their business without putting up a fight. This results in general in a war on freightrates.

CHAPTER 5: SEA-RIVER CHEMICALTANKER

Figure 10 (left) shows a typical seagoing IMO 2/3 chemicaltanker able to carry 2.200 tons of cargo at a draught of 5.0m. 307 (right) shows a IMO 3 type sea-river chemicaltanker of 1.600 tons at a draught of 2.7m and 2.200 tons at 3.1m. The difference in dimensions of the two ships is quite striking. Both ships have 12 tanks.

The minimum parcelsize of the both vessels is approximately 185 tons, which is too much to compete in the specialized chemicals trade. Parcel sizes are smaller and the new sea-river vessel should not only be able to have sufficient carrying capacity at a minimal draught (2.7m) but also have smaller tanks (approx. 100 tons).

Figure 11 and Figure 12 shows the design of this sea-river chemicaltanker of 2.222 tons. The 23 stainless steel tanks are of the cylinder tanktype and prefabricated in a factory. The hull is of a simple design and low cost. The total investment required is approx. ECU 8.5 million. The principal dimensions of the three chemicaltankers are compared in Table III.

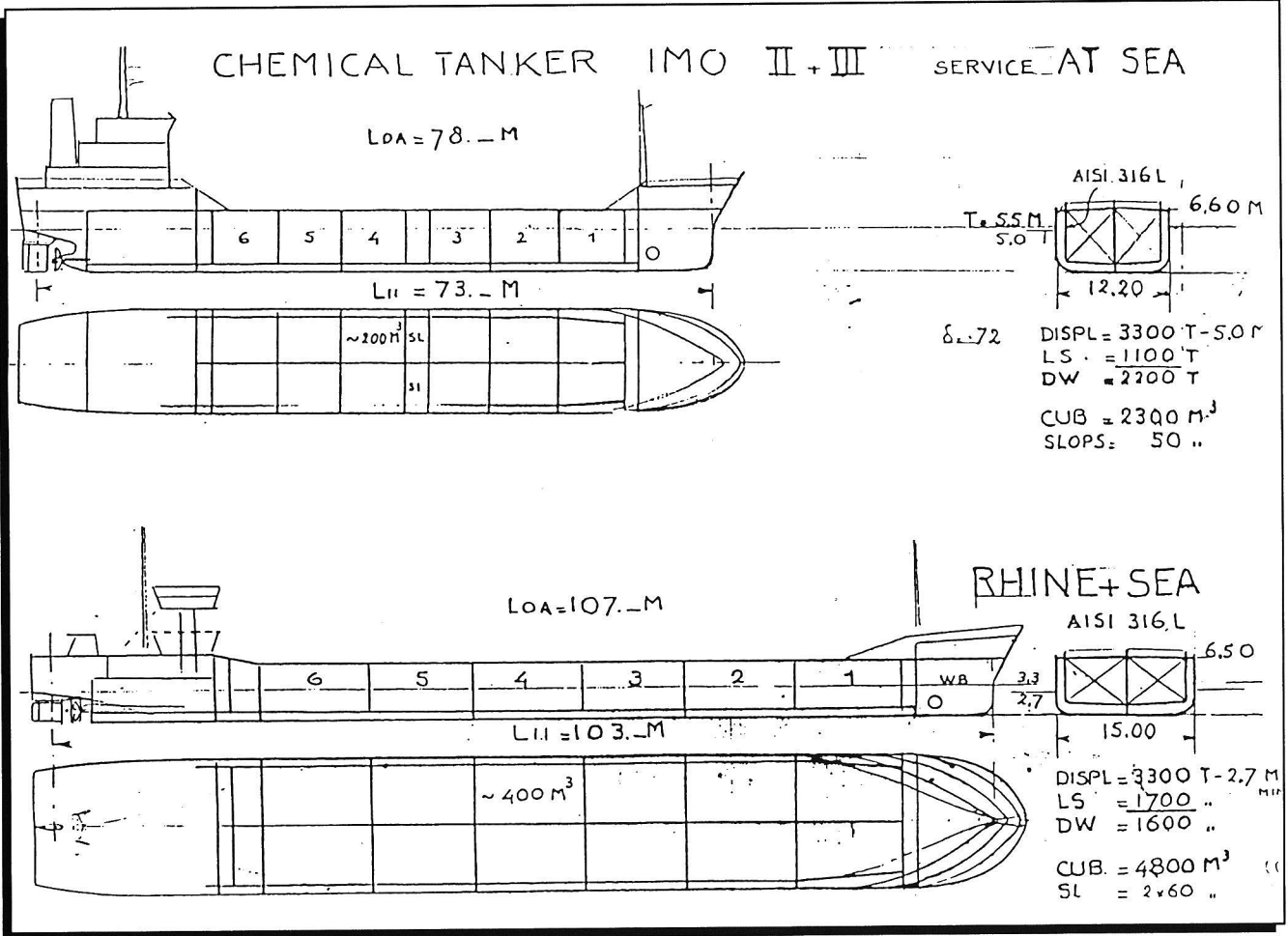
	L _{oa}	L _{ll}	B	H	T	Dwt	∇	C _B	L*B*H	spec wght	light wght
Dimensions	m.	m.	m.	m.	m.	ton	m ³	--	m. ³	kg./m. ₃	ton
shortsea chemical-tanker	78	73	12.2	6.6	5	2200 (sea)	2300	0.72	5800	190	1100
conventional sea-river chemical-tanker	107	103	15	6.5	s. 3.1 r. 2.7	2200 1600	4800	0.80	10000	170	1700
cylinder tank Sea-river chemical-tanker	103	99	15	7	s. 3.1 r. 2.7	2200 1600	5200	0.80	10400	150	1550

(s) = seagoing/(r) = sea-river

Table III: Comparison chemicaltankers

The sea-river tanker has a minimum draught of 2.7m and a maximum air draught at the river Rhine of 8m. The vessel is able to load and discharge at all the major chemical plants on the Rhine in Germany. It can therefore offer a truly door-to-door service.

Figure 10: Seagoing chemicaltanker (left) and sea-river chemicaltanker (right)



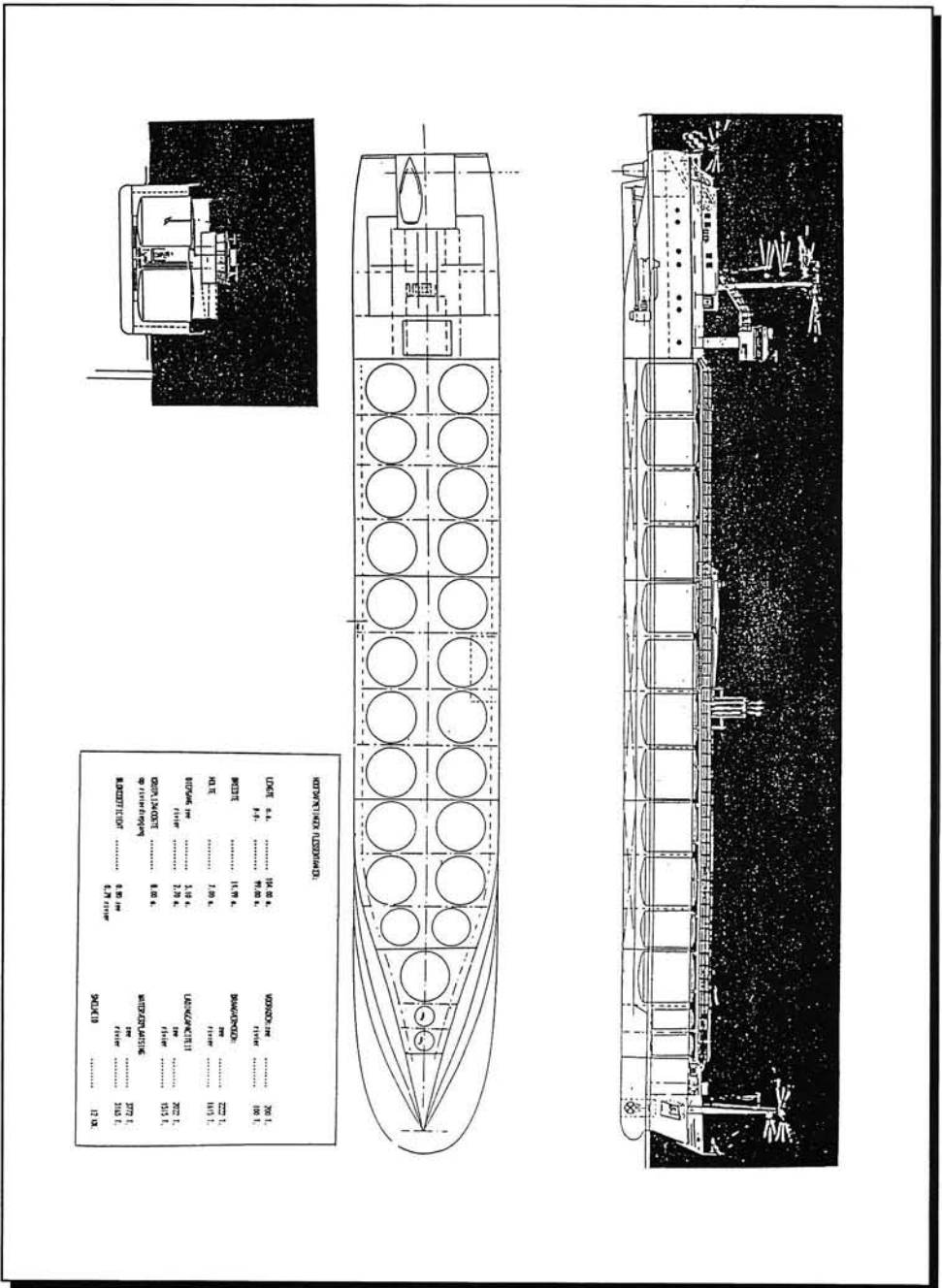


Figure 11: Design sea-river chemical tanker

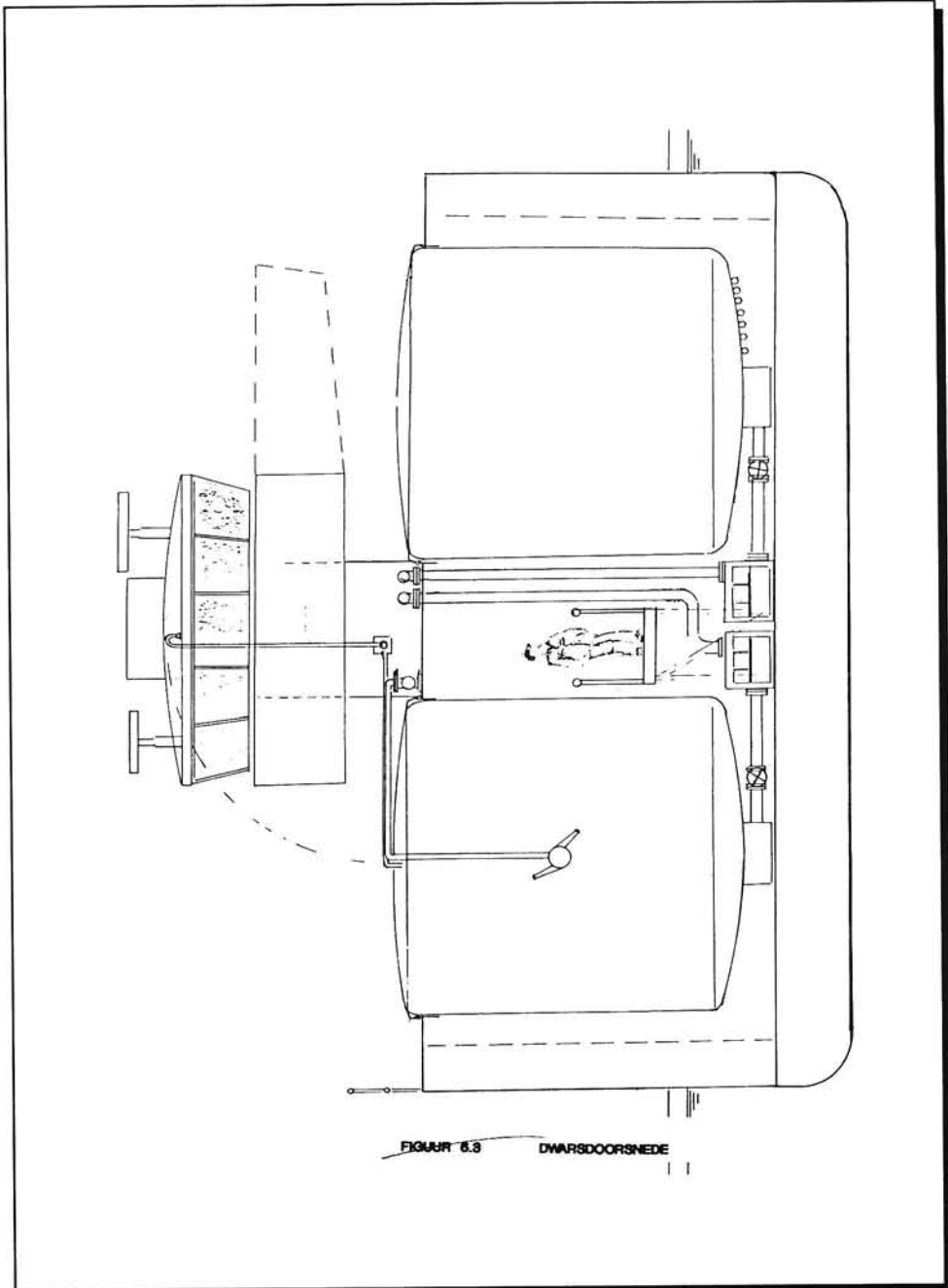


Figure 12: Transverse section sea-river chemicaltanker

Part IV: Sea-river Chemicaltanker

The speed at sea is 12 knots (23 km/hour) and is limited by regulations on the Rhine to 10km/h upstream and 17km/h downstream (speed over land). It can transport 23 different parcels of approx. 100 tons each.

The ship is superior in some other aspects. First of all, the tanks are all stainless steel (no coatings) and remain valuable even after the economic life of the hull, machinery and equipment (20 years). The tanks, which constitute a large part of the total cost of the ship, can be easily taken out and put into a new hull. Besides, the ideal cylindertanks are easy to clean with minimal slops, which makes it environmental friendly.

The tanks are completely separated and pose no cargo incompatibility problems, or contamination from heating coils (placed outside). The cylindertanks are isolated which saves energy for heated cargoes. These design characteristics, durability (re-use of tanks), slopreduction and, energysaving make it a promising alternative.

The sea-river vessel can transport 2.200 tons in a weekly roundtrip between the Rhine and the UK. If the trade is balanced both ways, the maximum transport capacity is 200-250.000 tons per annum per ship.

One ship could theoretically replace $250.000/25 \text{ tons} = 10.000$ tanktruck movements. If the capacity of a tanktruck is a roundtrip every 3-4 days, than one sea-river chemicaltanker could replace 100 trucks! The benefit for the environment would be impressive.

Why then may these performance indicators not be enough to change the existing transport patterns? There may be several reasons:

- * The transport volumes are too small;
- * Not all destinations in the UK are on water, and require additional landtransport;
- * The service level (frequency) is too low in comparison to daily departures by truck;
- * The existing transport operators of trucks, inland barges, tankfarms, railcars, will fight back and compete on price, which reduce the revenue base.

CHAPTER 6: EVALUATION OF TRANSPORT COSTS

A financial model is constructed which includes all the variables of the tankers, such as speed, fuel consumption, specific gravity of the cargo, distances, load factors on the Rhine, daily running costs, capital costs and of course the revenues. The freight rates vary depending on the port of origin of the cargo. In this particular case, three stretches have been distinguished, Ludwigshafen-Thames (distance 475 nautical miles). Leverkusen-Thames (327nm) and Rotterdam-Thames (166nm).

The theoretical average required freight rates for these stretches amount to ECU 25/ton, ECU 16.4/ton and ECU 8.6/ton respectively. **Figure 13** shows the comparative transport costs of the other alternatives. The sea-river chemicaltanker is superior, i.e. has lower costs per ton than any other transport alternative.

Why then is this tanker not yet in operation and has it not created a new door-to-door corridor? The answer to that question is that the transport volumes are too low to employ several tankers year-around on this route.

One tanker offers a sailing frequency of once a week, which is often too low for the requirements of the shippers/consignee's. It increases their intermediate storage costs and this adds to the logistical costs, though marginally, of the total chain. For this reason, the tanker has to call at other ports in the UK and the number of ships has to increase to at least two, preferably three, so it can offer a sailing every 2-3 days. The sea-chemicaltanker becomes a part of the broken-transportchain.

Figure 14 shows another transport route via the port of Immingham by road to the chemical plants in Leeds and Birmingham. The results of the transport comparison are shown in **Figure 15**, for Leeds and Birmingham respectively.

These figures make it clear that the sea-river tanker loses its competitive advantage, but can in general compete with most of the modes on costs, but not on transittime.

Part IV: Sea-river Chemicaltanker

- 1 = I. tanker/Storage/Sea-going tanker
 2 = Tank rail car/Storage/Sea-going tanker
 3 = Container rail car/Ferry/Container rail car
 Cyl = Cylinder tanker
 5 = Container truck/Ferry/Container rail car

- 6 = Inland taker/Feeder/Tank rail car
 7 = Container truck/Sea-river LO-LO/Container truck
 8 = Container truck/Ferry/Container truck manned
 9 = Container truck/Ferry/Container truck unmanned

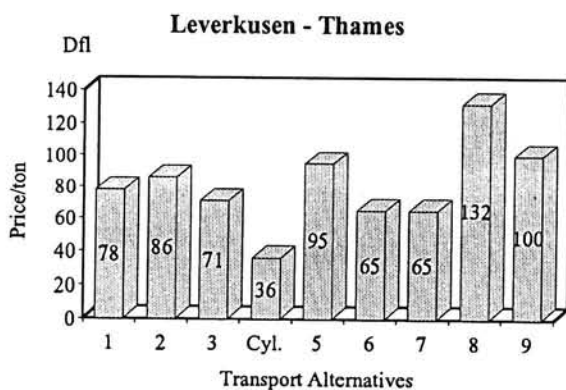
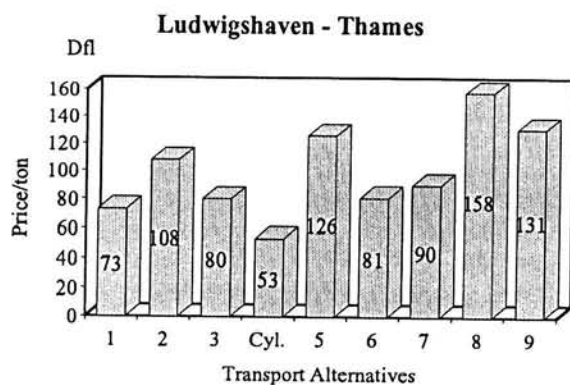


Figure 13: Freight rates - route 1

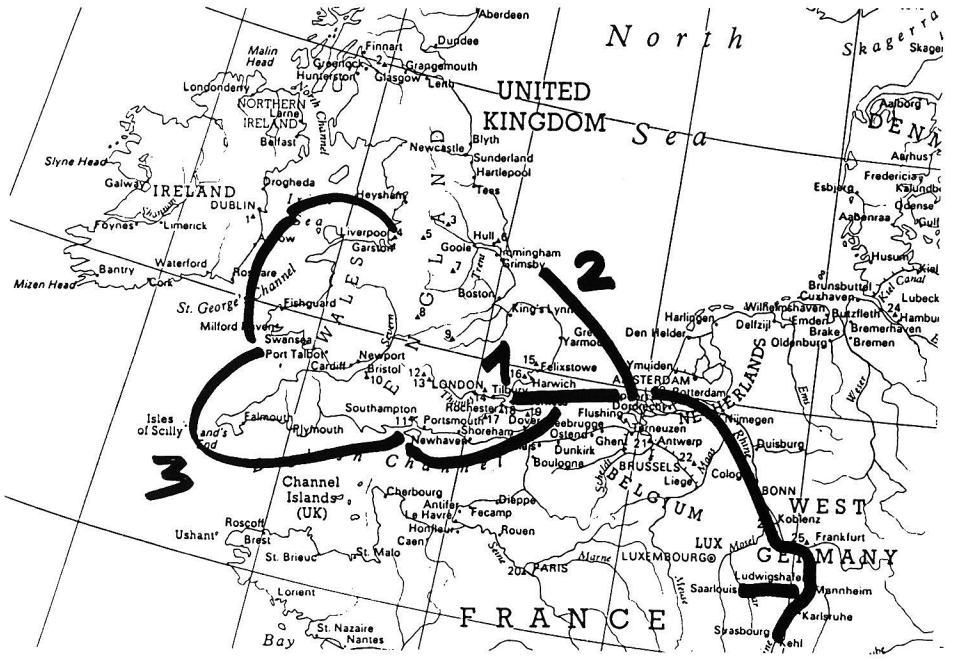


Figure 14: Transport route

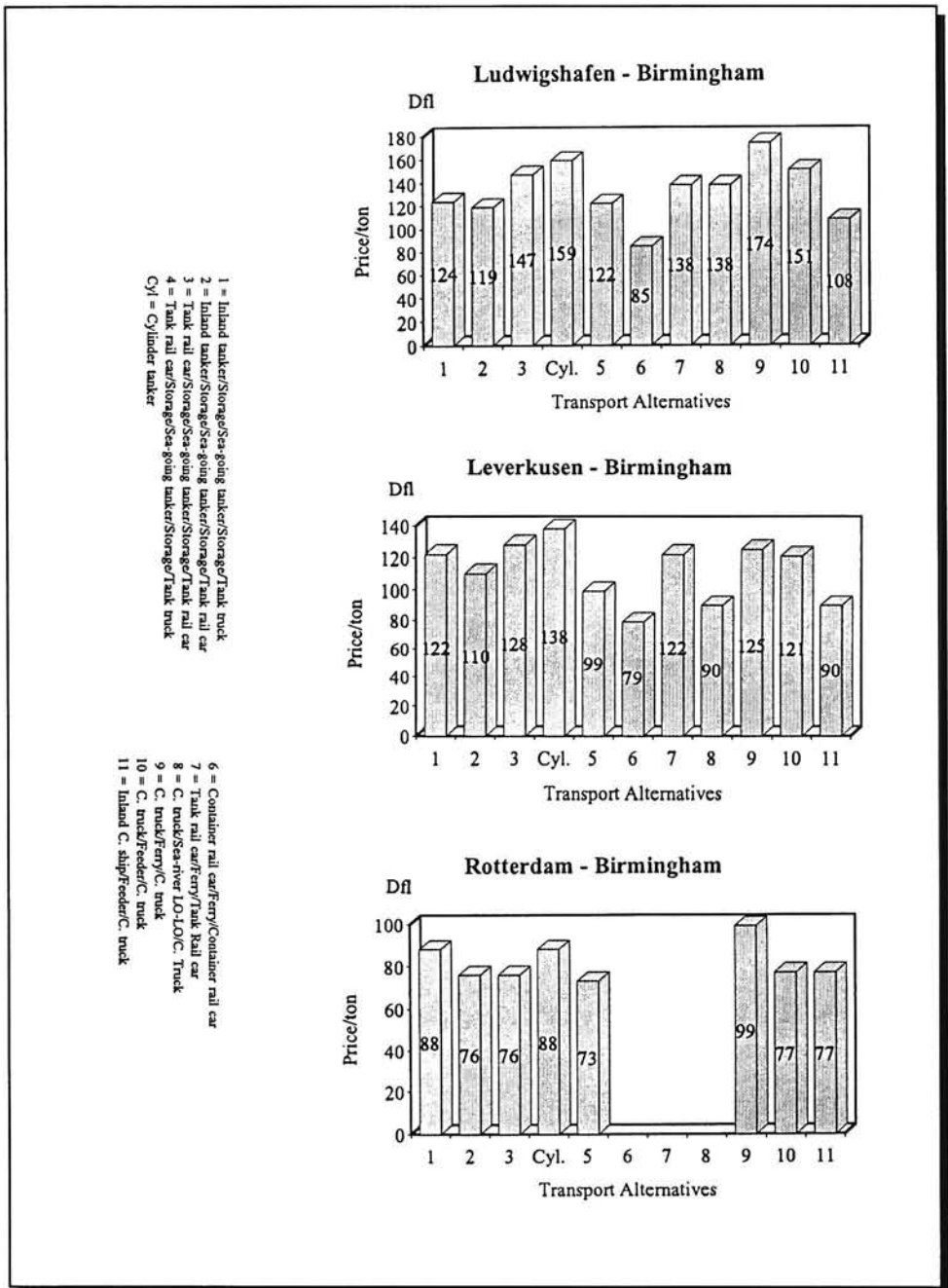


Figure 15: Freight rates - route 2

CHAPTER 7: HOW TO IMPROVE THE COMPETITIVENESS?

As soon as the sea-river tanker becomes part of a broken transportchain, it has to use roadtanker transport to deliver the chemicals from a port to an inland destination. Increasing the cost of roadtransport does not improve the competitiveness of the sea-rivertanker.

So the only solution seems to be to use the tanker on port-port routes, where transhipment is not required.

These could be for example destinations on the Manchester Canal on the westcoast of the UK. A third route has been selected: Ludwigshafen-Leverkusen - Rotterdam - Manchester Canal - Swansea - Fawley - Rotterdam Leverkusen - Ludwigshafen.

The results of the freightrate calculations are shown in **Figure 16**. The number of alternatives is restricted to four. The sea-rivertanker is on the longest stretch Ludwigshafen-Manchester on an equal cost-footing with the two other modes; only the all road-ferry alternative is significantly more expensive.

The conclusion that can be drawn from these figures is that a sea-river tanker is on longer routes not more competitive than the traditional transport options by sea. It is clearly competitive to a close destination like Fawley on the Southern coast of England.

This suggests a maximum zone of competitiveness and excludes long distances of the sea-rivetanker to, for example the Swedish industry around lake Varnern, or the Saimaa Canal in Finland, but could include destinations on the Seine in France. This is largely determined by the lack of economy of scale because of the limited deadweight capacity caused by the draught limitations.

Nevertheless is it worth to develop this option in the future, when more stringent regulations on the transport of chemical by trucks are imposed.

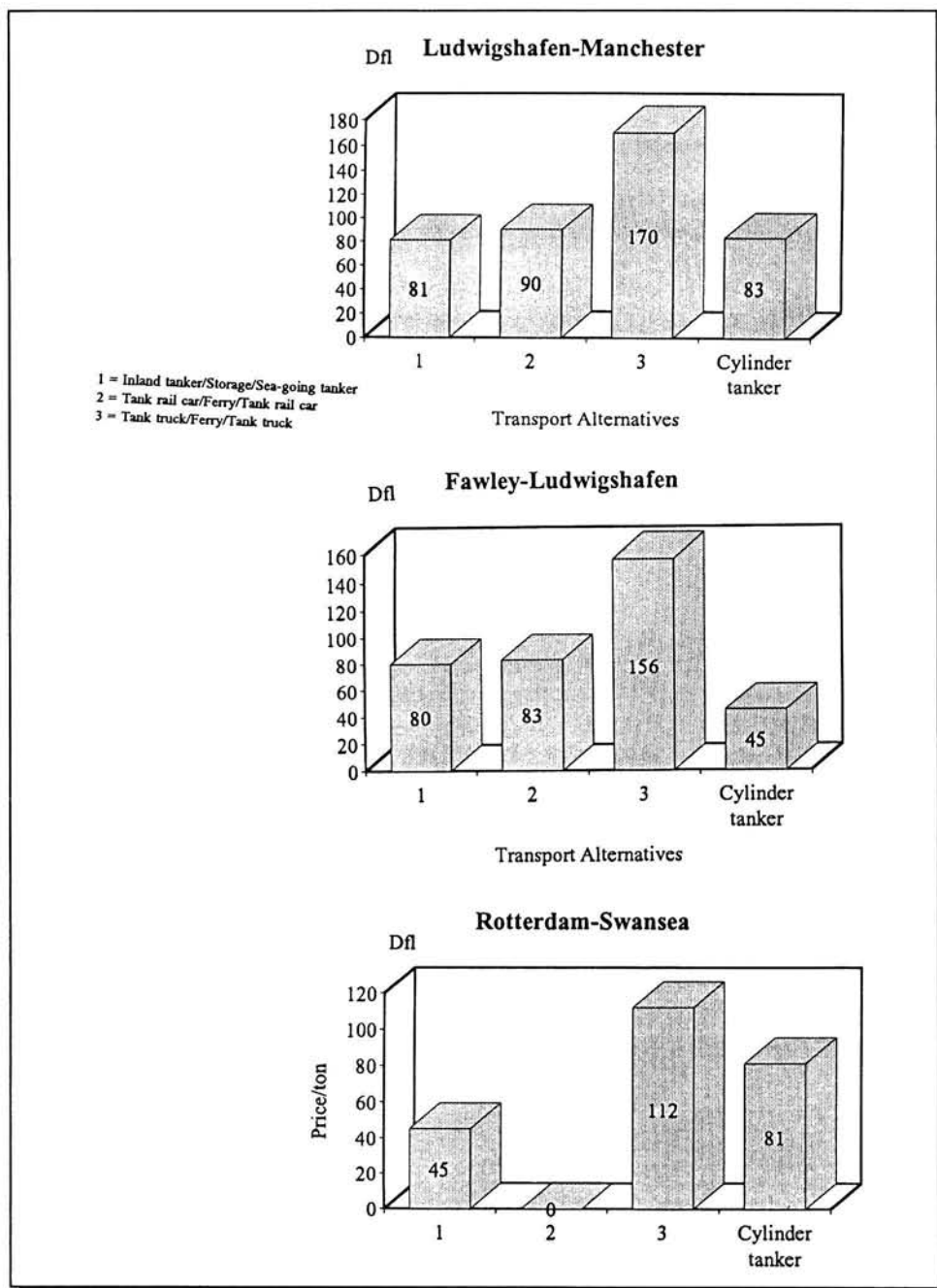


Figure 16: Freight rates - route 3

CHAPTER 8: INNOVATION: THE CYLINDERTANKTYPE CHEMICALTANKER

The subject of this book is port and slops management of chemicaltankers. **Part I** illustrated the detailed analysis of a port call and the cause and extent of delays in the port of Rotterdam. **Part II** addressed the same problem, but at a higher conceptual and planning level: How to reduce the overall porttime through the port of Houston, given the occupancy rates of the 40 terminals in this port.

Both case-studies illustrate the complexity of the issue, and the many variables involved. The picture gets even more complicated when the issue of tankcleaning and slops is added in **Part III**. Especially the slops-reduction issue is a key-element in the future design of chemicaltankers.

A radical new way to design tankers, could be based on the use of large cylindrical tanks, which are completely independent. The sea-river chemical-tanker, as discussed in **Part IV**, is an example of such a design.

In the future it is very likely that the rules and regulations laid down in IMO's "International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk" will become much more strict regarding the handling and disposal of slops.

The motto of this book "Solving not Shifting" emphasis this trend. The potential for further major slops reductions on conventional chemicaltankers is limited, as tankcleaning and stripping systems have been optimised during the last decade. As costs of slops disposal increases in the coming years, shipowners and shipdesigners will become more willing to explore alternatives. The cylindertype chemicaltanker could be the solution. In this **Part IV** the outline of such design is given.

From an academic point of view, the development fits in well with the engineering trends towards a sustainable future, based on a low environmental impact and renewable resources. The innovation which will have to take place in the design, can be described in terms of a S-curve shift.

S-CURVE THEORY

The S-curve is a graph (**Figure 17**) of the relationship between the effort put into improving a product or process and the results achieved by that investment. Initially, as funds are put into developing a new product or process, progress is very slow. Then, suddenly development goes very fast and gradually it levels off, when the scope for further improvement of the technological process reduces.

Some companies continue to invest heavily in the existing technology, with relatively little return on investment. Others, the innovative ones, look for a radical new technology, though still undeveloped, which might eventually out-

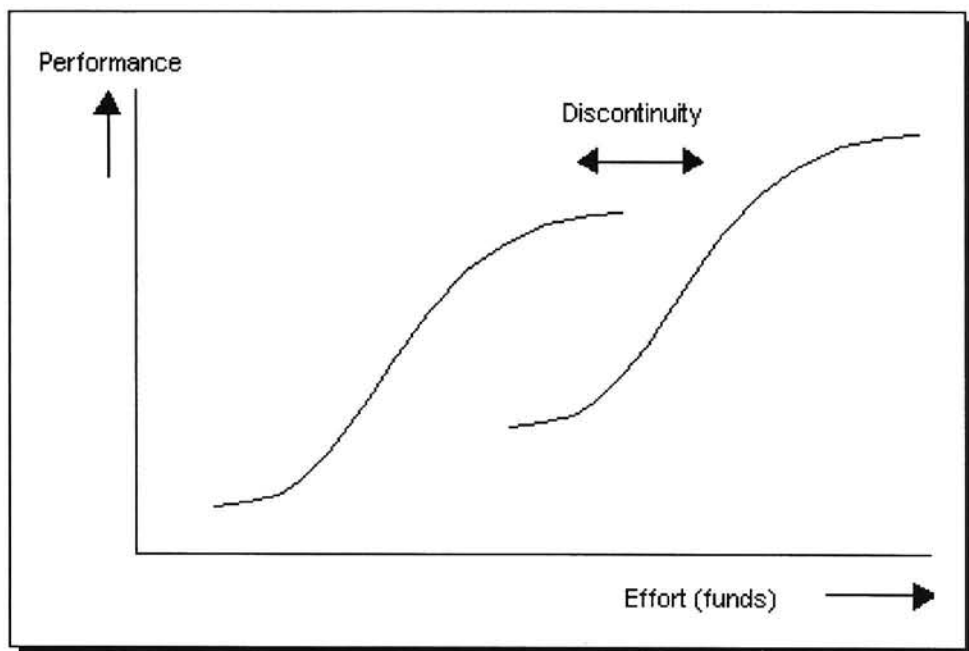


Figure 17: S-curve

perform the current one. The original S-curve is replaced by another, which represents a sort of discontinuity. I am of the opinion that the cylindertanktype chemicaltanker will be the start of a new S-curve in chemicals shipping, as shown in Figure 18.

CYLINDERTANK CHEMICALTANKER

Figure 19 shows a part of a cross-section of a tanker equipped with independent stainless steel cylindrical tanks. In this case, the capacity is approximately 1100 cubic metres per tank, and is based on the carriage of super-phosphoric acid. This tank has been designed by the Dutch manufacturer Holvrieka-Nirota in Sneek, as part of a research-project

The tanks have a height of some 20 m and are 8.5 m in diameter. The heating coils are placed outside the tank, while the tank itself is completely insulated. The tanks are prefabricated in a factory, and come up to the highest quality standards.

This design has a number of advantages, such as:

- * The cylindertank is easy to clean, with a minimum of slops, and in a very short time;

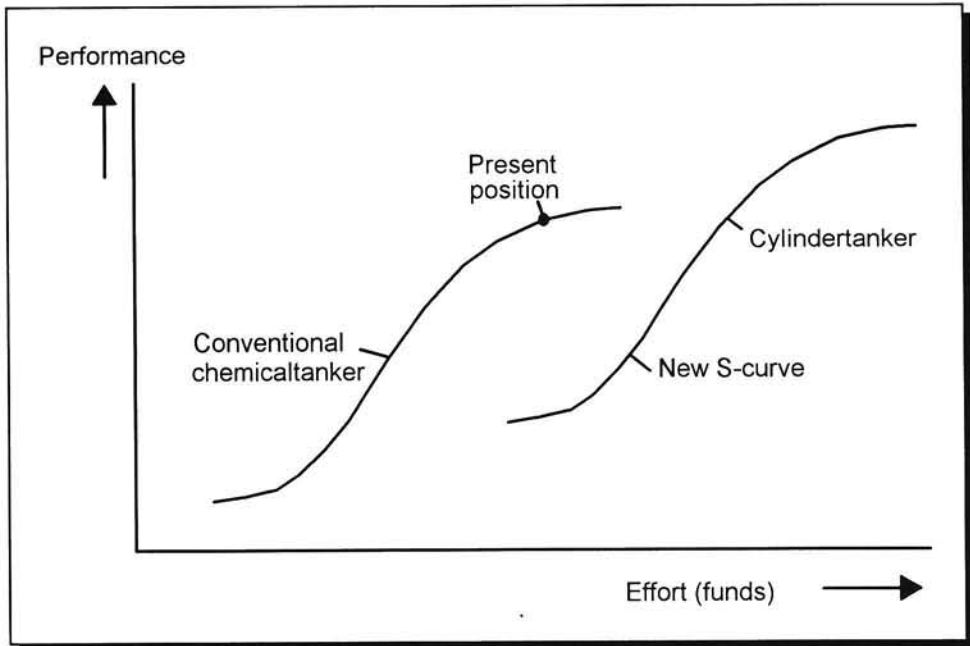


Figure 18: S-Curve shift in chemical tankers

- * The stainless steel tanks can carry all IMO-type products, as the tanks are completely independent;
- * The insulation reduces the energy consumption for heating (or cooling);
- * The expensive part of the ship, the stainless tanks, can be recuperated at the end of the commercial life of the tanker;
- * The construction time of the ship can be shortened, as hull and tanks are built in parallel.

There are many more benefits, but these will depend on the size of the chemical tanker. The design and development of the cylindertanker may be the subject of a separate publication. It is the most promising new technology in chemicals shipping, and it not only "solves" the environmental issue, but at the same time enhances the operational efficiency and may improve the financial return on investment for the owner.

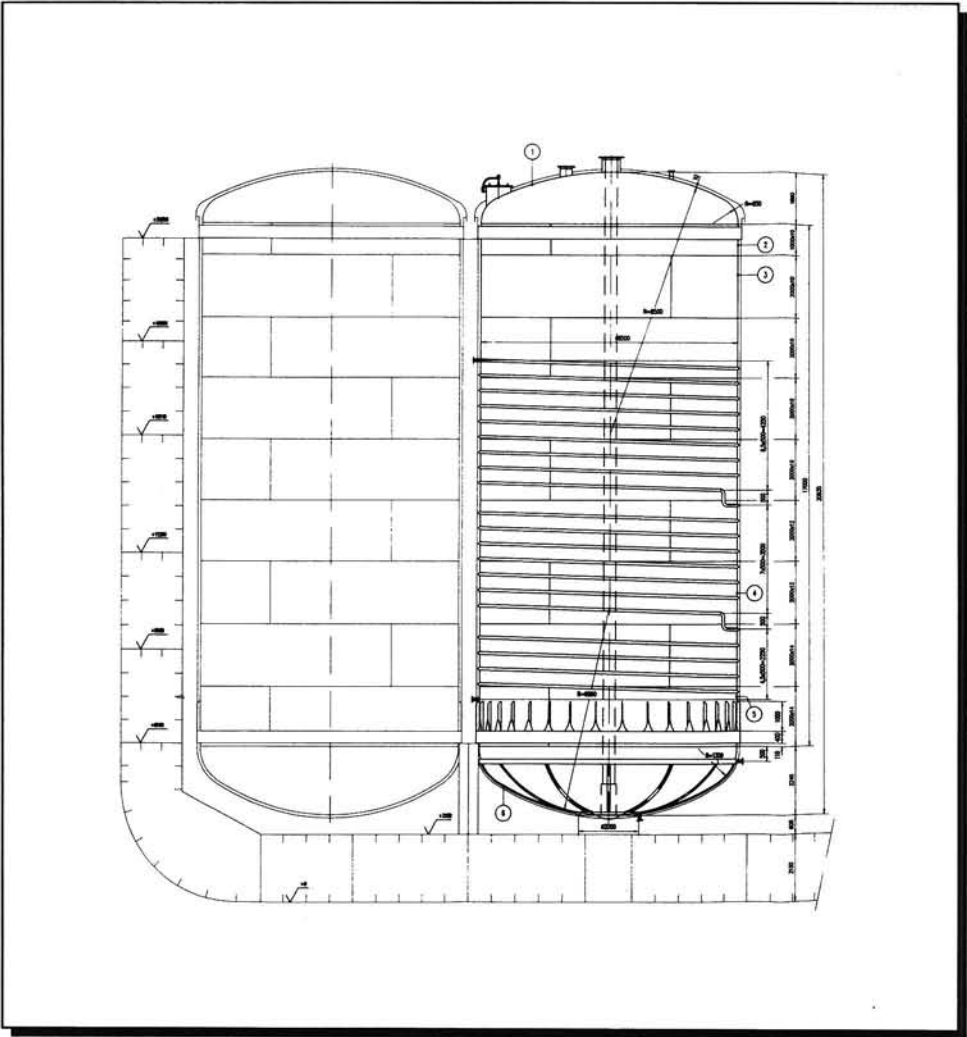
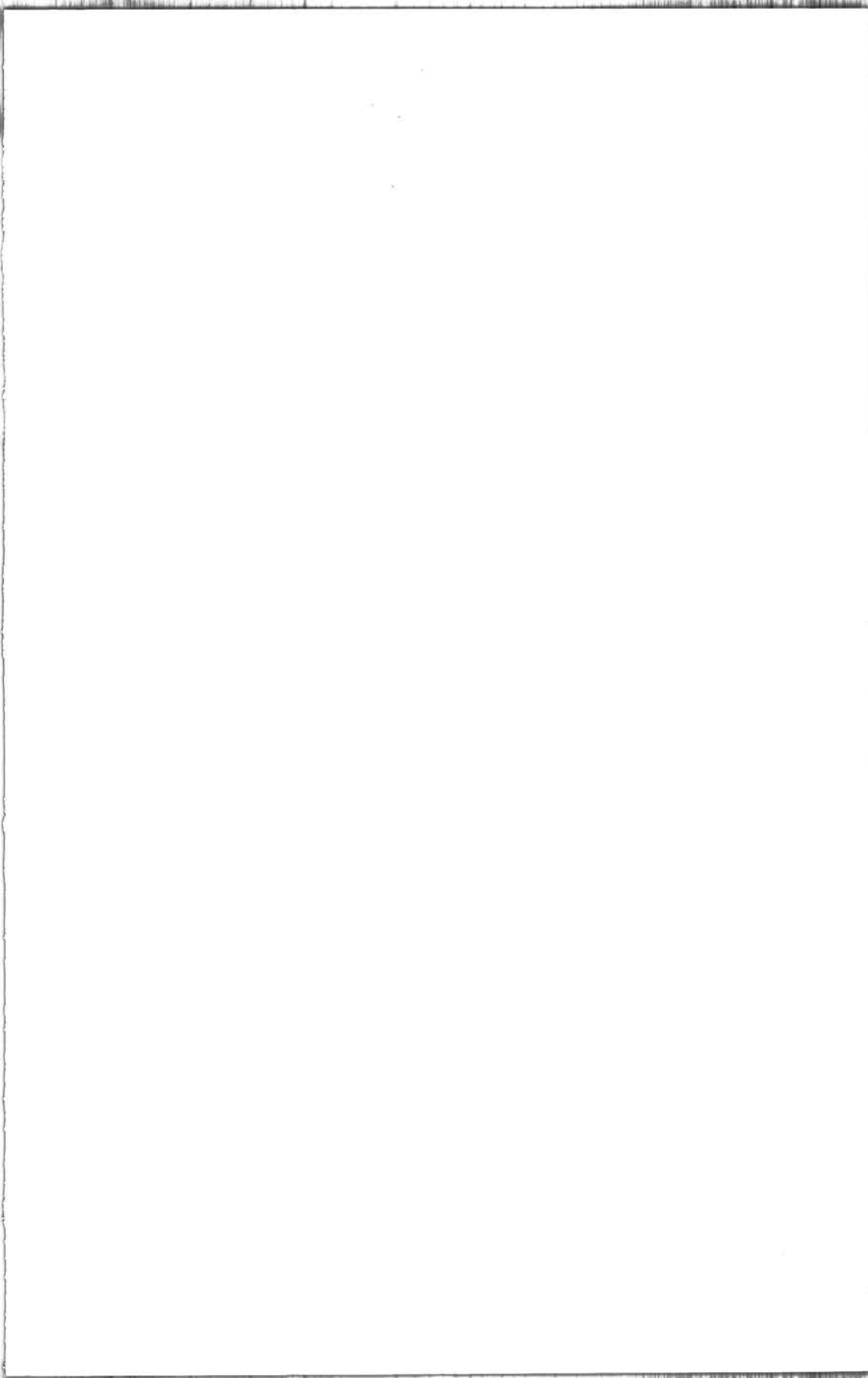


Figure 19: Cross-section cylindertanker



INNOVATION IN CHEMICALS SHIPPING

Chemicaltankers are complex and expensive ships, as they often carry hazardous cargoes. A lot of experience and knowhow has been gathered over the last decades and formalized in detailed design-rules and regulations from the International Maritime Organization and the Classification Societies.

From a technical point of view, the present generation double-hull chemicaltankers forms a milestone in design and safety.

In spite of the increased technological sophistication of chemicaltankers, one major problem seems difficult to solve over the years: the time spent in port (porttime) of chemicaltankers remains very long in relation to the time spent at sea. A major chemicaltanker owner and operator, faces a porttime of its entire fleet of deepsea chemicaltankers of around 40 percent of the year.

As a chemicaltanker only makes money for its owner while transporting cargoes at sea, this company wanted to understand in more detail the reason why, in spite of all the professional efforts already allocated to this problem, they did not succeed in a substantial reduction of porttime of their fleet.

This book addresses this problem and shows via two case-studies in the busiest chemical ports in the world, Rotterdam and Houston, the potential for improvements.

Chemicaltankers carry many different products, which are often incompatible. Therefore tanks have to be cleaned before loading another product. This not only takes time for washing and inspection, but also creates a lot of wastewater, the so-called slops. Some of these slops can be pumped over board while at sea, but some have to be brought to slop receptionfacilities, where they are treated and neutralized.

There are basically two ways to solve this problem:

- reduce the volume of slops, and
- treat the slops on board the chemicaltanker

The first solution requires a fundamental re-design of the chemicaltanker, while the second option leads to a small sloptreatment plant on board the vessel.

Both options are explored in two case-studies in this book.

The book is relevant to all those professionals involved in chemicals shipping, such as the shipowners, naval architects, shipbuilders, terminal operators, shippers, government-agencies, environmental consultants.