OPTIMIZATION STUDY OF THE NAUTICAL DEPTH OF THE APPROACH CHANNEL TO THE PORT OF PALEMBANG, INDONESIA

by
Ir. R. Groenveld and Ir. J. Mutsaers, Delft University of Technology
The Netherlands

ABSTRACT

The port of Palembang is located on Sumatra, one of the biggest islands in the Indonesian Archipelago. The approach channel to the port of Palembang has a length of approximately 100 km and is constituted by the Musi-river.

Currently the nautical depth of the Musi-river is maintained between LWS-5 m and LWS-6.0 m. Because of the increase in cargo flow to and from Palembang a feasibility study on the enlarging of the nautical depth of the Musi-river channel had to be carried out.
The two underlying studies to estimate the optimum nautical depth are:

1. *Channel Improvement Study and*
2. V*essel Traffic Study*.

For the estimation of the optimum nautical depth two models have been developed:

- A tidal wave penetration model in DUFLOW software
- A probabilistic simulation model of the vessel traffic in PROSIM–software.

Based on the channel improvement study and the vessel traffic study the lowest transportation costs were attained at a maintenance depth of LWS-6.5 m in combination with a 30% draught increase of the relevant vessels.

1. INTRODUCTION

The objective of the *Channel Improvement Study*, for the approach to the port of Palembang was to estimate the lowest level of transportation costs. This lowest level of transportation costs is achieved by a suitable combination of dredging works and adaptations of the fleets calling the port of Palembang.

In the *Vessel Traffic Study* the influence of the nautical depth of the approach channel on the shipping costs was estimated. Because of the confined water depth of the approach channel vessels are confronted with high waiting times while a part of the fleet calling Palembang can only be partly loaded.
The objective of the *Vessel Traffic Study* was to establish the relation between the nautical depth of the approach channel and the shipping costs, in which the characteristics of fleet composition and throughput prognosis were appreciated.

Based on the developed relations

1. nautical depth - capital and maintenance costs of dredging and river works and
2. nautical depth - shipping costs,

the optimum nautical depth was estimated, as the lowest level of costs as optimization criterion.

For the estimation of the optimum nautical depth two models have been developed:

- A tidal wave penetration model in DUFLOW software was constructed to predict the water levels and current velocities in the different cross sections of the Musi-river. The results of this model were used to calculate the dredging volumes and costs for the considered different nautical depths of the channel.

- A probabilistic simulation model of the vessel traffic served to estimate the ship waiting times and the related shipping costs. This vessel traffic simulation model was developed in PROSIM-software. The Duflow model provided the input data with respect to tidal water levels variations for the different nautical depths considered.

2. THE MUSI RIVER

2.1. River characteristics

The Musi-river is a part of a network of rivers (see Figure 1).
For the estimation of the costs of deepening the Musi river navigation channel, the character of the Musi river had to be identified. Data on water levels, current velocities, discharges had to be collected [4].

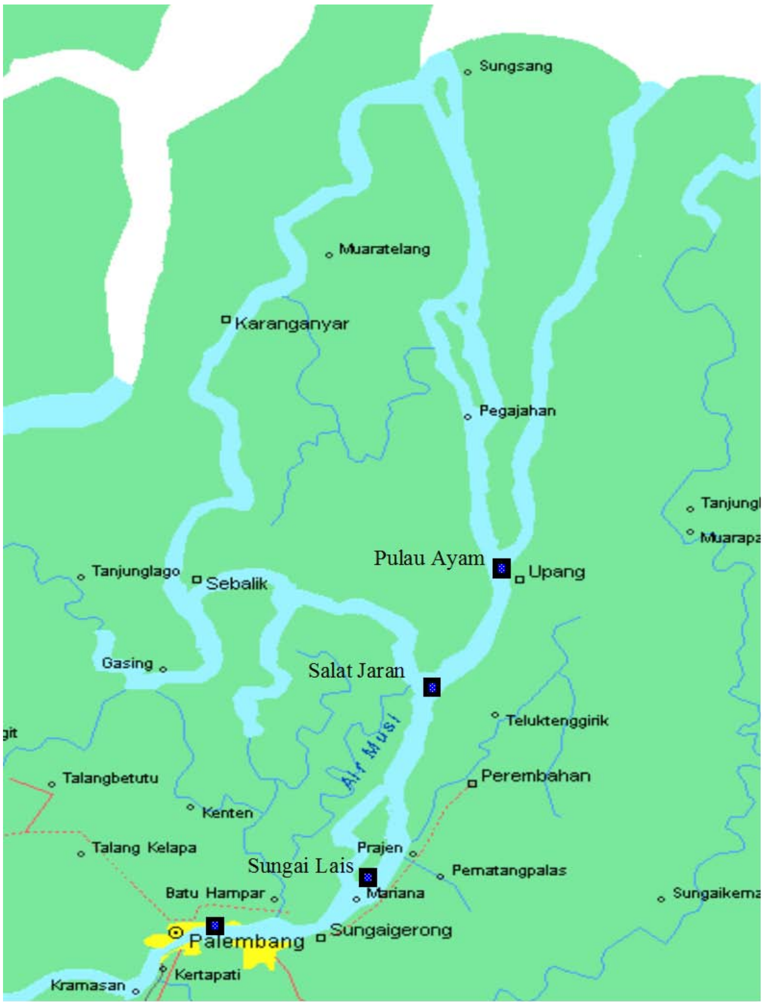

Figure 1: situation Palembang with approach, the Musi River

The Musi river behaves like a tidal estuary. The upstream river discharges are of minor importance, during the dry season (March- September) the average upstream discharge is estimated at 300 m^3/s and during the wet season (October-September) at 700 m3/s. Figure 2 shows that the tidal influence is dominant. The period is diurnal and during spring tide the amplitude is approximately 1.25m. As can be seen from the figure, 90% of the tidal differences in mouth of the Musi river still exit still in Palembang [1].

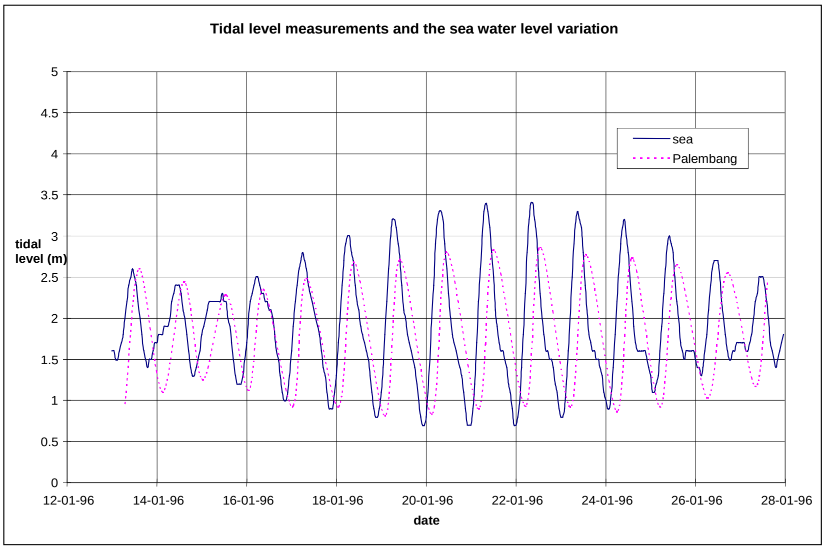

Figure 2: Water Levels Palembang and Sea

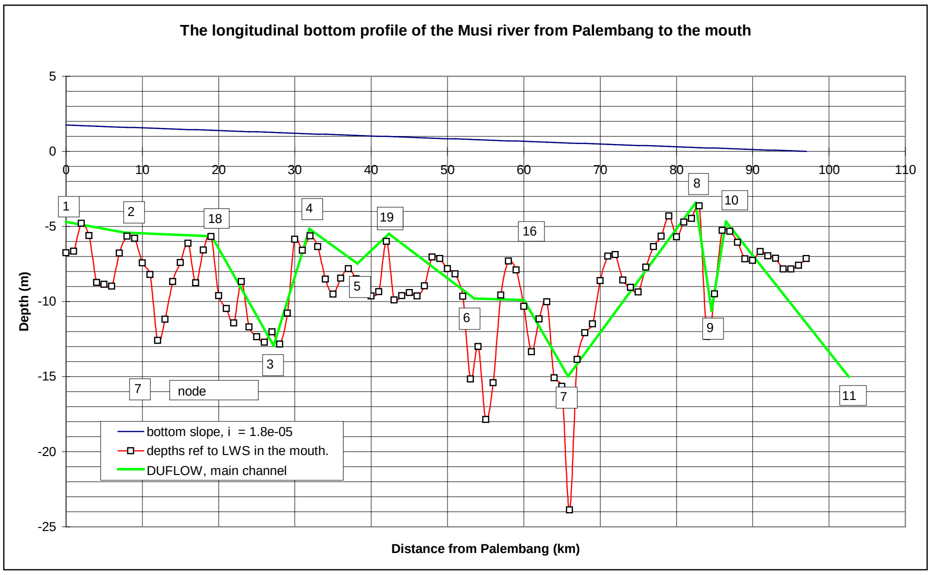

Figure 3: Longitudinal profile Musi river navigation channel

Morphology

Two mechanisms contribute to the development of bars in the Musi river, settlement of bed load material and flocculation and deposition of wash load material. The first mechanism is dominant to about 50 km downstream of Palembang and the latter dominates from that point onwards. Figure 3 gives the longitudinal profile of the Musi river navigation channel.

The river slope is estimated at $1.8*10^{-5}$

The grain size distribution ranges between Palembang to the mouth of the river from 0.6 mm tot about 0.01 mm.

The Indonesian state-owned dredging company, Rukindo intends to maintain the navigation channel at a level LWS-6.5 m with two trailer suction hopper dredgers with hopper volumes of respectively 2400 m3 and 5000 m3. Table 1 shows the yearly dredging amounts in the 1992-1995 period.

Table 1: average Musi river dredging amount during the 1992-1995 period

Part of the river	m^3/year	%
upstream of P.Ayam	318,515	13
river mouth	210,935	9
outer bar	1,863,724	78
total	2,393,173	100

However based on the results of the measurement campaigns the bottom levels of a number of bars were estimated at LWS-5.0 m to LWS – 5.2 m, while in level of the outer bar was even LWS–4.7 to LWS-3.6.
The width of the 2 lane navigation channel to the port of Palembang in the Musi river was reported to be about 150 m and applicable for nearly all vessels.

3. CHANNEL IMPROVEMENTS

3.1. DUFLOW tidal propagation model

In the introduction it was already mentioned that to know the relation, *nautical depth - capital and maintenance costs of dredging*, a tidal wave penetration model had to be developed for an estimation of the current velocities, water levels and discharges in the different locations of the Musi-river.
After development of the model, water levels, current velocities and discharges were determined for the different nautical depths (LWS-6.5 m, LWS- 7and LWS-7.5) of the river navigation channel [2].
As the Musi river is a part of a network of rivers, the tidal propagation model of the Musi river had to cover this network Figure 1 shows this network.

3.1.1. Boundary conditions and validation

At two locations in the DUFLOW model of the Musi river boundary conditions have been specified:

1. the discharge upstream of Palembang and
2. the downstream seawater level variation.

To account for the seasonal influence discharges of 300 m^3/s during the dry season (March until September) and 700 m^3/s during the wet season (October until September) were used.

Validation and calibration of the model
Prototype measurements have been used for the validation and calibration of the DUFLOW model.
The DUFLOW model was calibrated using the water level and current velocity variations at 4 locations: Palembang, Sungai Lais, Salat Jaran and Pulau Ayam.
Figure 4 compares the registered water levels with the water levels simulated by the DUFLOW-model after calibration.
It was concluded that the DUFLOW model of the Musi-river is sufficiently accurate for the study at hand.

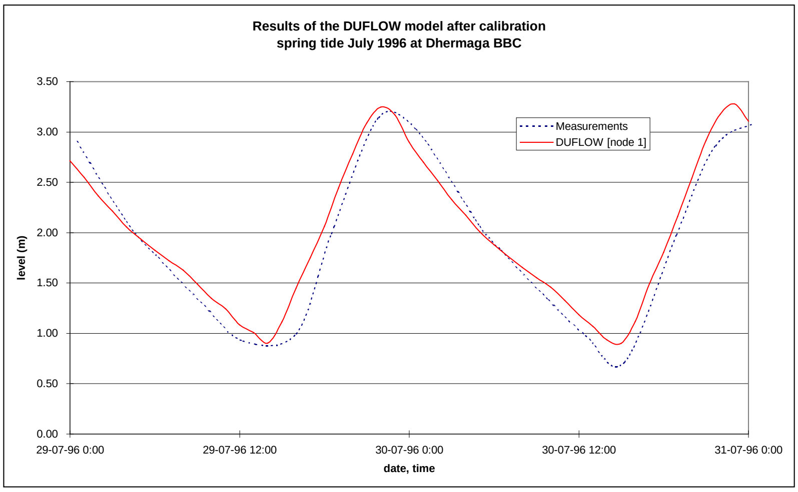

Figure 4: Calibration on water levels

3.2. Dredging

In chapter 2 it was already stated that from Palembang to about 50 km downstream of Palembang (Pulau Ayam) bed load material causes sedimentation while from Pulau Ayam to the outer bar siltation is caused by flocculation of wash load material.
Therefore to account for the dredging volume three categories were distinguished: a. Capital dredging, b. Maintenance dredging upstream Pulau Ayam (bed load material) and c. Maintenance dredging (flocculation).

Capital dredging

The current minimum with of the Navigation channel is maintained at approximately 150 m. Based on this width the capital dredging volumes have been estimated, see Table 2.

Table 2: Capital dredging volumes

Nautical depth below LWS	River bars volume [m^3]	P. Payung/outerbar volume [m^3]	Total volume [m^3]
6.5	28,249	4.684,321	4.712,750
7.0	670,060	5,993,245	6,663,305
7.5	2,937,407	8,564,019	11,501,425

Maintenance dredging upstream Pulau Ayam

Due to the enlarging of the nautical depth at the bars of the Musi river a reduction of the current velocity and with that a reduction of the transport capacity occurs, resulting in an increase of sedimentation. To account for the sediment transport capacity the formula of Englund & Hansen was used [6]. Based on this formula and the results from the Duflow model the bed load transport capacities and sedimentation rates at the dredged bars were estimated (see Table 3).

Table 3: Present and calculated maintenance dredging amounts from Palembang to Pulau Ayam

LWS [m]	S. Lais [m^3/year]	A. Kumbang [m^3/year]	S. Jaran [m^3/year]	S. Upang [m^3/year]	P. Ayam [m^3/year]	Total [m^3/year]
present	83,343	24,065	96,336	62,217	52,555	318,515
-7.0	91,713	29,518	118,136	65,173	56,537	361,077
-7.5	99,344	34,493	129,293	69,332	56,030	388,492
-8.5	112,680	42,764	148,728	76,881	58,698	439,751

Flocculation of wash load material
Wash load material is finer graded than bed load material and is carried in suspension by the river. Wash load material settles to the bottom of the river due to flocculation.
The siltation volumes from Pulau Ayam to the outer bar were determined by extrapolation of data provided.
The calculated total maintenance dredging volumes [5] are shown in Table 4.

Table 4: total dredging volumes

LWS	river shoals volume [m^3/year]	Pulau Payung/ outerbar volume [m^3/year]	total volume [m^3/year]
-6.5m	318,515	2,781,485	3,100,000
-7.0m	361,077	3,538,923	3,900,000
-7.5m	388,492	4,411,508	4,800,000
-8.0m	414,122	4,885,879	5,300,000
-8.5m	439,751	5,360,249	5,800,000

According to Pelabuhan II (the Palembang Port Authorities) the current Musi river maintenance level is LWS-6.5m. However, as already remarked, the actual maintenance level is between LWS-5.0 m and LWS-6.0 m [3].

3.3. Dumping locations

Because of the low m^3 price for maintenance dredging (IRP[1] 2,250, 1996), which is prescribed, the dredged material is dumped in the Musi river. As the possibility exists that dumped material is transported back to the navigation channel the feasibility of the location should be examined critically.

3.4. Dredging costs

It was assumed that the dredging costs are carried out with two dredgers owned by the State Dredging Company Rukindo.
For the estimation of the dredging costs the following costs aspects have been recognized:
Operational costs of the dredgers with crew, fuel and lubricant, depreciation, insurance

1. Production of the dredgers with:
   a. distance to disposal site,
   b. shape dredging area,
   c. time to dump the material
   d. delay factors as weather conditions, mechanical breakdowns and crew inefficiencies,
   e. soil type to be dredged
   f. characteristics of the dredgers

Table 5: dredging costs

LWS	dredging costs [billion] }]IRP/year]
-6.5m	6.75
-7.0m	8.63
-7.5m	11.4
-8.0m	13.2

[1] 1 us $= 2660 irp

-8.5m	16

Table 5 shows the dredging costs per year for the different nautical depths.

4. Shipping on the Musi river

4.1. The present navigation channel of the Musi river

The navigation channel from the sea to the port of Palembang has a length of approximately 100 km. As stated before a minimum depth of LWS-6.5 m is tried to be maintained; however at some locations a smaller depth is encountered. Figure 5 and Figure 6 show the shallow parts in the navigation channel.

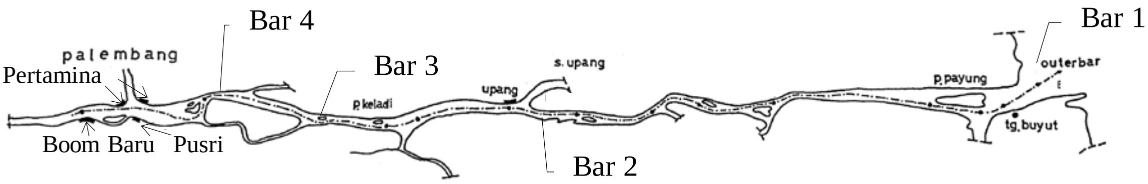

Figure 5: Location of bars in the Musi River

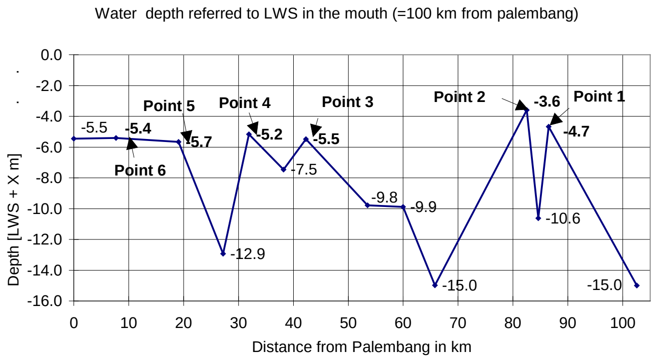

Figure 6: Schematized longitudinal water depth profile for Musi navigation channel

The minimum width of the approach channel is approximately 150 m.
The most important terminals of Palembang with quay lengths, average service times and the average number of vessels calling the terminals are presented in Table 6. Figure 7 shows the location of the terminals in Palembang.

Table 6: Characteristics fleets and terminals

	Boom Baru	Pertamina	Pusri	Other terminals
Vessels per month	60	90	30	43
Average service times [minutes]	2800	1800	2900	3100
Average inter arrival time [minutes]	730	487	1460	1018
Quay length [m]	1235	1200	780	not applicable
Annual throughput [ton]	2,373,220	10,062,120	1,905,133	not applicable

In the shipping analysis the ships have been divided into 4 categories according to their origin/destination, based on port of Palembang records.

1. Boom Baru terminal (general cargo and container cargo) , with two general cargo quays and one container quay
2. Pertamina terminal (crude oil and oil products)

3. Pusri terminal (fertilizer)
4. Other terminals, (all the other vessels calling the port of Palembang).

The first 3 categories have been chosen, because these 3 terminals pay the annual dredging costs (Pelabuhan II (Boom Baru) 15%, Pertamina 60% and Pusri 25%). The data on the "Other Terminals" are necessary to account for the influence on the ship traffic to the first three terminals.

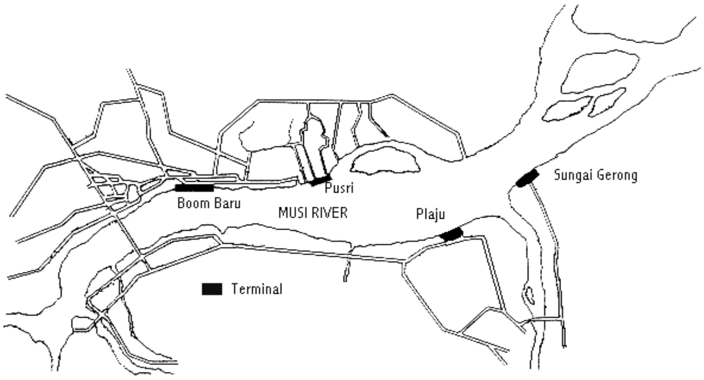

Figure 7: Port of Palembang

As a lot of parameters, controlling the shipping process, have a stochastic character. Therefore a probabilistic simulation model of the vessel traffic from and to the port of Palembang has been developed in PROSIM-software. The model served to estimate the influence of the nautical depth of the channel on the ship waiting times and with that the influence on the shipping costs.
The characteristics of the vessels and the terminals were based on the port of Palembang records. The DUFLOW model provided the tidal data.

4.2. Vessel traffic simulation model "PALEMBANG"

Introduction

PROSIM [7] is an advanced software system for combined discrete/continuous simulation using a personal computer. Simulation is used to study the dynamic behaviour of a system by means of experimentation with a model of that system. A model is a description of the "real life system" by leaving out all non-relevant aspects. The configuration of the model PALEMBANG is presented in Figure 8

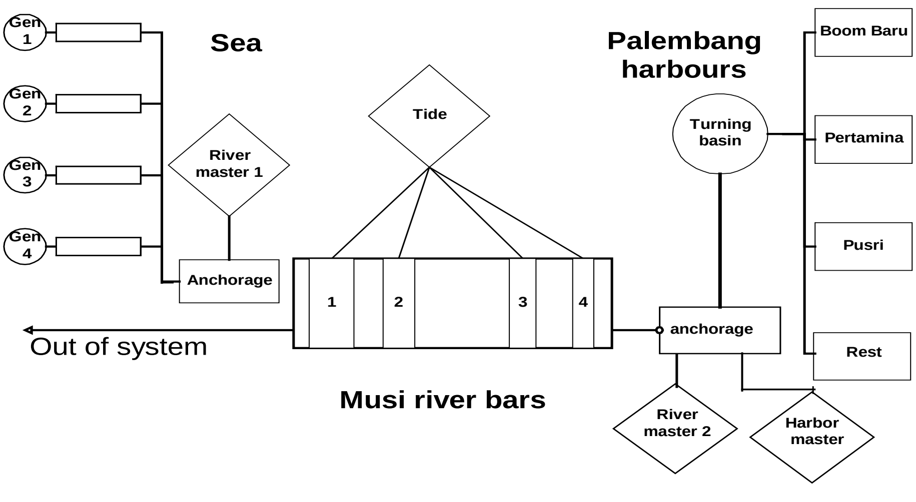

Figure 8: Configuration of the Model Palembang

Description of the PALEMBANG simulation model

When a vessel has been generated by one of the four generators, the vessel enters the anchorage at the outerbar.

The river master for incoming vessels checks the tidal conditions and the traffic situation. If permission has been granted the vessel will leave the anchorage queue and will enter the Musi river channel. After her stay in the channel the vessel will enter the waiting queue of the port of Palembang. The *harbour master for incoming vessels* checks, the traffic situation and a berth will be allocated by the *quay master*. After a berth is assigned and the traffic situation allows entrance, the ship leaves the waiting queue, manoeuvres to her terminal and "enters" the “quay queue” of the terminal. When the vessel has been unloaded and loaded (equal to the service time of that vessel) *the harbour master for outgoing vessels* checks the traffic situation in the harbour. The *river master* checks the tidal conditions and the traffic situation of the Musi-river. If no problems are encountered, the ship will leave the port of Palembang and enters the Musi River channel. After her stay in the channel the process of the ship will be terminated and the ship will leave the system.

Input data

Important input data concern the fleet characteristics. A ship from a fleet is characterised by a number of parameters (attributes of the ship) as for instance type, DWT (and related parameters as length, width, draught), inter arrival time and service time. Some parameters are stochastic and are described by using distribution functions; examples of stochastic parameters are service time, inter arrival time and dwt. In the simulation model, all the values of the stochastic parameters are determined by taking samples from distribution functions. The mentioned Palembang records were used to set up the distribution functions [3].

As an example Figure 9 shows the registered inter arrival times and the exponential distribution function, used in the model to generate arrivals of vessels for the Boom Baru terminal. Figure 10 gives the relation between draught and dwt of the vessels calling the Boom Baru terminal.

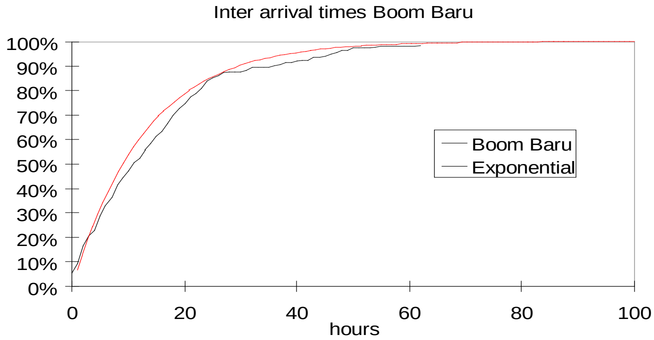

Figure 9: Inter arrival times of the Boom Baru vessels

Shipping costs

Basically shipping costs can be divided into 4 categories:

- capital costs, interest and capital repayments,
- operating costs, expenses due to day-to-day running of the ship,
- voyage costs, fuel, port charges, etceteras,
- cargo handling costs, loading, stowing and discharging.

For the estimation of the total shipping cost a total round trip was considered, consisting of:

- time spend at sea

- time spend in the port of Palembang (waiting time, sailing time on the Musi river and service time)
- time spend in the port of origin

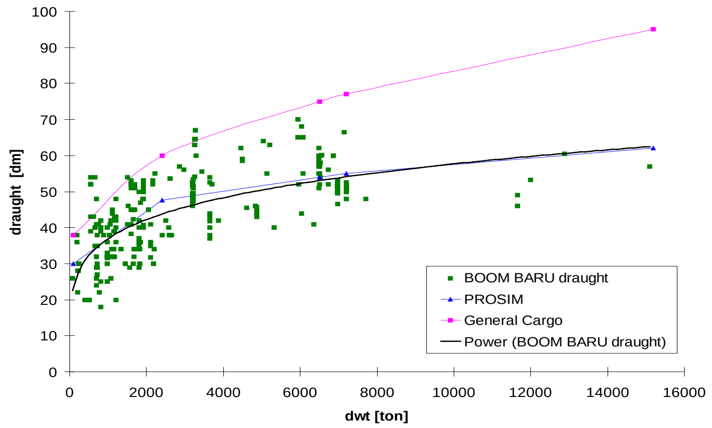

Figure 10 draught distribution over dwt of the Boom Baru vessels

Also effect of decrease of number calls when the nautical depth increases was accounted for. The time spent at sea per round trip was calculated on the assumption that vessels at sea have an average speed (10 knots). Furthermore it was assumed that all voyages are to or from Singapore, West-Indonesia or East-Indonesia, resulting into an estimate of the average number of days spent at sea per voyage. Based on the assumptions mentioned above, a shipping costs approximation could be made [8], [9].

4.3. Results of the vessel traffic simulation study

In the first step waiting times as a function of the nautical depth and draught increase:

1. existing fleet
2. fleet with 10% draught increase
3. fleet with 20% draught increase
4. fleet with 30% draught increase

were registered. Figure 11 shows the average waiting times over all fleets.

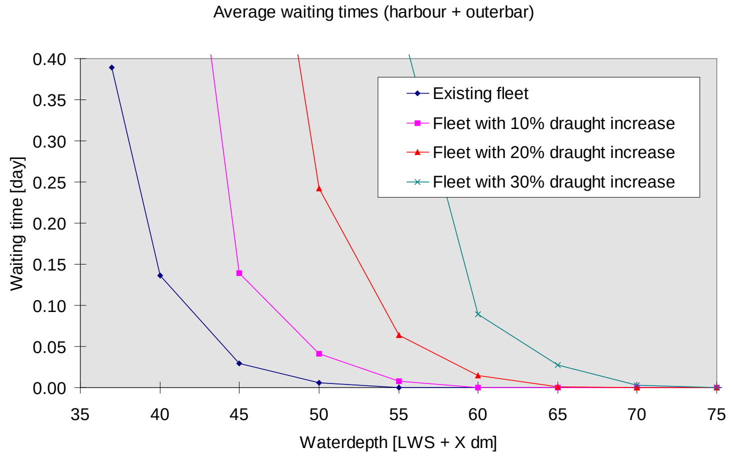

Figure 11 Average waiting times for 4 fleet compositions

Based on waiting times, the estimation for the round trip time and the number of trips, the total shipping costs were determined. The graphs in
Figure 12 show that for channel depths up to approximately LWS -4.3 m the existing fleet gives the lowest shipping costs. From LWS-4.3 m to LWS-5.2 m a fleet with 10% draught increase is preferred and from LWS -5.2 m to LWS-6 m a fleet with 20% draught increase. From LWS-6 m 30% draught increase gives the lowest shipping cost level.

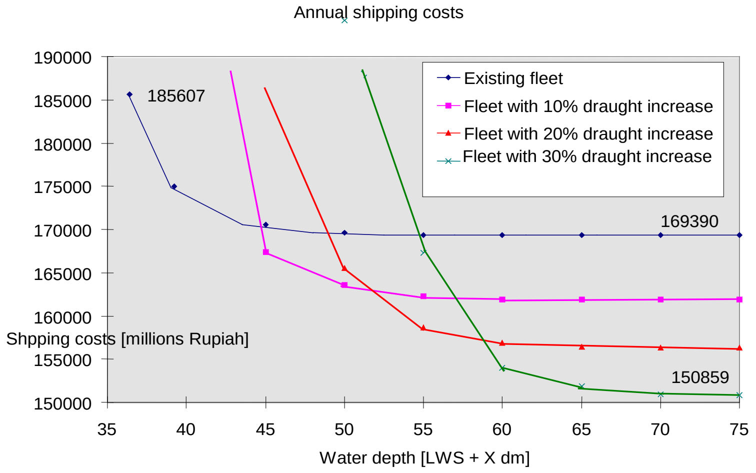

Figure 12 Annual shipping costs as a function of navigation depth

5. THE OPTIMUM NAUTICAL CHANNEL DEPTH

For the optimum nautical depth of the Musi-river channel the criterion of the lowest level of costs was applied. The total costs as a function of the nautical depth are presented in fig 13. From this graph the conclusion can be drawn that the optimum nautical depth of the Musi River is around LWS - 6.5 m in combination with a 30% fleet draught increase**.**

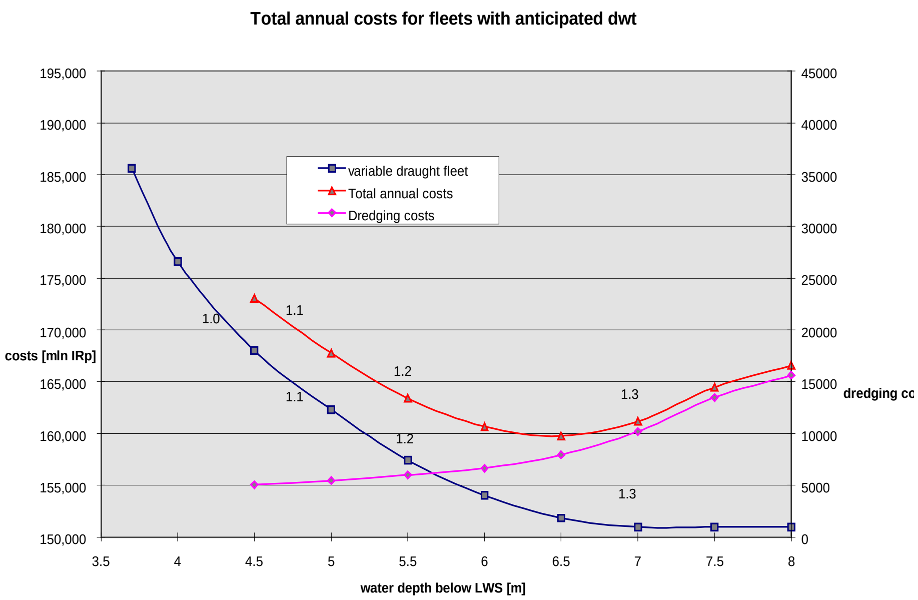

Figure 13: Total costs

6. CONCLUSIONS

- The Musi-river is strongly influenced by tidal conditions at sea and the Musi river has a significant interaction with its branches.
- A combination of LWS-6.5 m nautical depth and a 30% fleet draught increase (with respect to the present day situation) was identified as the optimum
- A 10% throughput increase does not change the optimum nautical depth significantly

7. ACKNOWLEDGEMENT

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