COMPUTER SIMULATION MODEL INTERNATIONAL CONTAINER TERMINAL TANJUNG PERAK, SURABAYA, INDONESIA

R. Groenveld and S. Wanders
Delft University of Technology – Faculty of Civil Engineering and Geosciences
Hydraulic Engineering Group
P.O.Box 5048
2600 GA Delft The Netherlands
E-mail: pmss@planet.nl

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ABSTRACT

This paper describes the simulation study to determine the capacity of the Container Terminal of Surabaya as designed for the year 2005.
The Surabaya container terminal complex will consist of three independently operating terminals: two terminals for the international container traffic and one for inter island traffic. The quays of the three terminals will be connected to the container yards only by one bridge. So the only interaction between the terminals occurs via the traffic on the bridge.

First a model of the present situation (1997) was developed, verified and validated.

In the second phase three models were developed for:
a. the new international terminal,
b. the inter island terminal and
c. the bridge.

The results of the models pointed out that the capacities of the portainers and the stacking areas of the container yards are influencing the total capacity of the terminal.
Especially the dwell times of the containers in the yard could seriously effect the overall capacity of this terminal.
If the efficiency of the terminal operation can be improved and the dwell time of containers in the yard can be reduced, both to standard levels, the terminal will be able to handle about 1.4 million boxes per year or 2 million TEU per year.

1. INTRODUCTION

The "Tanjung Perak" International Container Terminal is located in the port of Surabaya. While Surabaya is situated on east part of Java (see figure 1-1), which is the most populated island of Indonesia.

Figure 1-1: Location Surabaya

The port of Surabaya is the second major port of Indonesia and the main port of East Java.
Before the economic crisis hit Asia the container flow through the "Tanjung Perak" International Container Terminal had experienced such an increase that it was expected that the present facilities of the terminal might not be able to handle the container flow in the near future.
In order to deal with the anticipated increase of container throughput, the container terminal is currently being expanded with (see figure 1-2):

- another 500 meters quay for international container traffic located west of the present quay (ICT2),
- 450 meters quay for inter-island traffic along the bridge (ITT),
- expansion of the container yard,
- corresponding upgrading of the terminal equipment.

Because it is uncertain to which extent the capacity of the terminal can be increased and which alterations of terminal facilities and/or improvements of terminal operations will be required to achieve this, a simulation study on the future operative "Tanjung Perak" International Container Terminal has been carried out.

Objectives
The objective of this study is to investigate the capacity of the future container terminal after completion of the scheduled expansion and to assess the impact on various terminal operations (with particular attention for the increased traffic on the bridge). Also part of the objective is to identify the possible

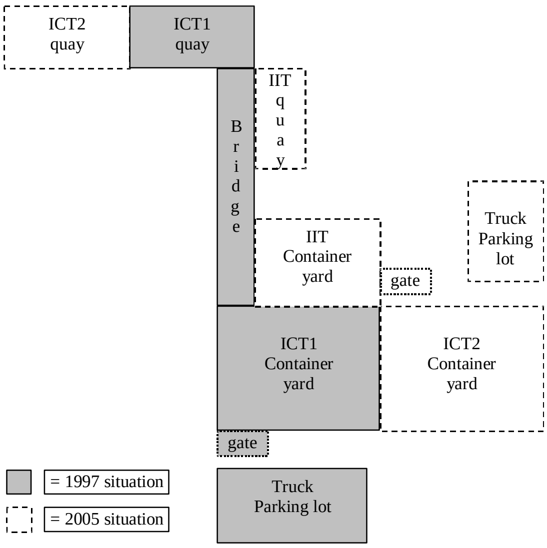


Figure 1-2 Layout Tanjung Perak International Container Terminal

constraints and to analyse the measures that can be taken to further increase the terminal capacity in the future.

The complicated terminal system was investigated by the development of a number of computer simulation models in PROSIM software:

- a model of the International Container Terminal as it was operating in 1997 (ICT1 model),
- a model of the second International Container Terminal (ICT2 model),
- a model of the Inter Island Terminal (IIT model);
- a model of the bridge connecting the quays with the yards. The two ICT models and the IIT model generated the input data needed for this model.

As it was planned that the two International Container Terminals and the Inter Island Terminal would operate independently from each other, three independent simulation models of these terminals were developed.
The bridge model connects the three terminal models providing the traffic boundary conditions for this bridge model.

2. INTERNATIONAL CONTAINER TERMINAL

In order to be able to create a computer simulation model of the container terminal, first an extensive data investigation and survey was carried out. After obtaining a proper insight of the operations and the performance of the terminal, the simulation model could be developed and subsequently verified and validated.

The layout of the terminal in 1997 can be seen in figure 2-1 below.

The quay has a length of 500 meters and consists of maximal three berths. According to terminal management a quay occupancy of about 70% was reached in 1997.
Four rail-mounted gantry cranes (portainers) are responsible for the unloading and loading of the vessels. The quay is connected with the mainland by means of an 1800 meters long bridge used as a two-lane road.
The container yard (as can be seen in figure 2-1) contains 10 container stacks: five stacks for the export containers, four stacks for the import containers and one stack for the empty containers. Each stack has a capacity of 1848 TEU's (stacked 66 TEU long, 7 TEU wide and 4 TEU high). The average dwell time of the export containers in the yard is four to five days. The import containers have an average dwell time of 8 days.
Eleven RTGC's (Rubber Tired Gantry Crane) are stacking the container. Both tractor-trailers (TT) and trucks are loaded and unloaded by the RTGC's. North of the stacks a parking lot is available for trucks and for RTGC's.
TT's are used for the transport of containers from the stacks to the quay and vice versa. One TT is capable to transport 2 TEU: either one 40-ft container or two 20-ft containers. In case a TT is not operational, it is parked in the TT parking lot in the NE corner of the container yard. According to terminal management, seven TT's are working for each portainer in operation, or in total 28 TT's (4 portainers x 7 TT's). In practice however, it seems that approximately 5 or 6 TT's are operational per portainer instead of 7.
For the transport of containers to and from the terminal, different types of trucks are used. The majority of these trucks have a capacity to carry maximal 2 TEU.

2.1. Vessel characteristics

Inter arrival times
The arrival times of the ships at the terminal (in 1997, 992 ships called at the terminal) provide an insight in the "*inter-arrival times*" of the ships. The inter-arrival time is the time between the arrival of two successive ships at the terminal.
The inter-arrival times are assumed exponentially distributed. The average inter-arrival time in 1997 was 8 hours and 52 minutes (table 2-1 below).

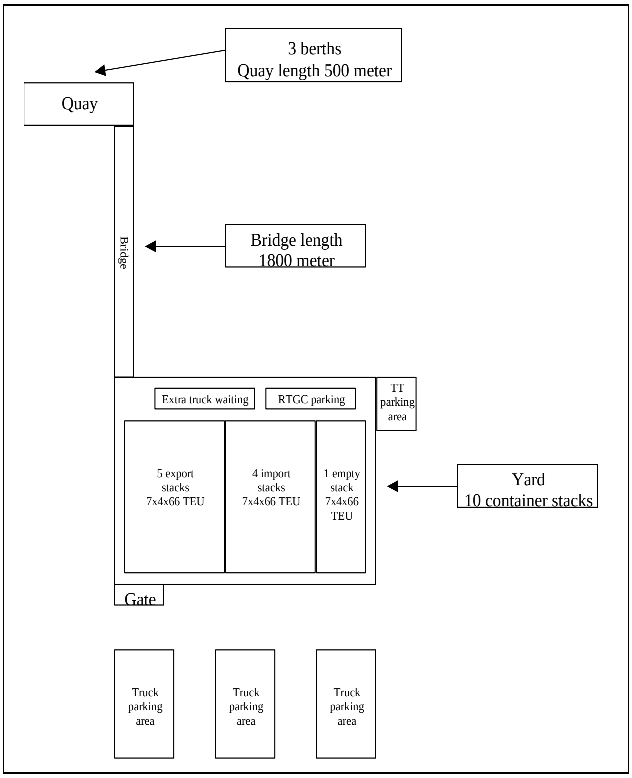


Figure 2-1: Layout ICT1 - terminal

Vessel turn-around times
The "turn-around time" of a vessel is defined, as the time the vessel is moored at the quay. According to the 1997 records, the average turn-around time of a vessel at the terminal was 19 hours and 10 minutes (see table 2-1)

Vessel length distribution
The average vessel length in 1997 was 153 meter (see table 2-1). No distribution function could be selected to fit the ship length data.

Table 2-1: Vessel Characteristics

	inter arrival times [hours]	turn around times [hours]	length [m]
Minimum	0.00	2.75	114.00
Maximum	43.75	68.00	208.00
Mode	0.33	14.92	121.00
Mean	8.83	19.16	152.58
Std Deviation	6.74	7.35	24.50
Variance	45.46	54.05	600.17

Container characteristics
A total throughput of nearly 390,000 box moves (about 570,000 TEU) was realised in 1997. The average number of boxes unloaded and loaded per ship was 393 in 1997. The distribution of (full and empty) containers imported and exported in 1997 is summarised in table 2-2. Obviously there is more export than import traffic.

Table 2-2: Container characteristics

	Import	Export
total boxes	184,059	205,651
% average	47	53
av. per ship	186	207
% 20' full	43	54
% 40' full	28	41
% 20' empty	13	2
% 40' empty	16	3

2.2. Crane production rates

Portainer production rate
According to the 1997 terminal records, the portainer production for unloading and loading containers was approximately 21 box moves per crane per hour.

Yard survey results
The yard survey showed that one, two or three Rubber Tyred Gantry Cranes (RTGC's) are possibly working simultaneously in the same stack The number of RTGC's at work in a stack, depends on the number of free RTGC's, the number of ships at the quay and the number of carriers waiting to be serviced.

Besides stacking activities, a RTGC has to drive to other locations along the stack (approximately once every five container lift actions) and occasionally the stack will also have to be re-shuffled by a RTGC. This occurs about once every four container lift actions.
Lift on/ lift off, drive times and reshuffle times are specified in table 2-3.

Table 2-3: Results RTGC survey

	Lift on/off times	Reshuffle times	Drive times
Minimum	17.30	19.60	5.55
Maximum	107.00	73.00	235.10
Mode	39.73	27.61	39.98
Mean	51.27	38.90	45.52
Std Deviation	16.82	13.31	42.58
Variance	282.84	177.29	1812.66
Skewness	0.41	0.77	2.62

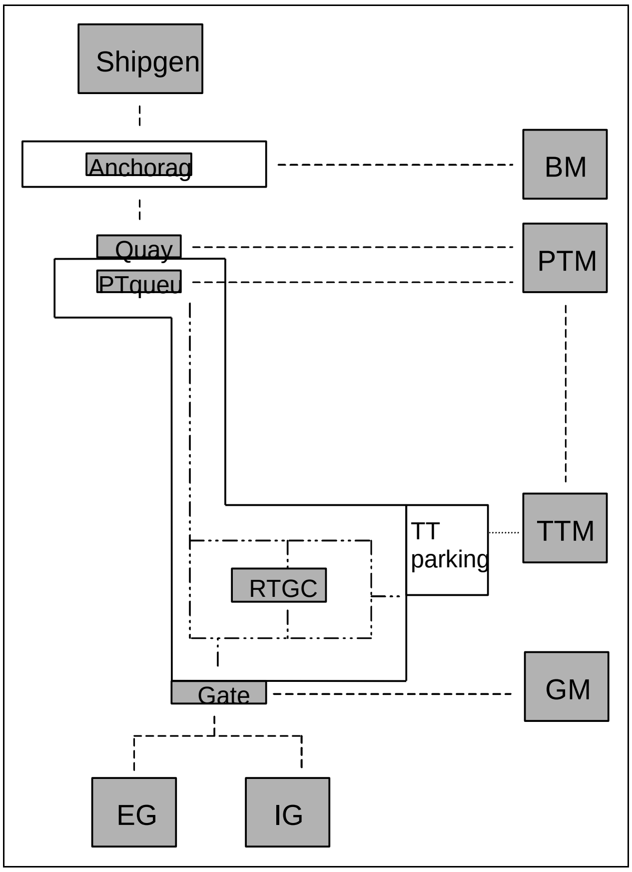
The table indicates that a RTGC can make approximately 30 box moves per hour. These RTGC actions are best characterised by a gamma shaped distribution.

2.3. Computer simulation model ICT1

Introduction
As stated before the model was developed in Prosim software using the process description method.

The process description method describes the processes of each live component in the model [Sierenberg, 1988]. Table 2-4 shows the major components of this model.
The model has two "*boundaries*": one located at the seaside and one at the landside (see figure 2-2).

- Seaside: this boundary is set at the harbour anchorage, where the vessels arrive after having been generated;
- Landside: the gate of the terminal constitutes the landside boundary. Trucks are generated to arrive at the gate and wait in a parking lot until further notice.



Shipgen : Ship generator
BM : Berth master
PTM : Portainer master
TTM : Tractor-trailer master
GM : Gate master
EG : Export generator (trucks)
IG : Import generator (trucks)

Figure 2-2: Model ICT1

After a vessel has been generated by the "*shipgenerator*" with all necessary attributes, she will enter the harbour anchorage until granted permission to moor at the quay. When a vessel is generated, an "*exportgenerator*" is also activated to generate the necessary trucks with export containers, for this vessel. When the "*berthmaster*" grants the vessel permission to moor at one of the berths, this vessel will sail to its assigned berth and moor. Once the ship has arrived at the quay, the "*portainermaster*" is activated who will assign one or two portainers to the ship. After this is done, the "*tractor-trailermaster*" and the "*importgenerator*" are activated. The "*tractor-trailermaster*" instructs a number of tractor-trailers (TT's) to commence activities and the "*importgenerator*" creates the trucks needed to pick up the import containers. The activated portainers will first unload the vessel and finally load the vessel. RTGC's in the container yard are activated the moment a truck or tractor-trailer arrives at the stack. To instruct the tractor-trailers as to where to go and what to do, there is a “*trafficmaster*” at the quay and at the yard. A “*trafficmaster*” at the gate is responsible for the admittance of the trucks into the terminal yard. In the model also three “*traffic lights*” have been introduced to manage the traffic on the bridge. Once a vessel has been completely serviced (unloaded and loaded) it will deberth and is terminated when sailing to the sea. When a vessel is in the process of leaving, the “*berthmaster*” is notified and the portainers and tractor-trailers are either reassigned or made passive.

Table 2-4: Major components model ICT

Component	**Task**	**Component**	**Task**
Ship Generator	generates container vessels	quay traffic master	manages quay traffic
Ship	carries out ship process	yard traffic master	manages yard traffic
berth master	manages berths occupancy	generators trucks	generates trucks at inland side
portainer master	manages assignment of cranes	trucks	carries out truck process
portainer	carries out portainer process	RTGC	carries out RTGC process
bridge traffic master	manages bridge traffic	TT-master	manages TT use
gate traffic master	manages gate traffic	TT	carries out TT process

3. Future container terminals

3.1. Overview future terminals

The present International Container Terminal is currently being expanded with a second International Container Terminal (ICT2) and an Inter Island Container Terminal (IIT). Since it is planned that these three terminals will be operating independently by 2005, two additional terminal models were developed.

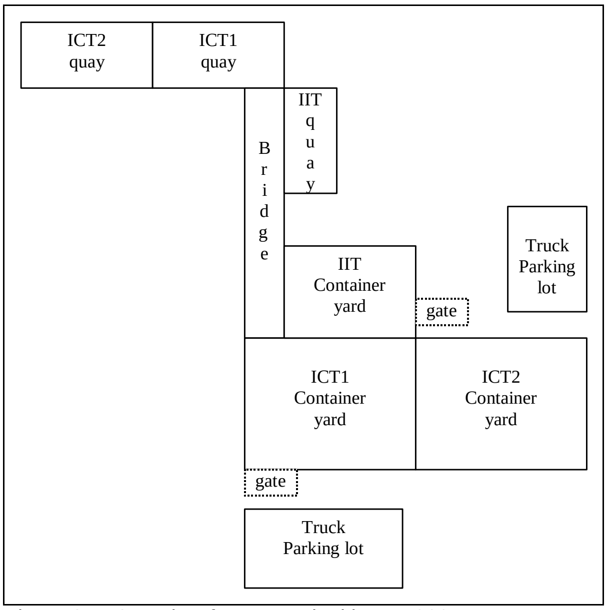


Figure 3-1: Overview future terminal layout 2005

As all three terminals are to use one and the same bridge, a model of the bridge was created to investigate the increased traffic load.
So the following four simulation models have been used to investigate the performance of the future container terminal: ICT1 model, ICT2 model, IIT model and the BRIDGE model.
In figure 3-1 below, an overview of the future terminal layout can be seen.
The ICT2 quay (also with a length of 500 meters) will be located west of the existing quay and the ICT2 container yard will be located to the east of the existing container yard (see figure 3-1).
The IIT quay (450 meters length) is being constructed alongside the bridge and the IIT container yard will be located north of the existing container yard (see figure 3-1).
The required service level of the vessels was used to determine the maximum capacity of a terminal configuration.
The maximum average waiting time of 2 hours, or about 20% of the service times of the vessels, was set as lowest acceptable service level.

3.2. First International Container Terminal

Introduction
According to terminal management, it is not envisaged to change the present terminal equipment. This means that after the expansion, the same quay cranes (portainers), yard cranes (RTGC’s) and tractor-trailers will be used. The container yard will not be extended and will thus keep its present capacity.

Modelling assumptions
In order to predict the theoretical maximum container throughput the terminal will be able to handle in the future, the following assumptions have been made:

- *Portainer production rate*

According to terminal management the portainer production rate can be increased from 21 box moves per hour per portainer up to 30 box moves per hour if the efficiency of various terminal operations is improved. It was therefore assumed that the portainer production rate increases to 30 box moves per hour per portainer.

- *Efficiency level portainers*

During the survey an “efficiency level “ of the portainers of 67% was monitored.
For future situations this level was increased to 80 %. .

- *Container distribution*

The distribution of the import and export containers per vessel and the distribution of the container size and container load were assumed not to alter in the future.

- *Stack volume*

A reduction of the average dwell time of containers was expected. For the import containers an average dwell time of 4 to 5 days and also for the export containers an average dwell time of 4 to 5 days was assumed.

Analysis results computer simulation model ICT1
The maximum number of box moves that can be handled by the terminal, with the earlier made assumptions, amounts up to about 580,000 (see table 3-1 below), which is more than a 50 % increase of container throughput. This number of box moves is reached at 70 % quay occupancy and an average waiting time of the vessels in the anchorage of about two hours.

Table 3-1: Simulation results ICT1 with 6 TT per portainer

box moves/year	vessels	quay occ.	t.a.t.	i.a.t.	av. waiting time anchorage (hours)
517,147	1316	61%	12.0	6.5	0.1
579,345	1474	72%	12.7	5.8	2.0
650,034	1654	85%	13.3	5.1	16.1

The capacity of the RTGC's in the container yard remains sufficient, even with this increased container throughput.

3.3. Second International Container Terminal

The new International Container Terminal will operate in the same way as the present terminal. According to the terminal authorities, the new terminal will be a replica of the existing terminal.

Model boundaries and assumptions
The only difference with the ICT1 model, concerns the larger driving distance between the quay and the yard:

- On the quay, the TT's (Tractor Trailers) have to drive an additional 500 meters to reach the portainers and the bridge;
- When leaving the bridge and driving to the container yard, the TT's now have to drive 300 meters extra before reaching their destination (the same applies when leaving the yard);
- This additional travel distance applies also for the trucks with the ICT2 container yard as destination.

Analysis results computer simulation model ICT2
The new International Container Terminal can handle about the same amount of containers as the existing terminal, approximately 580,000 box moves. The main difference concerns the slightly higher vessel turn-around times and average waiting time in the anchorage (see table 3-2). This is due to the fact that the TT's and trucks have to drive longer distances.
By assigning 7 to 8 TT's per portainer these differences are reduced. Assigning more TT's has the same effect as for the original terminal; namely the waiting times for the TT's at the quay and yard will increase.

Table 3-2: Simulation results ICT2

TT's per pt	box moves/year	vessels	quay occ.	t.a.t.	i.a.t.	av. waiting time anchorage (hours)
6	578,578	1472	75%	13.3	5.8	3.2
7	579,111	1474	73%	12.9	5.8	2.1
8	578,973	1473	72%	12.7	5.8	1.9
10	579,111	1474	72%	12.7	5.8	1.8

t.a.t. = turn around times
i.a.t. = inter arrival time

3.4. Inter Island Terminal (IIT)

Introduction
At present the Inter Island Terminal (IIT) is being constructed, scheduled to be operational in the year 2000. The quay is situated alongside the bridge with a length of 450 m. Initially the berths are provided with two portainers with a production rate of 16-17 box moves per hour supplemented with two cranes with a lower production rate of 9 box moves per hour. This Inter Island Terminal is planned to service only vessels with loads larger than 100 TEU. These vessels (coasters) are supplying smaller ports unable to accommodate larger vessels.
Again the service level of the vessels was used determine the maximum capacity of a terminal configuration.
With respect to this terminal the maximum turn around time of 20 hours was set as lowest acceptable service level.

The simulation model has the same structure as the previous models (ICT1 and ICT2).
Here only the results will be presented.

Analysis results computer simulation model IIT
The following can be concluded:

- The terminal can handle approximately 230,000 box moves per year (corresponding with nearly 1200 vessels) at a 70 % quay occupancy (see also table 3-3 below).

Table 3-3: Run results IIT

TT's per pt	box moves/year	vessels	quay occ.	t.a.t. (hours)	i.a.t. (hours)	av. waiting time anchorage (hours)
5	231,070	1261	70%	20.0	7.0	1.7
8	231,045	1261	70%	19.9	7.0	1.6

- The capacity of the terminal yard is also sufficient for the in the model assumed container dwell times;
  Increasing the number of TT's in the model does not have a significant effect on the total number of containers that can be handled. Instead the waiting times of the TT's at the quay and in the yard increases.

3.5. Bridge model

Introduction
At present with one International Container Terminal in operation, the bridge is used as a two-way road, wide enough to accommodate a third lane.
With the expansion of the terminal the number of active TT's at the terminal will increase from about 24 TT's at present to about 72 TT's in the future. Since the Inter Island Terminal quay is situated alongside the bridge, it cannot be avoided that TT with different quay and yard destinations will have to cross traffic lanes.
This increased traffic flow, compounded by the fact that different traffic flows will have to cross traffic lanes, makes it necessary to review the bridge situation.

Description of the Bridge model
The model has three boundaries: two (ICT quays and IIT quay) at the bridge entrance from the quay-side and one at the bridge entrance from the yard-side:
The TT's with the quay as destination are generated at the yard-side entrance and terminated once they have left the bridge and arrive at the quay.
The models ICT1, ICT2 and IIT provide the boundary conditions for the bridge traffic. Figure 3-2 presents the configuration of the Bridge Model, illustrating the use of the different traffic lanes as has been simulated in the computer model.

Table 3-4 Components in the computer simulation Model Bridge

	Module	Description
1	Define	Definition
2	Mainmod	Run control
3	TTgenerator	Generates tractor-trailers with their inter-arrival times
4	TTprocess	Tractor-trailer process
5	Crosslightprocess	Traffic light to manage the traffic crossing the traffic lane to reach the IIT quay
6	Insertlightprocess	Traffic light to manage the traffic driving onto the bridge coming from the IIT quay
7	Yardlightprocess	Traffic light to manage the traffic driving onto the bridge coming from the yard
8	ICTquaylightprocess	Traffic light to manage the traffic coming from the ICT quays with destination yard

Once a TT has been created by the "TT-GENERATOR" the TT will wait for permission to drive onto the bridge. Permission is granted by the traffic lights. The only purpose of these traffic lights, ruling the traffic from the ICT quays and from the ICT yards is to ensure that the TT's maintain a minimum distance between one and another.

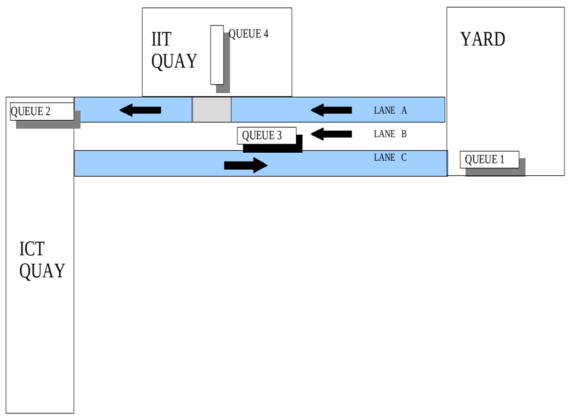


Figure 3-2: Configuration bridge model

The traffic light, controlling the traffic from IIT quay, is checking moreover a safe insertion onto traffic lane A. For the traffic with destination IIT (coming from the IIT-yard), using lane B, a traffic light is checking a safe crossing of lane A. For this purpose queueing is possible on lane B.
The components of the Bridge model are shown in table 3-4.

Simulation results computer simulation model "Bridge"
The bridge has been simulated for a situation that all three terminals are operating each at the highest traffic load.
As stated before the capacity for both ICT terminals and the IIT terminal is estimated at respectively 580,00 boxes and 230,000 boxes per year. Three runs were carried out:

- a run where ICT portainers are operating with 6 TT each and the IIT portainers with 5 TT each.
- a run where ICT portainers are operating with 8 TT each and the IIT portainers with 8 TT too.
- a calamity run where ICT portainers are operating with 6 TT's each and the IIT portainers with 5 TT each

During the first run, the waiting times for the TT to enter the bridge were in the order of seconds with maximum queue length of 3 TT. In the second run, where more TT were used, slightly higher waiting times and queue lengths were registered.
Concluding it appears that the traffic load on the bridge, created for a situation that all three terminals operate at a theoretical maximum container throughput does not negatively effect the terminal operations at all.

At last a so-called calamity simulation run was carried out.
If one of the berths cannot be used for a period of time filling up of the anchorage will occur, leading to higher quay occupancies than under normal conditions.
This exceptionally high peak load at quays will cause extra traffic load on the bridge. This situation was simulated for each of the terminals, handling the maximum container throughput.

The model showed that the length of the queues and the average waiting times of the TT's in the queues are only slightly higher than under normal conditions. The magnitude of the waiting times is still too small to have a significant influence on the turnaround time of the vessels.

4. CONCLUSIONS AND RECOMMENDATIONS

1. The simulation language Prosim, using the process simulation method, satisfied quite well the demands of the models to be developed. It is expected that flow oriented or object oriented languages which are now a days strongly supported by the use of icons from templates would have caused much more problems in formulating the models.
2. The real life system was schematised by using three independent terminal models. To simulate the interaction between the traffic coming from the terminals on the bridge, a separate bridge model was developed. This schematisation satisfied quite well.
3. Because of the relative low traffic intensity on the bridge the interaction did not influence the terminal operations, so feedback to the terminal models was not required.
4. The capacities of both ICT terminals and the IIT terminal amount respectively 580,00 boxes and 230,000 boxes per year. So the overall capacity the terminal is estimated at 1.4 million boxes per year or 2 million TEU per year.
5. Due to political changes in Indonesia, the ICT's and probably the IIT will be integrated to one terminal resulting in different operational rules.
   It is foreseen that in such a situation a nesting system of models should be developed for an estimation of the capacity.

5. REFERENCES

Book
Sierenberg & de Gans b.v. (1987-1993) "Personal Prosim Reference Manual", Third edition 3.00, Waddinxveen, The Netherlands

Book
Sierenberg & de Gans b.v. (1987, 1988) "Prosim Textbook", release 3.03, Waddinxveen, The Netherlands

Lecture notes
Velsink, H. prof. ir. (October 1994) "Ports and Terminals", Planning and Functional Design, lecture notes f12/f13, Delft University of Technology, Delft, The Netherlands

Lecture notes
Groenveld, R. ir. (October1994) "Service Systems in Ports and Inland Waterways", lecture notes f12/f13, Delft University of Technology, Delft, The Netherlands

Technical report
Report Inter Island Container Terminal, Surabaya (December 1997) "Rencana Pengoperasian Dermaga Peti Kemas Antar Pulau" (in Indonesian)

Internet site:
http://www.petra.ac.id/english/science/manufactures/pelabuhan/index.htm
"General Picture- P.T. Pelabuhan Indonesia III"