SAFETY AND CAPACITY WET INFRASTRUCTURE PUERTO AMÉRICA, VENEZUELA

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Abstract

Lake Maracaibo is the largest brackish lake of South America. Presently Lake Maracaibo suffers from an increased salinity, eutrophication and pollution from oil exploitation.
The dredged navigation channel used to access the various harbours on the lake causes increased salinity from the Gulf of Venezuela. To reduce salt intrusion the closure of the dredged channel is considered. As a result however, these harbours will become inaccessible for deep draughted vessels.
For this reason a new port has been designed, called Puerto América, at the entrance from the Gulf of Venezuela on the peninsula San Bernardo and the Island of Zapara.
The purpose of Puerto América is to tranship oil, petrochemicals, coal, containers, grain and general cargo.
Especially with respect to nautical safety, influencing the capacity of the wet infra structure of this port, a manoeuvring simulation model and a traffic flow simulation model were developed. Based on safety criteria the output of the manoeuvring simulation model results in traffic rules and manoeuvring strategies, which in turn are used as input for the traffic flow simulation model to determine the capacity of the wet infrastructure.

After a brief summary of the environmental conditions, commodity throughput and expected vessel types, the paper gives a description of the manoeuvring and the traffic flow simulation models. The combination of the two models proved to be highly valuable tool to optimise the harbour systems. Overall dimensions of dredging works, breakwaters and the number of berths were optimised using these models.

1.0 Introduction

In order to export the oil produced in Lake Maracaibo, a channel was dredged through the outer bar near the island of Zapara in the early fifties to provide access for tankers to the various port facilities along the borders of Lake Maracaibo, Venezuela.

Due to ingress of seawater via this man-made channel the water in the lake gradually changed from fresh to brackish water. Sustained by the dominant trade winds the water inside the lake developed a vertical stratification, which collects in its deeper layers pollutants from various sources.

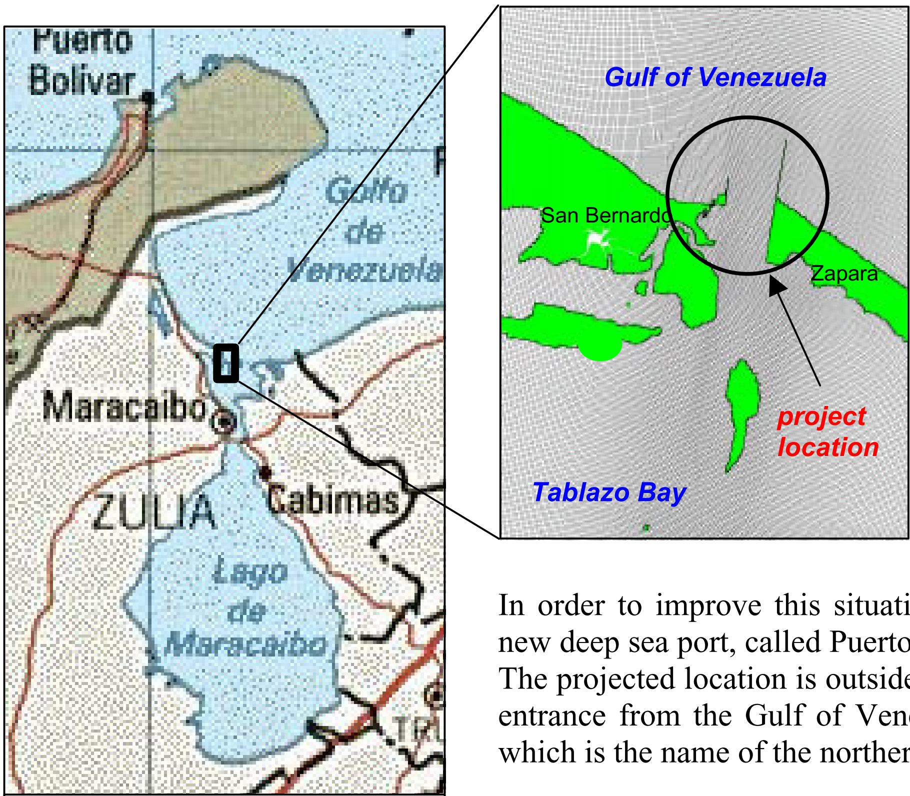

Figure 1 Project Location

In order to improve this situation, the realisation of a new deep sea port, called Puerto América is considered. The projected location is outside Lake Maracaibo at the entrance from the Gulf of Venezuela to Tablazo Bay, which is the name of the northern part of the lake.

From a nautical point of view the location of the entrance to Tablazo Bay is characterised by complex current patterns and is furthermore exposed to waves and wind.

Because the port is intended to handle a large variety and quantity of solid as well as liquid products in a relatively small area, there are important requirements for optimising the capacity of the wet infrastructure while also maintaining the nautical safety.

To accomplish these requirements it was decided to apply, right from early stages of the project, sophisticated mathematical manoeuvring and traffic simulation models as an integral part of the design process.

2.0 Description Of Models

2.1 Manoeuvring Simulation Model

The new deep sea port of Puerto América is to be situated around the entrance from the Gulf of Venezuela to Lake Maracaibo. From a nautical point of view this location is characterised by complex current patterns, and moderate wind and waves.
Given the complexity of the environmental conditions and the potentially pollutant type of cargoes to be handled, like crude oil and liquid petroleum products including refrigerated liquefied gasses it was important to support the design decisions with
realistic nautical constraints.
Therefore ship manoeuvring simulations were carried out to directly (from a safety point of view) and indirectly (as a constraints generator for traffic flow simulations) support the dimensioning of the wet infrastructure.

The simulation model used was Alkyon's real-time manoeuvring simulator SHIP-NAVIGATOR. This model is capable of simulating ship manoeuvres in real-time as well as faster than real-time. Control is exercised either manually or through a track-following autopilot. With these possibilities the model allows for both a fast analysis of a large number of design alternatives as well as for a detailed analysis of berthing and de-berthing procedures. The simulator is a dedicated design tool, i.e. it is programmed such that design modifications can be modelled and tested quickly and cost-efficiently. It does this by application of quick-interface tools to the most sophisticated flow and wave simulation models like DELFT-3D and SWAN.

2.2 Simulator Application

SHIP-NAVIGATOR models a large variety of nautical and physical aspects. In the case of Puerto América the following aspects were incorporated in the model:

Table 1 Simulator aspects modelled for Puerto América

Aspect	Nautical demands	Model implementation
Current	Effect of quickly varying current patterns on manoeuvre	Small spatial grid spatial and time variation
Bathymetry and tide	Accessibility and effect on manoeuvrability of reduced UKC	Spatial and time (tide) variation
Wind	Forces on vessel	Gust effects included
Waves	Forces on vessel	Spatial variation of Hs, Tp and direction. Directional spreading applied.
Tugs	Correct abilities for different types of tugs w.r.t. towing, pushing and behaviour in waves	Various tug models with own resistance, utilisation of wave shielding in lee side of vessel
(De)berthing in current	Use of mooring lines as part of the manoeuvre	Ship winch model
Manoeuvring strategy	Carry out realistic manoeuvres with proper use of engine, rudder and tugs, also in close-quarters.	Real-time manoeuvring.

2.3 Modelled area

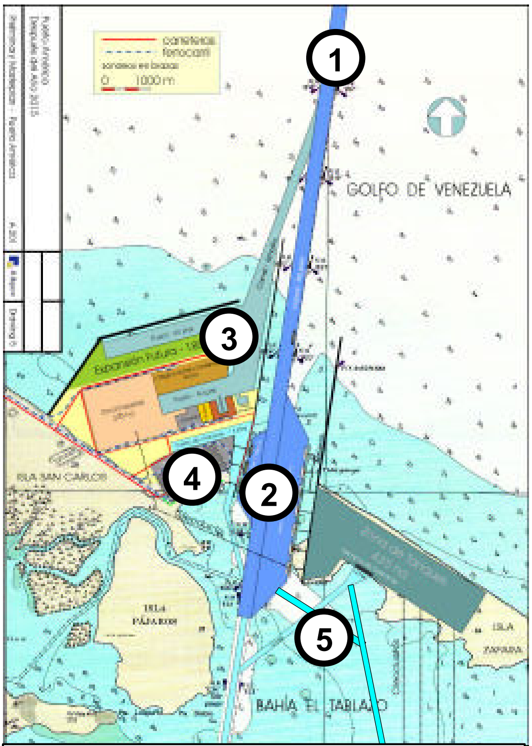

Figure 2. Main harbour sections

Figure 2 shows the four main wet infrastructural sections of Puerto América which were incorporated in the manoeuvring simulation model: (1) the main access channel, (2) the manoeuvring area at the deep water port, (3) the access and basins of the common user port, (4) the barge harbour and (5) the navigation channels to the hinterland.

Especially the choice and location of the various access and navigation channels were items of investigation, because with the disuse of the deep channel to the various terminals in Lake Maracaibo, also the bathymetry and current flow patterns in the area are bound to change.

To evaluate the different alternatives extensive flow model computations were carried out. Figure 3 shows a snapshot from an animation of the Gulf of Venezuela – Lake Maracaibo model.
The figure shows the computational grid with the water level in Lake Maracaibo fairly constant, and with the level of the gulf near Tablazo Bay being considerably higher and fluctuating with the tide. This difference between the constant level in the lake and the oscillating gulf creates a strong current in the entrance to Tablazo Bay, where Puerto América is situated.

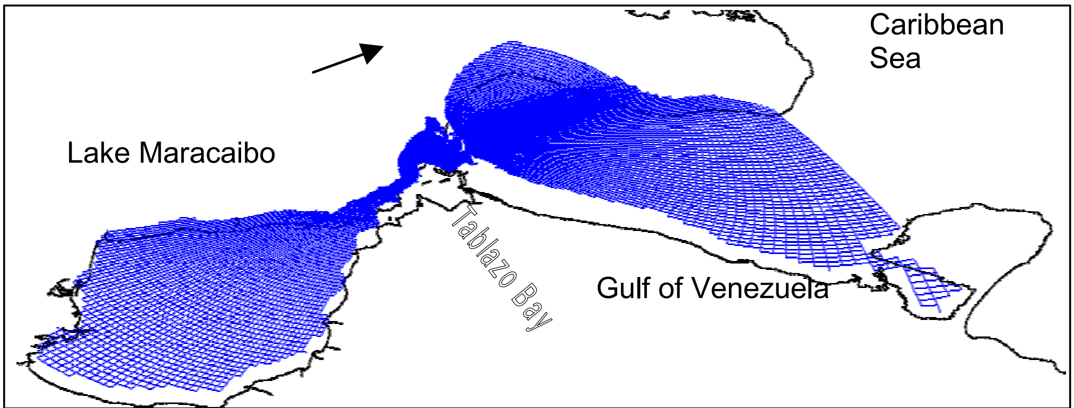

Figure 3. Tide simulation of Gulf of Venezuela and Lake Maracaibo

2.4 Type of Vessels

Due to the nature of Puerto América, a large hub for a variety of goods, transport is accomplished by large ocean going vessels on the sea-side and largely by inland vessels at the lake-side.

For instance refrigerated liquids, hot and viscous crude oils, asphalt, fuel oils and petrochemicals, but also various sections of the containerised cargo are intended to be transported by barge.

This meant that arrival and departure of both large vessels like a 150,000 dwt crude carriers as well as small vessels like 2,500 t barges needed to be simulated on the manoeuvring simulator.

2.5 Type of Conditions

For spring tide conditions, between the breakwaters the depth averaged current may reach values up to 2.5 knots. These strong currents show large variations in magnitude and direction. As an example Figure 4 shows the varying patterns during a 1.5 hour period before HW.

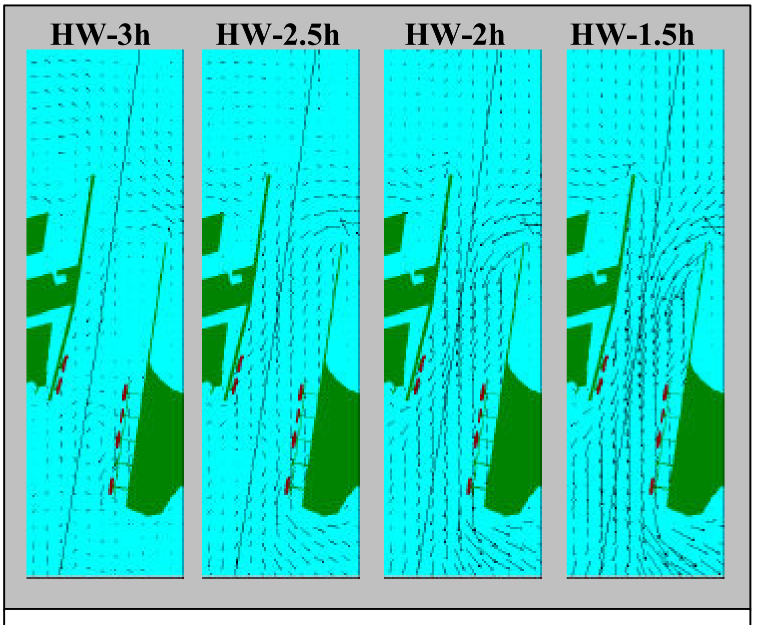

Figure 4. Current variation in deep water port

The wind conditions at the project site are dominated by trade winds, which generally blow from directions between north-east and south-east. Tropical storms may occasionally pass over the Bay of Venezuela to the north of the site. A wind speed of 11 m/s is exceeded 8 % of the time.

The waves in the Gulf of Venezuela are directly related to the governing wind conditions. The main wave directions are from the north east direction sector. In the access channel a significant wave height of 1.75 m is exceeded 6% of the time.

2.6 Traffic Flow Simulation Model

As for many ports in the world a lot of parameters controlling the ship traffic to and from Puerto América are stochastic of nature. This necessitates the development of probabilistic traffic flow simulation models for estimation of capacities of port systems. In this case PROSIM software was used as simulation language. PROSIM is an advanced software system for combined discrete and continuous simulation using the so-called 'process description method'. The process description method describes all relevant components in the respective modules of the model and the interactions between the components.
The model was used to support the optimisation of the required number of berths in relation to the approach channel dimensions and transhipment capacities.
The configuration of the traffic flow simulation model, called Harboursim, used to simulate Puerto América, is presented in Fig. 5. The main components of this model are listed in Table 2.

Table 2 Components of the model

Component		Specification
Main	Single component	The component Main initialises the model and reads the input data from the files
Fleet generators (10)	Class of components	Generates the vessels of the specified fleets according to statistical inter arrival time distributions and assigns values of attributes
Ship	Class of components	Follows the process of the ship according to the vessel type and destination
Traffic control of incoming vessels	Single component	Controls incoming traffic with respect to tidal conditions, traffic situation and berth occupancy
Traffic control of departing vessels	Single component	Controls departing traffic with respect to tidal conditions and traffic situation.
Terminal masters	Class of component	Controls the occupation of the berths of the terminal and sets and registers the service times of the vessels. Handles requests for entering and leaving the port system
Tidal conditions	Single component	Generates and registers the tidal conditions in the model (current velocities and water levels)
Wave conditions	Single component	Generates wave conditions in front of the quays

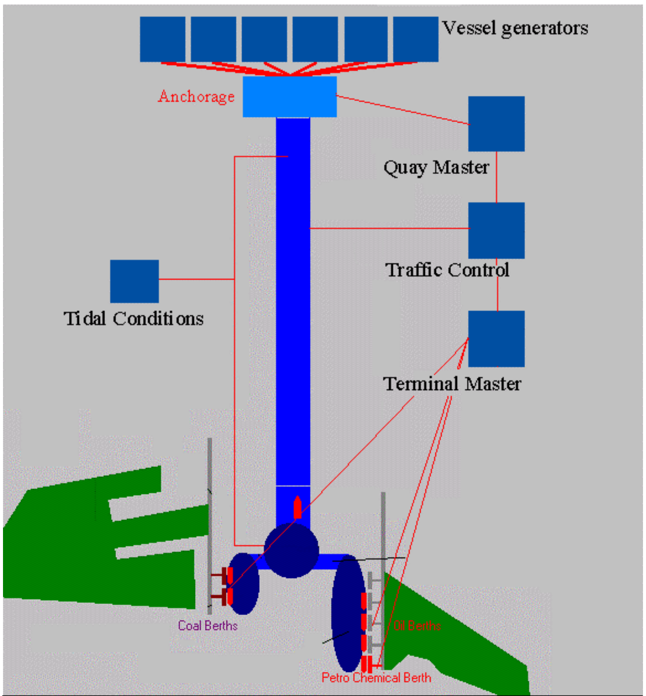

Figure 5: Main components in the model

2.7 Generation of the Different Vessel Types

A total of 10 generators are used to generate or to create the ship traffic from and to the port, viz. 6 generators for the oil carriers, 2 generators for the coal carriers and 2 for the petrochemical vessels. The generated number and type of vessels depend on the year and the realised port facilities as for instance the depth of the approach channel.

Table 3 Generators of Vessels

Generator type	Attributes of the vessels					
	capacity	**Terminal number**	**Draught Incoming/leaving**		**Arrival pattern**	**Transhm. rate [t/h]**
Oil carrier type 1	5000 - 35000	2	6	7 - 8	N.E.D	490
Oil carrier type 2	35000-84000	2	7	9	N.E.D	954
Oil carrier type 3	65000-97500	2	9	12.85	N.E.D	1215
Oil carrier type 4	97500-138750	2	9	14.4	N.E.D	1177
Oil carrier type 5	125000-168750	2	9	15.6	N.E.D	1402
Oil carrier type 6	145000-198750	2	9	16.6	N.E.D	1598
Coal carrier type 1	5000-35000	3	6.3	8 – 9	N.E.D	402
Coal carrier type 1	212500-185625	3	9	16.4	N.E.D	2348
Petrochemical type 1	5000-30000	1	3.5	6.3	N.E.D	450
Petrochemical type 2	30000-50000	1	8	9	N.E.D	720

Table 3 gives a specification of the generators used in phase 2 (2015) and the attributes assigned in the generation process.
Based on experience a rather irregular inter arrival time distribution has been chosen to model arrivals of vessels viz.: the negative exponential distribution (N.E.D.)

$F(t) = 1 - e^{-\lambda . t}$, where:

F(t) = cumulative distribution function
8 = number of arrivals per time unit
t = inter arrival time

Process of the ship

The process of the ship is presented in Figure 6.

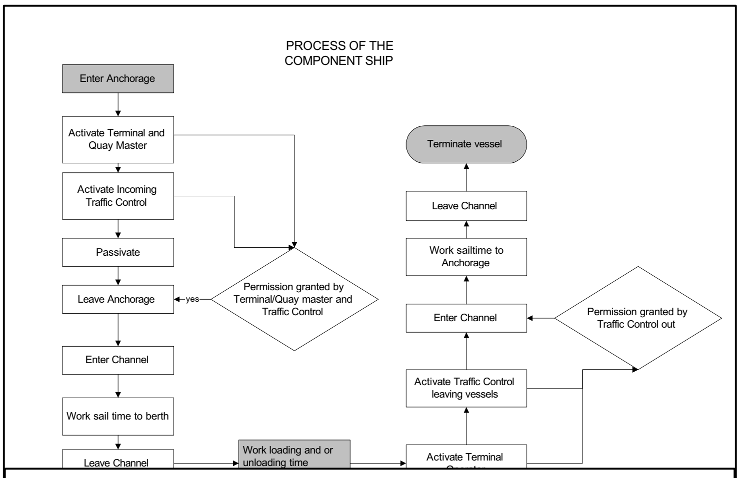

Fig. 6: Process of the ship

After generation, the ship enters the Anchorage, activates the Terminal Master,
and the component Traffic Control for permission to enter the port system. Permission will be granted if tidal conditions (water levels and current velocities) and traffic situation (occupation of the various channel sections) do not cause any conflicts with other vessels. In addition the availability of a berth is checked.
If all conditions are fulfilled the ship enters the port system.

In the next step the ship continues to the berth. The service time includes the loading and or unloading time and the additional time for berthing and deberthing. Based on the parcel size of the ship and the associated transhipment rate, the time required for loading or unloading is estimated.
The additional service times for oil vessels larger than 100,000 DWT are for example estimated at:

Manoeuvring	1.5 hour
Connecting to manifold	0.5 hour
Other	1 hour
Disconnecting manifold	0.5 hour
Deberthing/manoeuvring	1.5 hour

After unloading and/or loading and possibly ballasting of the vessel permission is requested to leave the port system. Again the traffic situation and the tidal conditions are checked; if no conflicts exist the ship will depart, enters again the channel and follows her route to the end of the approach area. Finally all relevant data of this particular ship will be registered and subsequently the ship leaves the port system and the simulation of this ship is terminated.

2.8 Vessel Traffic Control Incoming and Departing Vessels

Two components one for the incoming and one for the leaving traffic check the tidal conditions (water levels and current velocities), the status of the traffic and the availability of a berth when a vessel requests permission to enter the system. Figure 7 shows the water depth in the channel when simulating a 54-ft channel.

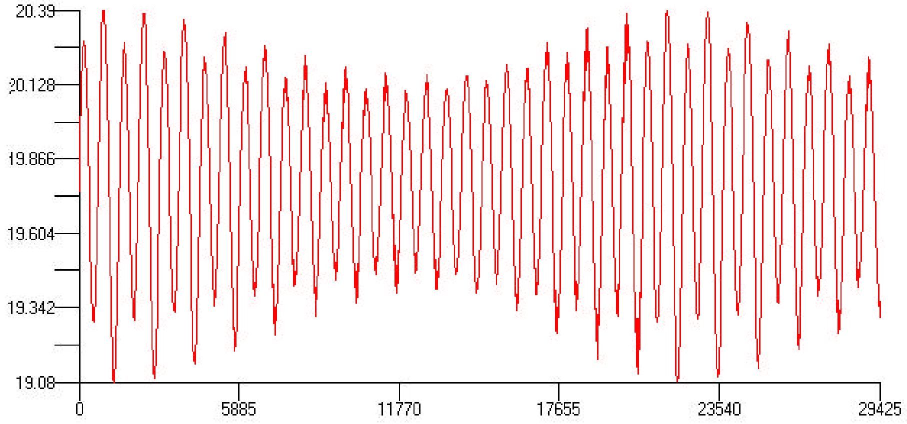

Figure 7: Water levels for a 54-ft channel

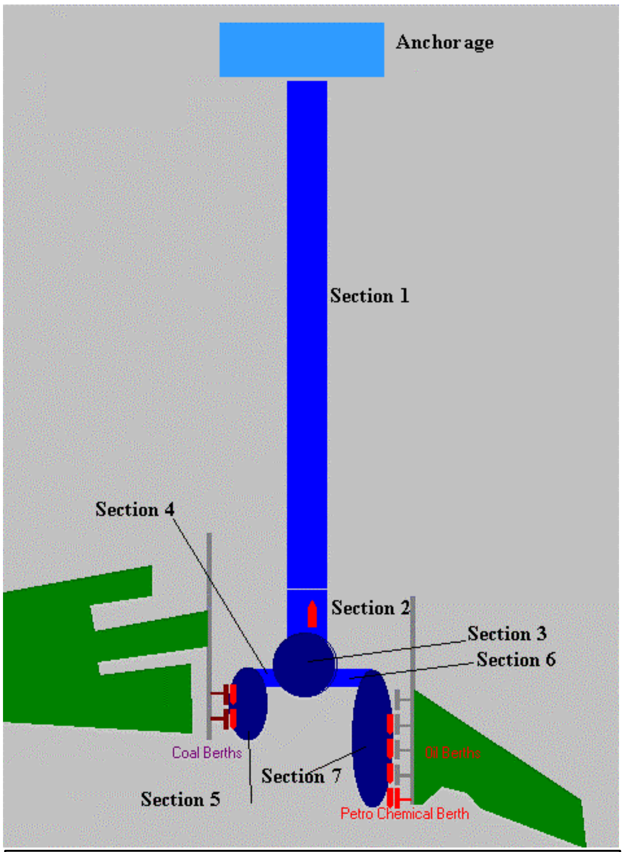

Figure 8: Traffic sections approach area

Figure 8 presents the various channel sections and manoeuvring areas.
The traffic rules with respect to overtaking and encountering have been determined in the manoeuvring simulation study see chapter 2.
Some channel sections are one way and others two way depending on the different vessel types.
Channel sections 1 and 2 are one way channels for vessels with a beam exceeding 27 meters, which corresponds with a vessel size of approximately 35000 DWT. Overtaking is not allowed in any sections.
Sections 3, 5 and 7 represent turning basins and manoeuvring areas. The model does not allow a vessel to enter such an area when another vessel is already turning or manoeuvring in one of these areas. As an example Figure 9 shows the Process of the incoming traffic control.

Process of Terminal Master

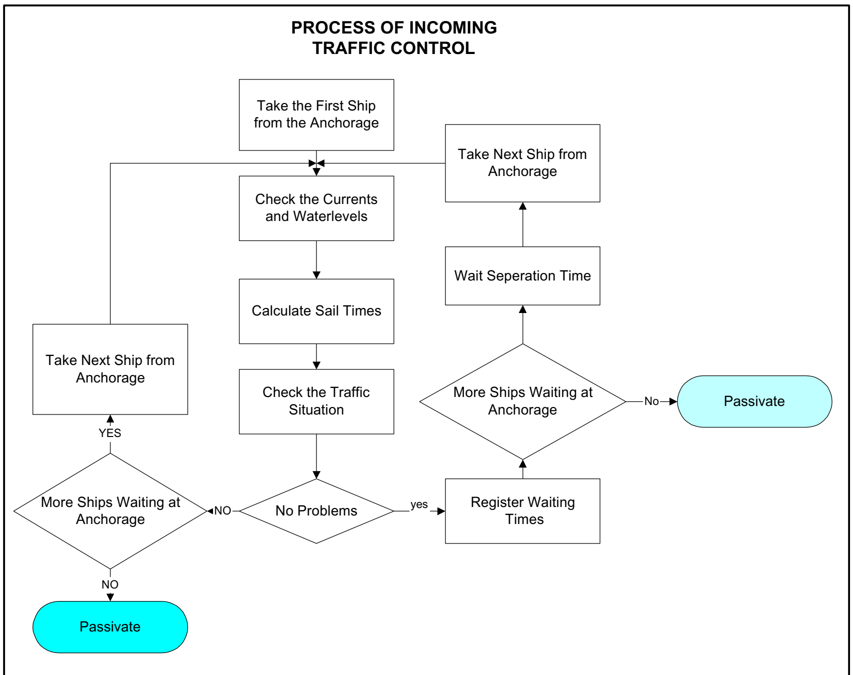

Figure 9: Process traffic control incoming vessels

The process of the Terminal Master consists of two parts. In the first part the Terminal Master assigns a berth to an arriving vessel and sets the required service time for this vessel. In the second part the Terminal Master arranges the departure of the vessel and joins the vessel to the request list (set) of the component 'Traffic Control of Leaving Vessels'. From here on this component takes control of the vessel.

2.9 Output of the Model

Many data are registered during the simulation runs. The main output data concern the berth occupancy rates of the various terminals and the waiting times of each individual vessel upon arrival at the approach area and prior to departure from the berth.
The waiting time prior to departure is important because during this period the vessel occupies the berth, which raises the berths occupancy rates.
Waiting times are not only registered in hours but also in units of the average service time, as critical waiting times are mostly expressed in units of the average service time.

3.0 Application Of Models

3.1 Results of Manoeuvring Simulation Model

3.1.1 Access Channel and Deep Water Port

The manoeuvring simulation study for the deep water port study focused on the liquid bulk section on the east side of the port (the coal section on the west side had been the subject of an earlier study). An important aspect of this study was the choice of the maximum dimensions of the vessels and the arrival and departure times with respect to the tide. This required an iterative process of interaction between the vessel traffic study and the manoeuvring study. First the traffic study provided the initial vessel sizes and arrival times and subsequently the manoeuvring simulations resulted in feed-back to the vessel traffic simulations with maximum ship dimensions as a function of nautical safety, safe interval times between vessel, blockage times of the turning basin, berthing and deberthing sequence times etc.

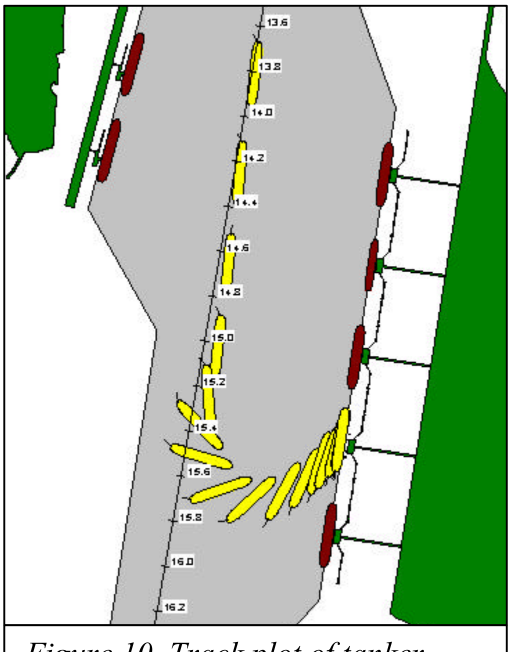

Figure 10. Track plot of tanker arrival in deep water port

The final set of arrival runs was executed with a Capesize crude-oil tanker assisted by one 60 t bollard pull azimuthing thruster tug (Z-peller) at the stern and two 45 t conventional tugs at the bow.
Figure 10 shows an example of an arrival run with the tanker.
Apart from the input to the traffic computations also various infrastructural conclusions were derived from the simulations. For example a benefit in dredging was possible by reducing the channel width north of the bifurcation of the channel to the common user port. Also a shift of the liquid bulk section to the north was needed because of the strong currents at the southernmost jetty.

3.2 Common User Port.

Simulations were executed for panamax sized bulk carriers and container vessels.

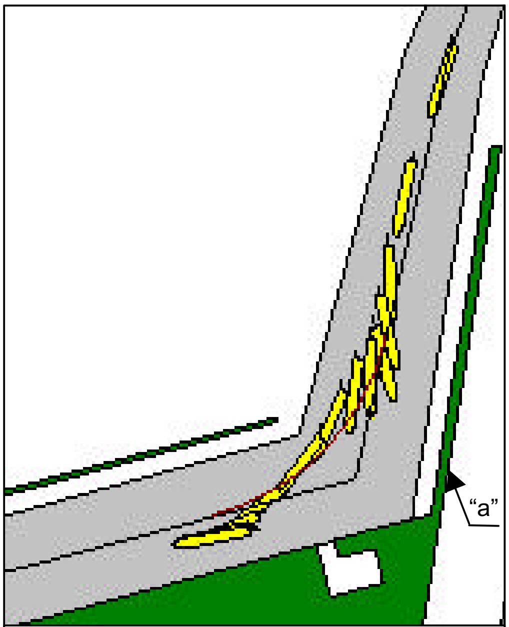

Figure 11. Container vessel arrival in common user port

Again several cost-benefits to the design could be identified, like a considerable shortening of the breakwater “a” shown in Figure 11. Obviously also the tranquillity at the berths was investigated before actually deciding for a re-dimensioning of the breakwater.

Inland harbour and navigation channels

The transport to the hinterland of refrigerated liquefied gases and very viscous products, such as asphalt and Boscan crude needs to be carried by barge over Lake Tablazo and Lake Maracaibo. But also for other bulk cargoes and containers, inland vessel transport is often a cost-beneficial method.

To investigate the possibilities for these transports simulations were carries out for both towed barges (tug towing single barge) and pushed barges (pusher with two barges), carrying either bulk cargo or containers.

The general conclusion from the simulations is that a push-combination is much better to control and would be a recommended way of transporting the barges, especially when the volume of traffic increases. The currents in Tablazo bay, in combination with the strong winds and still considerable wave action at the deep water port meant that especially the towed barges (see track plot of towed barge simulation in Figure 12) required wider navigation channels than originally anticipated.

Figure 12. Track plot of towed container barge.

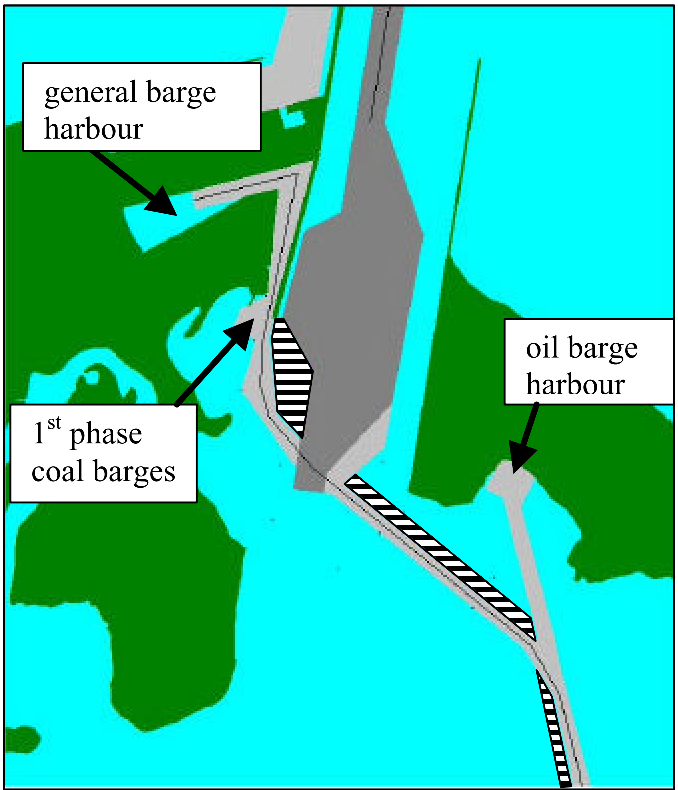

Figure 13. Inland navigation channel widening

It was concluded that a number of areas need to be kept at a sufficient depth or need widening (depending on the volume of traffic) for barges and tugs (dashed areas shown in Figure 13). Also several operational recommendations were derived regarding the operations near the barge harbour.

3.3Results Traffic flow simulation model

The main objective of the simulation runs is to estimate the required number of berths for each commodity during each phase of the project. Moreover the simulation runs were performed to acquire knowledge of the influence of the depth of the approach channel on the required number of berths and the effect of the loading rates. Two phases were considered viz. the traffic conditions for the year 2007 and 2015 in combination with four channel depths namely: 42 ft, 47 ft, 51 ft and 54 ft. In total 16 runs were carried out. In this paper only the model results for channel depths of 42 ft and 51 ft are presented in detail.

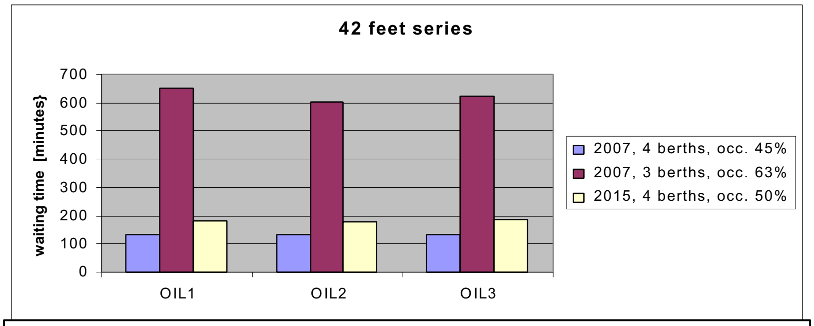

Figure 14. Simulation runs 42 ft channel, oil carriers

Figure 14 shows the results of the 42-ft channel runs for the oil carriers. Decreasing the number of berths from 4 to 3 a steep in crease of the waiting times is observed. Also the influence of the berth occupancy ranging from 45% to 50% is quite clear.

Starting from a maximum waiting of 30 % of the service time 3 berths would be acceptable in the first phase (2007) but to cope with unforeseen irregularities 4 berth are advised.

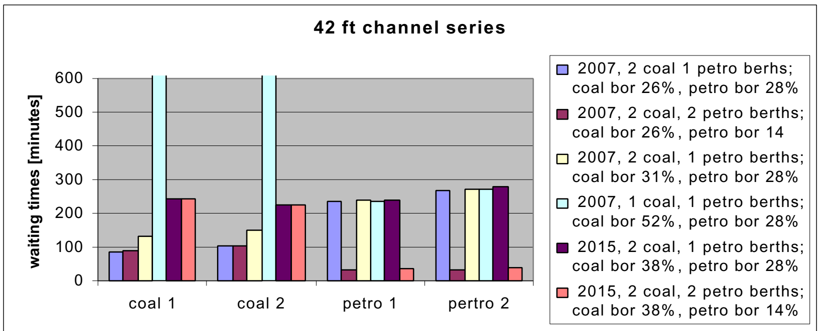

Figure 15. Simulation runs 51-ft channel, coal carriers and petrochemical vessels

Figure 15 shows the simulation results for the coal carriers and petrochemical vessels. To satisfy the design requirements it is quite clear that 2 coal berth are required. Only one berth would give an unacceptable rise of the waiting times. For the petrochemical vessels 1 berth will be sufficient.

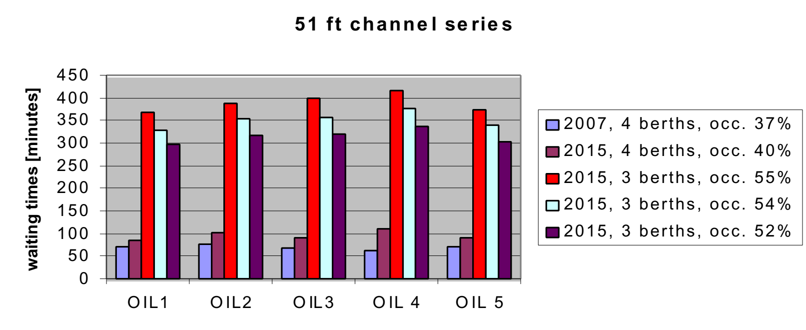

Figure 16. Simulation runs 51-ft channel, oil carriers

As the 51-ft channel generates more traffic Figure 16 shows that 4 oil berths are necessary. Reduction of the berth occupancy rate from 55% to 52 %, by increasing the transhipment rate, causes some reduction of the waiting times but not enough to satisfy the design requirements when dealing with only 3 berths.

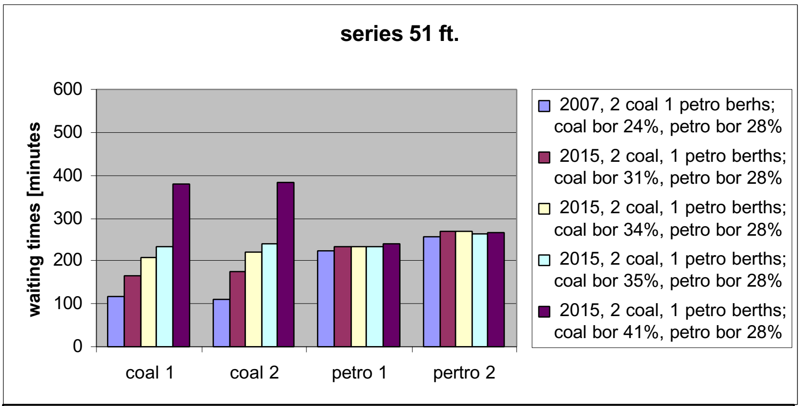

Figure 17. Simulation runs 51-ft channel, coal carriers and petrochemical vessels

Figure 17 gives results for the coal carriers and petrochemical vessels. The influence of the coal berth occupancy (ranging from 24% to 41 %) on the waiting times (going up from about 110 to 380 minutes) is significant. Should the occupancy increase to more than 35% an additional coal berth is required.

With respect to the waiting times of the petrochemical berth is remarked that with an occupancy of 28% the influence of the other ship traffic is not significant. The waiting time, expressed in units of the average service time, stays at a level of about 45% of the service time and is considered to be acceptable.

An overview of the required number of berths is given in table 3.

Table 2: Required number of berths versus channel depth and traffic year

Traffic year	**Maximum draft channel**											
	42 ft			47 ft			51 ft			54 ft		
	oil	coal	petr	oil	coal	petr	oil	coal	petr	oil	coal	petr
2007	3	2	1	4	2	1	4	2	1	4	2	1
2015	4	2	1	4	2	1	4	2	1	4	2	1

4.0 Conclusions and Recommendations

1. To restore the original environmental conditions of Lake Maracaibo the development of a new port called Puerto América is considered, compensating the port facilities presently located along the borders of this lake.
2. When dealing with complicated port systems, such as Puerto América, the relationship between safety and port capacity needs to be estimated by application of manoeuvring and traffic flow simulation models in an interactive way.

3. Starting from a basic layout for Puerto América the manoeuvring simulation model facilitated checking nautical safety levels dealing with tidal, wind and wave conditions. In this way estimations were obtained of:
   - optimum vessel dimensions, related to wet infra structure alternatives,
   - the most suitable locations for the terminals, especially for the oil terminal,
   - lengths of breakwaters, especially the west breakwater along the main channel,
   - the required channel dimensions of the inland vessels.
4. To estimate the capacity of this port system, the manoeuvring simulation study provided ship traffic rules and the dwell times of vessels in the various channel sections which served as input for the traffic flow simulation model.
5. The traffic flow simulation study showed that predominantly waiting times were caused by berth occupancies and only for a minor degree by water level restrictions and occupation of turning and manoeuvring basins.

5.0 References

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Keywords: Port development, Manoeuvring Simulation, Ship traffic Simulation.