Delft University of Technology Faculty of Civil Engineering

Thesis

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A master plan study

The Ulsan Port development plan

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1. INTRODUCTION.

Throughout ancient times, ports have existed. In the early days, a port was basically an area of (naturally) sheltered water where ships could anchor. The cargo was put aboard small vessels, brought ashore and sold at a public sale or stored until market prices made it attractive to sell. Ships' arrivals were very unpredictable, because they were dependent on the weather conditions.

Nowadays, a port is one of the major links in the transport chain. The only resemblance with the old ports is the transhipment and storage of cargo. The function of a modern port is to provide an interface between sea transport and land transport of both people and cargo. The basic requirements for a port to carry out its function are that it:

- has an adequate water area of sufficient depth for navigation and berthing.
- provides adequate shelter so that berthing, loading and unloading can take place safely and efficiently.
- has a sufficient land area for loading and unloading the ships, for handling and storage of cargoes.

The shipping-companies often impose a schedule for their ships, so that the arrivals are known (except for storm delays, etc.). To be able to provide the highest degree of service and efficiency, the ship movements and other port related traffic must be streamlined, together with the cargo handling operations. The complications in the present port studies originate from the following factors:

- The large scale harbour activities.
- The increasing demands regarding safety and environmental aspects.
- The development of port related industries on the port's premises or in the direct vicinity.

In order to be able to achieve such a large project, several planning stages can be recognised: a. Long term planning

Periods of about 20 years.

Port strategic and infrastructural master plan.

b. Medium term planning

Periods of 3 to 5 years.

Planning, design and execution of new terminals.

c. Short term planning

Periods of 1 year.

The procurement of equipment, adaptations to the design.

When designing a new port, the sequence a. to c. must be followed. In this study, only item a. is worked out. This phase alone is already a very extensive study. Even with one phase, the master planning, not all factors can be worked out. Figure 1.1 gives an overview of the total master plan and the parts that will be dealt with in this study. The grey blocks will be discussed in this study, the transparent blocks will not.

The subject of investigation in this study is the extension of Ulsan Port in the south east of the Korean peninsula. The existing port of Ulsan is mainly an industrial port, with refineries, petro-chemical industries, car manufacturing and ship building. The Korean government is setting up an overall port development strategy, in which Ulsan Port must be transformed from a mainly industrial port to a multi purpose port. Besides this transformation, the existing cargo throughput is envisaged to increase significantly over the next decades. These trends require the development of new port facilities in the Ulsan region.

A consortium of Korean consultants already has drafted a master plan for the Ulsan Port development. This plan contains many less preferable solutions. Therefore, this study tries to come up with other and better solutions.





Figure 1.1 The aspects in master planning.

The existing cargo handling facilities are discussed in chapter 2.

A more detailed problem description than given above can be found in chapter 3. In this chapter the need for development is broadly described, together with a critical view of the existing government master plan. The problem definition and objective, together with the boundary conditions and assumptions are also part of chapter 3.

The following chapters are a chronological enumeration of the important factors in the master plan study. Chapter 4 starts with the assessment of the future cargo flows, combined data from various sources.

When the cargo flows are known, the matching ship movements can be derived. This exercise is carried out in chapter 5.

In chapter 6, the numbers of ships are converted into necessary quay lengths and amounts of jetties. The calculation is made with the aid of the queuing theory. The queuing theory calculations can be found in the appendices C and D.

When the quay lengths are known, the terminal areas can be assessed. The results can be found in chapter 7. The calculation of the container terminal stacking areas, made with the help of general area determination formulas, can be found in appendix E.

Guidelines for the design of the approach channel, entrance and port basin dimensions are derived in appendix F, the results and theory are discussed in chapter 8.

The preceding work now leads to the design of alternative layout plans, described in chapter 9 and to be viewed in appendix G.

After evaluation of the different layout plans, by means of a multi-criteria evaluation, a final design is chosen in chapter 10.

Finally, conclusions and recommendations regarding this study are given in chapter 11.



2. THE ULSAN EXISTING FACILITIES.

2.1. Ulsan Main Port.

At present, the port of Ulsan has two main functions, being the receiving of raw material for the oil and petro-chemical industry, and the distribution of cargo on a regional level. These functions are roughly divided in three separate ports:

- Ulsan Main Port
- Onsan Port
- Mipo Port

Together, these ports are under the authority of the Ulsan District Maritime & Port Authority. This organisation represents the local authority of the Ministry Of Maritime Affairs and Fisheries and consists of six divisions, of which Port Operations is the most important for this study.

Port Operations, managed by the Harbour Master, is responsible for the day to day operational management of the port of Ulsan. The 80 employees are responsible for the waterside management. The Vessel Traffic Services System (VTSS) also resides under Port Operations. The VTSS controls the safety and efficiency of all ship movements within the Ulsan Port limits.

The location and the facilities of the different parts of the port are displayed in table A.1 and figure A.1 in Appendix A.

In this section the Ulsan Main Port is discussed.

This part of the port is naturally protected, as it is situated at the borders of the Taehwa River. The consequence of this "inland port" is that the water depth is restricted to 12 metres (varying from 5 to 15 metres).

The facilities in this port are of diverse nature. This is a consequence of the origin of the port. It is the oldest part of the port of Ulsan. Here the various types of cargo shipped to and from the port in its early days were handled, varying from general cargo to fish, etc. The majority of the berths are owned by the Korean government.

Throughout the years, other industries are established in the vicinity. On the west bank of the Taehwa river, chemical companies like Korea Fertiliser and oil refineries like Yukong are settled. Yukong is owner of seven berths, of which the greater part is jetty-type. The east bank is occupied by the multinational Hyundai, with a large car assembly factory, steel pipe factory and the largest dockyard in the world.

There is day and night pilotage in this part of the port. Vessels ranging to 150,000 DWT are allowed up to and inclusive Yukong pier # 8. Vessels ranging to 70,000 DWT are allowed to sail up to and including Yukong pier # 6 (see figure A.1 in Appendix A). Beyond Yukong pier # 6, the maximum vessel size is reduced to 40,000 DWT.

2.2. Onsan Port.

Onsan Port is a newly developed port on the south west side of Ulsan. Originally a creek, it was deepened and protected by two breakwaters. This is a dedicated industrial port, facilitating the newly established oil refineries and petro-chemical plants. Privately owned jetties are situated at the north side of Onsan Port, facilitating the oil refinery of Ssangyong and the petro-chemical company Daehan Co. The southerly basin, with quays owned by the government, is dedicated for unloading ores and solid chemicals. The water depth varies from 11 to 15.5 metres, but averages 11.5 metres.

For Onsan Port, only daylight pilotage is available. The permitted ship sizes range from maximum 10,000 DWT to a maximum 80,000 DWT, depending on the available water depth.

2.3. Mipo Port.

Mipo port is a separate port, located at the outer east side of Ulsan. It is not enclosed by the port limits of Ulsan Main Port and Onsan Port. The port is in use by a Hyundai subsidiary company, Hyundai Heavy Industry. This company builds ships, trains and parts for aeroplanes. It is one of the world's largest ship builders. The traffic to and from the port is much less than the major traffic to the Ulsan Main Port and Onsan Port. The water depth is restricted to 9.0 metres, so vessels ranging up to 20,000 DWT can be received.

2.4. Crude oil import facilities.

Beside the different port sites, an other important feature is the unloading of crude oil from VLCC's (Very Large Crude Carrier), ranging up to 325,000 DWT. Because deep water is available near shore, the decision was made that these large ships are not admitted within the port boundaries. In stead five locations, with a maximum distance offshore of 2,500 metres, were dedicated as crude oil import areas. The unloading is arranged via Single Point Moorings (SPM) and submersed pipelines.

A SPM is a mooring facility with only bow mooring or stern mooring capability. Via flexible hoses between the ship and the SPM structure, the liquid bulk can be transported to and from the storage areas. SPM's can have various designs, from anchor leg moorings to floating platforms with a heli-deck. The five Single Point Moorings in Ulsan are all CALM-type. CALM is short for Catenary Anchor Leg Mooring. A picture of such a CALM can be viewed in figure 2.1.



Figure 2.1 Catenary Anchor Leg Mooring system.

The buoys are held at their place by four to eight chains, anchored in the seabed. The SPM's in the Ulsan region are equipped with four chains. A ship moored at the buoy can freely turn with the wind or current. A result of this turning ability is that a large area around the SPM is prohibited for all other traffic. As the VLCC's can be 350 metres in length, together with the mooring line length and tolerances for the SPM location, a circle 800 metres in diameter must be cleared. Five of these circles are currently present in front of the Ulsan Main Port and Onsan Port. For a view at the SPM locations, see figure 2.2.

When designing a port extension, difficulties regarding the safety of SPM operations can be expected. Strict rules for safe navigation must already be applied at this moment. Report has been made of several accidents, comprising the SPM operations. Although these were no major accidents, a better solution should be found. Already the SPM number 1 has restrictions with regard to tanker dimensions, due to the prescription of tail tug assistance. The tail tug helps the ship to stay free from the SPM when winds and currents shift. Normally the tanker uses its own propulsion, but with the dense traffic nearby, this may be prohibited. In these cases the tail tug keeps sufficient tension in the mooring lines. When the tail tug (with towing lines) is prescribed, the maximum tanker length is restricted to 275 metres, corresponding with 150,000 DWT. This is a halving of the normal capacity, resulting in even more ship movements, because more tankers of less capacity must maintain the oil supply.

The ship's arrival at the SPM's is limited to daylight navigation only. The departure of ships is allowed night and day.

The permitted ship size for the different SPM's at this moment is:

Yukong # 1 : 150,000 DWT for reasons mentioned above.

	· · · · · · · · · · · · · · · · · · ·
Yukong # 2	: 300,000 DWT
Yukong # 3	: 325,000 DWT
Ssangyong	: 260,000 DWT
PEDCO	: 300,000 DWT

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Figure 2.2 Locations of the various SPM's in the Ulsan Port vicinity.



3. THE NECESSITY OF THIS STUDY.

3.1. Developments in the Ulsan region.

The port of Ulsan currently is Korea's largest crude oil import port and with the Hyundai Motor Co. it exports the largest amount of cars. Owing to these facts, it has become one of Korea's major ports, handling about 20 percent of the total national marine cargo.

Predictions of the future cargo flows show a major increase, due to continuous economic growth of the industrial hinterland, as already experienced in this decade. The existing facilities will not be able to follow this increment. An other reason for a port development is the Korean government's wish to extend the function of Ulsan Port from a purely industrial port to a multi-functional port.

As part of an overall port development plan, the Korean government has decided to develop and extend the port of Ulsan. For this matter, a master plan study has been carried out by a combination of two Korean consultants corporations and Korea Harbour Engineers Ltd.

3.2. The government master plan.

The government master plan consists of the following sections:

- An extensive data survey including the present natural conditions, a site investigation and the existing facilities.
- An assessment of the new port size, including the future marine cargo, the future handling capacity of the existing terminals and a cargo flow division between the existing facilities and the new port.
- A development plan with layout plans, different breakwater alternatives and quay face alternatives.

Other important issues, for instance effects on the environment, designing roads and railways and a feasibility study, are only superficially mentioned.

The master plan is based on a three-phase philosophy, see also figure 3.1. The first phase is the "New Ulsan Port", between the existing ports of Ulsan and Onsan. This phase must cater for the cargo increment until 2006. The "New Onsan Port" is the name of the second phase, reaching from the end of the south breakwater of Onsan southward. Together with phase 1 it must be sufficient to handle the cargo increment until 2011. The third and last phase are not yet fully designed. It should cater for the throughput of 2020. The location of this part is adjacent to the New Onsan Port, extending southward.

The Korean government intends to invite private companies to invest in the port development. One of the companies interested in the plan is the Sunkyong Group, owner of Yukong Oil and Gas. Yukong is a major import company of crude oil and operates several refineries and petro-chemical facilities. For this reason Yukong owns, beside numerous marine terminals, three SPM's which are located offshore as can be seen in figure 2.2.

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THE ULSAN PORT DEVELOPMENT PLAN

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3. The necessity of this study.





Figure 3.2 Relocation plan for the SPM's with new pipeline alignment.



3.3. The effects of the port development plan on the Yukong SPM operations.

A consequence of the development plan is the possibility of negative effects on the SPM operations, both in a commercial sense and from a safety point of view. These effects can not only occur during the building phase, but after completion as well.

The idea, proposed in the government master plan, is that the SPM's will all be relocated due to different fairway routings. Their new locations are indicated in figure 3.2. This relocation is planned to avoid collisions with vessels sailing on the busy Ulsan and Onsan fairways. When tug assistance is prescribed, the relocated buoys are still to close to the fairways and each other. As a consequence, the maximum ship size for Yukong buoys # 1 and # 2 must be restricted to 150,000 DWT [1]. This restriction may also be applied to the Yukong #3 and Ssangyong SPM's.

Together with this relocation, a new pipeline alignment is arranged. The disadvantage of this new alignment is that the landing of the pipes is almost 1,000 metres away from the Yukong refinery. The new pipeline alignment was necessary to avoid non-feasible crossings with the proposed new breakwaters and undesirable crossings of the port basin, with the quay wall and terminal area.

A second possible disadvantage is the location of the new breakwaters, just in front of the Yukong SPM's # 1 and # 2 in phase 1. The tug boats come as close as 300 metres off the breakwater. Reflection of waves can increase the downtime for SPM operations significantly. The Yukong # 3 and Ssangyong SPM also will be affected by the south breakwater location in phase 2. The relocated pipelines of the Ssangyong and KEPCO buoys seem to be all right for 2011 but when expansion in 2020 comes up, they again have to be moved to avoid problems with breakwater crossings.

There are serious concerns about these effects on the efficiency of the SPM operations. Yukong has indicated that reductions of the oil import capacity are unacceptable, as the refinery depends entirely on the three offshore SPM's. No interviews with the other SPM operators have been made, but it is likely that these companies have the same demands [1].

Besides operational restrictions, also safety of the unloading operations can be argued. This is due to the chosen port layout and the forecasted increase in traffic density.

3.4. Other critical remarks.

When looking at the proposed layout in the government master plan, several critical remarks can be made (see also figure 3.1):

- 1. The fairway leading to the phase 2 part of the port makes a 30° angle at the breakwater head. This is not a good solution and violates one of the basic port design rules.
- 2. The same south fairway is only 300 metres wide, leading to one way traffic. As the length of this approach channel is rather long, major queue forming probably occurs. The existing Onsan approach channel is equally narrow, but its length is significantly shorter. Both fairways should be controlled by a VTSS (Vessel Traffic Service System).
- 3. The branch off from the Ulsan Main fairway to Onsan is too narrow for ships to make a safe turn.
- 4. The entrance to the phase 1 part is difficult, as just after the breakwater heads, the ship must make a near complete stop (2 knots), turn over 70°, sail 200 metres, turn further over 20° and then berth.
- 5. The breakwaters are detached, resulting in open basins. This induces cross-currents in the basins up to 1 knot. As the basins are designed to be entered from one side, confusion may arise with regard to entering from the other open side, possibly leading to dangerous situations.



- 6. The detached breakwaters can only be seen as an attractive option when they consist of sunken caissons. Every other construction would be more expensive, as all construction activities must be done by floating equipment.
- 7. The terminal widths are relatively small, especially the pier located on the south side of the phase 1 part. This pier is only 350 metres wide and should provide space for two terminals.
- 8. The terminal areas are following the contours of the coast, resulting in bended quays. This is not very efficient in terms of flexibility of ship berthing. It should be better to have long straight quays.
- 9. The turning cycles in the basin entrances are relatively small, R≈500 metres.
- 10. The entrance to Onsan Port can be confusing to ships' crews without local knowledge. They encounter three breakwater heads, without clearly visible port basin entrances.
- 11. There seems to be no reason to maintain the existing Onsan Port north breakwater.

3.5. Problem definition.

It is expected that the port of Ulsan will encounter a major increase in cargo throughput. The existing Ulsan and Onsan facilities are not capable of dealing with this growth. Therefore additional facilities must be developed.

These facilities can not be created by using existing land, as there is little suitable space available and the local conditions preclude the dredging of basins inland (hilly rock, see section 3.7). The only option is the reclamation of a part of the sea. Even this solution entails difficulties, namely:

- A steep foreshore gradient and the existence of exposed rock close to the shore, to depths of 20 metres, implying large quantities of rock dredging to acquire sufficient water depth for berthing ships.
- The rock slopes down steeply in seaward direction to a depth of 75 metres or more.
- The covering of this deep rock with a layer, increasing in depth offshore, of very soft soil that is not suitable as a foundation for structures.

The proposed master plan as drafted by a consortium of Korean consultants, by order of the Korean Government, attempts to find a practicable solution to the preceding problems. This plan however, contains some major and many minor disadvantages for the present and future customers operating in the port. These disadvantages have been outlined in the preceding sections.

3.6. Objective.

The objective of this part of the study is to develop a new master plan for the Ulsan Port development. This will be done using the existing data from the government master plan. With this data, a cargo and traffic forecast can be made. This leads to requirements for the new facilities and eventually alternative layout plans are made. After evaluation one final design is selected.



3.7. Boundary conditions.

3.7.1. Climatic boundary conditions.

- 1. The wind rose data for Ulsan are pictured in figure 3.3. During the winter, the prevailing wind direction is north-west to north-east, while in the summer it is south to south-south-east.
- 2. Annual weather status in the Ulsan vicinity, see table 3.1.

Item		Measurement	Value	Remarks
Atmospheric	Average	Hpa	1,015.7	
Pressure	Maximum		1,040.8	
	Minimum		962.5	
Temperature	Average	°C	13.7	
-	Maximum		38.6	
1	Minimum		-12.5	
Humidity	Average	%	67.7	
	Minimum		15.9	
Precipitation	Average	mm	1,277.0	-
Vaporisation	Average	mm	972.4	
Wind	Average	m/s	2.2	
	Record high		(SW) 20.7	
	Max. instantaneous		(NNW) 36.7	
Days of	Clear	days	107	
phenomena	Cloudy		110	
	Fog		11	
	Rain		44	> 10 mm
	Snow		5	
	Frost		93	
	Thunderbolt		10	
	Storm		3	> 14 m/s
	Temperature		1	< -10°C

Table 3.1Meteorological data for Ulsan, collected from 1975-1994.

3.7.2. Oceanographic boundary conditions.

- 1. There exists a deep water ocean current at the seaward side of the Ulsan Port area. This is an east flowing annual longshore current.
- 2. The maximum tidal difference occurs at Onsan Port and amounts to 49.6 cm.
- 3. The tidal current in the Ulsan Port area has a yearly maximum of 0.8 knot.
- 4. The offshore extreme wave conditions, with a 1/50 year condition, as encountered in Ulsan can be found in table 3.2.



NNE S	7.1	11
NE	7.1	11
ENE	4.4	8
E	5.3	9
ESE	4.9	9
SE	6.4	10
SSE	7.4	11
*S	9.0	13
SSW	9.8	13

 Table 3.2
 Extreme (1/50 year) wave conditions for Ulsan.

- 5. The nearshore wave height conditions are restricted due to the sheltering effects of the promontory. The distribution of the nearshore wave heights can be viewed in figure 3.4.
- 6. The refraction effects are relatively small for water depths of around 25 metres.

3.7.3. Geotechnical and geophysical boundary conditions.

- 1. The foreshore consists of exposed hard rock down to depths of MSL -20 metres (Mean Sea Level).
- 2. The hard rock steeply slopes down to MSL -80 metres depth offshore. See figure B.1 in Appendix B for a drawing of the rock layers.
- 3. The offshore deep lying rock is overlaid by a small layer of clayey and silty sand, which in turn is covered with a thick layer (up to 55 metres) of very soft silty clay.

3.7.4. Topographical boundary conditions.

- 1. The Ulsan Port hinterland is very hilly, rising up to about 800 metres above sea level.
- 2. Ulsan city is situated on rolling terrain, with heights around 150 metres above sea level.
- 3. The south coastal area of the Ulsan vicinity consists of relatively flat terrain, suitable for developing new industrial complexes.

3.7.5. Bathymetric boundary conditions.

1. The water depths as encountered in the Ulsan coastal zone are shown in figure B.2 in Appendix B.

3.8. Assumptions.

- 1. The reason for the development and the direction towards a multi-purpose port are adopted from the government master plan.
- 2. Quarries for revetments, fill material and possibly breakwater core material are available within short distances.
- 3. The cargo forecast from the government master plan is thought to be correct, except for chemical products.
- 4. The ship sizes and accompanying ship lengths as indicated in the government master plan are copied.
- 5. The remaining data from the government master plan is used, unless specifically mentioned that it is not.

3. The necessity of this study.





Figure 3.3 Wind rose for the Ulsan Port surroundings.



Figure 3.4 The nearshore annual wave distribution for Ulsan Port.



4. ASSESSMENT OF FUTURE CARGO FLOWS.

4.1. Introduction.

When designing a new port or extension of an existing port, it is of major importance to have a soundly based impression of the future cargo flow and shipping traffic. The problem is that the desired cargo flows and shipping traffic have to be estimated for a period of twenty years from the present. The future cargo flows used in this study are all based on the 1995 cargo flow values, obtained from [2]. These values are then modified to future cargo flow values by multiplication with an annual growth factor, which can be found in [3], or are copied from [4]. It is unavoidable that the obtained values are not as accurate as desired, due to incomplete or unknown data.

4.2. Extracted 1995 cargo flows and shipping traffic.

At first, the totals of shipping movements in and out of Ulsan Port for 1994 and 1995 are reproduced in table 4.1. This information is taken from [2]. The numbers are divided in coastal and ocean-going and it becomes clear that the coastal traffic is about twice the ocean-going traffic. Another division is made in arrivals and departures. It is curious that the number of arrivals is not equal to the number of departing ships. The most probable explanation is that at the moments of counting some ships already are in the port and are only labelled "departing". On the other hand, some ships are counted as "arrivals" but have not left the port as the last count of the year is made.

		Ship movements			
YEAR		Total	Ocean-going	Coastal	
	Arrival	19078	5817	13261	
1994	Departure	19018	5686	13332	
	Total	38096	11503	26593	
	Arrival	20604	6644	13960	
1995	Departure	20647	6699	13948	
	Total	41251	13343	27908	

Table 4.1Total ship movements for Ulsan Port in 1994 and 1995.

The next table 4.2 shows the number of ships arriving and departing from Ulsan Port in 1995. This information is again taken from [2]. Now the ships are divided into different types, like the crude oil carrier or general cargo ship. The third and the last column of this table give an impression of the size of the different types of ships (the gross tonnage is a measure for the total cubic capacity of a ship). Notice: the upper table is for arriving ships and the lower table for departing ships.

1995 DATA	Import					
	Ocean-going			Coastal		
	Volume	No. of ships	Average tonnage	Volume	No. of ships	Average tonnage
	(1000 GT)		per ship	(1000 GT)		per ship
			(Gross tons)			(Gross tons)
Bulk carrier	6618	244	27123	1875	2160	868
Log carrier	338	31	10903	0	0	-
Cement ship	103	18	5722	399	98 '	4071
Car carrier	13478	390	34559	418	58	7207
Hot coil carrier	30	3	10000	35	18	1944
Refrigerator ship	340	35	9714	0	0	-
General cargo ship	17056	1623	10509	774	562	1377
Full container ship	3009	511	5888	0	0	-
Semi-container ship	628	62	10129	0	0	-
Crude oil carrier	29642	337	87958	2474	1180	2097
Product carrier	12570	767	16389	8802	6795	1295
Chemical tanker	13317	2297	5798	1627	1082	1504
Gas carrier	2813	139	20237	1971	667	2955
Others	1199	187	6412	869	1340	649
70744.0		0011		10011	42060	
TOTALS	101141	0044		19244	12900	1

	. Export					
	Ocean-going				Coastal	-
	Volume	No. of ships	Average tonnage	Volume	No. of ships	Average tonnage
	(1000 GT)		per ship	(1000 GT)		per ship
			(Gross tons)			(Gross tons)
Bulk carrier	6973	254	27453	1877	2165	867
Log carrier	366	33	11091	19	1	19000
Cement ship	101	18	5611	399	98	4071
Car carrier	13526	388	34861	425	59	7203
Hot coil carrier	30	3	10000	33	17	1941
Refrigerator ship	332	34	9765	0	0	-
General cargo ship	17387	1647	10557	788	565	1395
Full container ship	3111	515	6041	0	0	-
Semi-container ship	711	65	10938	0	0	-
Crude oil carrier	30224	339	89156	2488	1188	2094
Product carrier	12414	768	16164	8872	6773	1310
Chemical tanker	13365	2281	5859	1656	1096	1511
Gas carrier	2762	137	20161	1989	670	2969
Others	2350	217	10829	862	1316	655
TOTALS	103652	6699		19408	13948	

Table 4.2Sizes and numbers of the different types of ships.

Now that the numbers of the different types of ships are known, a coupling must be made between these types of ships and the commodities they transport. This coupling is made in table 4.3. Different commodities can be shipped with the same type of ship. The first column shows which type of ship is used to transport the commodity. In some cases, like for instance fresh fish, two types are in use: the specific reefer and the general cargo ship with refrigerated holds.

The commodities listed in the second column are found in [2]. The only commodity, not mentioned in this reference is container traffic. This cargo flow is expressed in another unit (TEU) and will be discussed in table 4.6.



The dimension of the cargo is metric tons. One metric ton equals 1,000 kilo.

When observing the data a strange deviation is notable: the item "Parts for vehicles" in the export-table. This commodity consists partly of cars. This amount can be derived from [3]. If this value is expressed in metric tons and assuming 1 car weighs 1,000 kilos, there are 4,286,000 cars exported every year. This is not a realistic premise. Most likely the amount of cars is expressed in freight-tons.

One freight-ton is equal to 1.0 m³ when the specific weight of cargo is less than 1.0 ton/m³ and equal to 1.0 ton when the specific weight is more than 1.0 ton/m³. In case of a car, the specific weight is clearly less than 1.0 ton/m³: take a car with dimensions 5.0*1.8*1.5 m³ and 1,000 kg in weight, then the specific weight equals 0.074 ton/m³. In this case, cargo must be expressed in m³.

1995	DATA

· · · · · · · · · · · · · · · · · · ·	IMPORTED CARGO	Ocean-going	Coastal	Total
		(1000 tons)	(1000 tons)	(1000 tons)
Bulk carrier	Cereals	1557	0	1557
Crude oil carrier	Crude oil	49281	32	49313
Product carrier	Oilproducts	8735	421	9156
Gas carrier	Gasses	3941	136	4077
Bulk carrier	Fertilizers-	314	2	316
Cement carrier	Cement	564	1322	_1886
Bulk carrier	Anthracite	124	0	124
Bulk carrier	Coals	1085	0	1085
Bulk carrier	Natural sand	62	671	733
Bulk carrier	Iron ore	11	0	11
Bulk carrier	Other ores	1898	16	1914
General cargo ship	Iron scrap	0	1	1
General cargo ship	Iron materials	892	780	1672
Chemical tanker	Chemical products	5397	556	5953
General cargo ship	Plastics, rubber	177	15	192
General cargo ship	Textiles	132	0	132
General cargo ship	Others	267	45	312
	Lumber			
Log carrier	1) In the rough	168	0	168
General cargo ship	2) Articles	1150	0	1150
	Food			
General cargo ship	1) Fats & oils	40	0	40
General cargo ship	2) Prepared food	540	0	540
General cargo/Refrigerator ship	3) Fresh fish	619	0	619
General cargo/Refrigerator ship	4) Other animal/vegetable products	631	0	631
General cargo ship	5) Sugar	346	0	346
	Machinery			
General cargo ship	1) Articles of base metal	207	0	207
General cargo ship	2) Machinery	100	12	112
General cargo ship/Car carrier	3) Parts for vehicles	8	3	11
	Totals	78246	4012	82258

	EXPORTED CARGO	Ocean-going	Coastal	Total
		(1000 tons)	(1000 tons)	(1000 tons)
Bulk carrier	Cereals	5	12	17
Crude oil carrier	Crude oil	183	238	421
Product carrier	Oilproducts	13188	18813	32001
Gas carrier	Gasses	260	1605	1865
Bulk carrier	Fertilizers	500	15	515
Cement carrier	Cement	0	0	0
Bulk carrier	Anthracite	0	5	5
Bulk carrier	Coals	0	0	0
Bulk carrier	Natural sand	1	7	8
Bulk carrier	Iron ore	2	0	2
Bulk carrier	Other ores	154	47	201
General cargo ship	Iron scrap	0	71	71
General cargo ship	Iron materials	706	283	989
Chemical tanker	Chemical products	1548	541	2089
General cargo ship	Plastics, rubber	527	0	527
General cargo ship	Textiles	15	0	15
General cargo ship	Others	22	972	994
	Lumber			
Log carrier	1) In the rough	0	0	0
General cargo ship	2) Articles	35	0	35
	Food .			
General cargo ship	1) Fats & oils	1	1	2
General cargo ship	2) Prepared food	3	2	5
General cargo/Refrigerator ship	3) Fresh fish -	0	0	0
General cargo/Refrigerator ship	4) Other animal/vegetable products	5	19	24
General cargo ship	5) Sugar	49	0	49
	Machinery			
General cargo ship	1) Articles of base metal	8	0	8
General cargo ship	2) Machinery	488	66	554
General cargo ship/Car carrier	3) Parts for vehicles	4286	356	4642
	Totals	21986	23053	45039

Table 4.3Imported and exported cargo in (freight) tons.

To determine the average cargo per call for the different types of ships and ocean-going or coastal categories, a combination of the previous tables has to be made. From table 4.2 the numbers of ships are used and combined with the annual throughputs of the different commodities, summed for the type of ship they are transported with (use table 4.3). Division of the annual transported volume by the number of ships yields the average cargo per call per type of ship.

For some ship types, a modified average cargo per call must be determined, due to a different assumption in arrival and departure status for these types. The assumption implies a specific cargo transport regime:

- a. If ships arrive with cargo, then they depart empty.
- b. If ships depart with cargo, then they arrive empty.

This assumption has been made for the following types of ships:

- Bulk carrier
- Crude oil carrier
- Product carrier
- Chemical tanker
- Gas carrier

4. ASSESSMENT OF FUTURE CARGO FLOWS.



The reason for this assumption is the nature of the transported commodities. To give an example: a crude oil carrier importing crude for a refinery will probably not load a new amount of crude oil (or any other commodity) in the same port. This ship unloads and departs in ballast to collect a new amount of crude oil in its export port.

The following formulae calculate the modified average cargo per call for a specific commodity:

number of ships arriving with cargo
$$= \left[\frac{\text{imported cargo volume}}{\text{imported + exported cargo volume}}\right] * total number of arriving ships}$$

average cargo per call for ships arriving with cargo = $\frac{\text{impol}}{\text{number of s}}$

imported cargo volume

number of ships arriving with cargo

Subtract the number of ships arriving with cargo from the total number of arriving ships to find the number of ships, arriving empty. For exported cargo the same procedure can be followed.

	Export								
1995 DATA	Ocean-going				Coastal				
	Volume	No. of ships	Average cargo	Modified	Volume	No. of ships	Average cargo	Modified	
	(1000 tons)		per call (tons)	average cargo	(1000 tons)		per call (tons)	average cargo	
	. ,			per call (tons) {4}				per call (tons) {4}	
Bulk carrier	662	254	2606	22944	86	2165	40	358	
Log carrier	0	33	0	0	0	1	0	0	
Cement ship	0	18	0	0	0	98	0	0	
Car carrier {1}	4288	388	11052	11052	214	59	3627	3627	
Refrigerator ship {2}	0	34	0	0	0	0	0	0	
General cargo ship	1859	1647	1129	1129 ~	1556	565	2754	2754	
Full container ship {3}	18 (1000 TEU)	515	35 (TEU)	35 (TEU)	0	0	0	0	
Semi-container ship	2 (1000 TEU)	65	31 (TEU)	31 (TEU)	0	0	0	0	
Crude oil carrier	183	339	540	540	238	1188	200	228	
Product carrier	13188	768	17172	28546	18813	6773	2778	2835	
Chemical tanker	1548	2281	679	3034	541	1096	494	1007	
Gas carrier	260	137	1898	30442	1605	670	2396	2602	
TOTALS	21088	6479	3304		23053	12615	1827		

	Import							
1995 DATA	Ocean-going				Coastal			
	Volume	No. of ships	Average cargo	Modified	Volume	No. of ships	Average cargo	Modified
	(1000 tons)	•	per call (tons)	average cargo	(1000 tons)		per call (tons)	average cargo
				per call (tons) {4}				per call (tons) {4}
Bulk carrier	5051	244	20701	22943	689	2160	319	358
Log carrier	168	31	5419	5419	0	0	0	0
Cement ship	564	18	31333	31333	1322	98	13490	13490
Car carrier {1}	0	390	0	0	0	58	0	0
Refrigerator ship {2}	625	35	17857	17857	0	0	0	0
General cargo ship	4484	1623	2763	2763	856	562	1523	1523
Full container ship {3}	20 (1000 TEU)	511	39 (TEU)	39 (TEU)	0	0	0	0
Semi-container ship	2 (1000 TEU)	62	32 (TEU)	32 (TEU)	0	0	0	0
Crude oil carrier	49281	337	146234	146343	32	1180	27	228
Product carrier	8735	767	11389	28546	421	6795	62	2835
Chemical tanker	5397	2297	2350	3034	556	1082	514	1007
Gas carrier	3941	139	28353	30442	136	667	204	2602
	I							
TOTALS	78246	6454	12124		4012	12602	318	

{1} Assumption: one car = $5.0*1.8*1.5 \text{ m}^3 = 13.5 \text{ m}^3 = 13.5$ freight-tons.

- 2 Assumption: 50% of all refrigerated cargo is shipped by general cargo ships with refrigerated holds.
- {3} Assumption: 10% of all container traffic is shipped by semi-container ships.
- 4) For bulk, crude oil, oil products, chemical products and liquefied gases, the average cargo per call is modified.

Table 4.4Determining the average cargo per call.

The amounts of container traffic are copied from table 4.6.

4.3. Assessment of the future cargo flows.

4.3.1. Information sources.

With the previous tables the totals of cargo flows and shipping traffic for 1995 are known. A complete overview is given in table 4.7. With this information a cargo forecast for the years 2011 and 2020 can be made.

The information in tables 4.7 to 4.9 is fairly complex and for clearness a description per "block" is given. A "block" is a combination of four columns, with borders of double lines in the tables. The three tables are constructed in an identical order. Unless specifically mentioned, the explanation per block is generally valid for the years 1995, 2011 and 2020.

4.3.2. Block 1: Volume.

The first block contains the annual cargo volumes, separated in four categories: import, export, oceangoing and coastal. The values for 1995 are copied from table 4.3. The values for 2011 and 2020 are extracted from [4], the predictions are listed in tables 4.5 and 4.6:

	2011	2011	2011	2011	2020	2020	2020	2020
	Import	Export	Coastal	Sum	Import	Export	Coastal	Sum
Grain	1,495	0	94	1,589	1,588	0	94	1,682
Cement	355	0	3,138	3,493	· 326	0	4,272	4,598
Coal	2,434	0	2	2,436	3,048	0	1	3,049
Lumber	2,759	0	0	2,759	3,247	. 0	0	3,247
Sand	27	0	1,490	1,517	27	0	1,967	1,994
Iron Ore	51	0	0	51	59	0	0	59
Other Ores	10,260	74	48	10,382	16,829	71	38	16,938
Steel-made	2,952	1,828	2,565	7,345	3,374	2,060	2,900	8,334
Scrap Iron	0	0	0	0	0	0	0	0
Vehicle	236	6,272	289	6,797	321	5,476	327	6,124
Other General	10,913	1,637	10,787	23,337	15,249	2,435	15,066	32,750
Crude oil	133,761	0	0	133,761	158,783	0	0	158,783
Liquid Cargo	20,718	25,369	33,812	79,899	25,835	37,011	42,970	105,816
Total	185,961	35,180	52,225	273,366	228,686	47,053	67,635	343,374

Table 4.5 Cargo forecast excluding containers (1000 (freight) tons) according to [4].



Classification		1995	2011	2020
Marine cargo	(1000 ton)	740	6,096	9,141
TEU base (1000 TEU)	Import Export Transhipment Coastal	22 20 0 0	185 253 0 0	272 366 0 0
	Total	42	438	648
Average cargo per TEU (tons)		17.62	13.92	14.11

Table 4.6Forecast of container cargo according to [4].

Some difficulties do occur; information in the cargo forecast does not fully match with the cargo flows of 1995 (table 4.3):

1). Coastal traffic.

In [4], coastal shipments are not separated in import cargo and export cargo. To determine the import flow and export flow in the year 2011 and 2020, the assumption is made that the ratio between import and export for coastal traffic does not change over the years. The ratios for 1995 are used and can be found in block 1 of the 1995 table.

 $coastal import_{2011} = \left[\frac{coastal import}{(coastal import + coastal export)}\right]_{1995} * total coastal cargo_{2011}$

2). Lumber.

Rough wood and articles of wood are shipped with different types of ships; rough wood is shipped with log carriers and wooden articles are shipped by general cargo ships. In the cargo forecast, only their collective noun "lumber" is mentioned. The amount of lumber must be separated in rough wood and articles of wood. This is done by using the 1995 ratios for these different types of cargo:

rough wood $_{2011} = \left[\frac{\text{rough wood}}{\text{lumber}}\right]_{1995} * \text{lumber}_{2011}$

3). Refrigerated cargo.

Refrigerated cargo is not mentioned in the cargo forecast. It is assumed that refrigerated cargo is placed under "other general cargo". The growth of refrigerated cargo will therefore be calculated equal to the growth of general cargo.

4). Chemical products and general cargo.

Another problem with the term "other general cargo" occurs. It appears that in this other general cargo all chemical products for the petro-chemical industry are included. These chemical products are shipped with chemical tankers instead of general cargo ships and thus must be excluded from other general cargo.

The ocean-going import is calculated from the annual growth rate of 3% for chemical products given in [3]. This value is reliable in a way that for the years 1995, 1996 and 1997 the cargo flow values match the growth rate.

The growth rate for ocean-going export of chemical products, that can be found in [3], seems not representative for long-term calculations. The proposed growth rate is almost 11%, based on the 1996 cargo flow. The cargo flow in 1997 however, shows a decrease of more than 12%. Another growth factor must be used. As the chemical products originate from the other general cargo in the government master plan, the volume for ocean-going export is calculated in relation to the growth of general cargo. The difficulty in this case is that the general cargo depends on the amount of chemical products and vice versa. To determine both values, iteration must be executed.

This procedure is again followed for the calculation of coastal cargo transport volumes. It must be kept in mind that in this case an extra condition must be fulfilled: the ratio of imported and exported coastal cargo of 1995 stays valid.

5). Liquid cargo.

Liquid cargo is the collective noun for oil products and liquefied gases. In the cargo forecast, this distinction is not made. The cargo volume in 2011 for the different fractions is calculated by using the ratio of products and gases in 1995 and it is assumed that this ratio does not change during the years. For coastal cargo volumes again two ratios are significant: products-gases and import-export. The first step is to determine which part of the total liquid cargo is imported and which is exported. The next step is to calculate the separate fractions of oil products and liquefied gases.

4.3.3. Block 2: Average cargo per call.

This block contains the "average cargo per call" values. For 1995 the modified values are copied from table 4.4. For the forecast of 2011 and 2020 the values are calculated via the following procedure:

- The forecasted cargo volume must be checked. If it increases substantially with regard to the 1995 value, an increase in cargo per call can be expected due to an increase in scale.
- When the forecasted cargo volume is constant or decreasing with regard to the 1995 value, the average cargo per call calculated for 1995 stays valid. The only exception is the cement ship, it's average cargo per call is decreased, because the 1995 value is extraordinary high.


4.3.4. Block 3: Number of ships.

Per commodity, the number of ships sailing in and out the Port of Ulsan is determined. The formula is very simple:

number of ships = $\frac{\text{cargo volume per commodity}}{\text{average cargo per call per commodity}}$

This formula is applied for every category ocean-going, coastal, import and export.

For 1995, the values from table 4.4 must be respected. For this reason the number of arriving ships is not equal to the number of departing ships, as explained earlier.

In the forecast for 2011 and 2020 the assumption is made that the number of arriving ships equals the number of departing ships.

The calculated numbers of ships do not represent the total amount of ships sailing in and out of the port. When calculating the number of ships arriving with cargo, the ships departing empty are not taken into account. When calculating the number of ships, departing with cargo, the number of ships arriving empty is out of the calculation. To take these missing numbers into account, two possibilities have to be investigated:

- 1. For the bulk carriers, crude oil carriers, product carriers, chemical tankers and gas carriers all ship movements must be doubled. This is due to the fact that these ships sail in ballast after unloading, so no ships depart with cargo, or before loading, in this case all ships arrive empty.
- 2. In all other cases, compare the number of ships importing cargo with the number of ships exporting cargo. When the smallest value is subtracted from the biggest, the ships that respectively depart or arrive empty are found.

4.3.5. Block 4: Ship movements in/out.

In this block, consisting of only one column, the total ship movements for the different types of ships are determined. It is a simple sum of the values in block 3. The totals are needed in table 5.2.

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5. ASSESSMENT OF THE FUTURE SHIP MOVEMENTS.

5.1. Adapting the government master plan cargo division.

In this chapter an assessment of the number of ships (per type) calling at the old port, being the existing Ulsan and Onsan facilities, and the new port is made.

From [4] table 5.1 is copied, containing the ratios of cargo going to the old port and new port. The values for the total future cargo ("required facility") are equal to the values in tables 4.8 and 4.9. An exception is the amount of general cargo: it seems that a considerable part of the cargo listed under general cargo in table 5.1 consists of liquid chemicals. The idea that these chemicals are shipped in barrels on pallets does not hold, as the volume of liquid chemicals is in the order of 15,000,000 tons per year (see tables 4.8 and 4.9). These chemicals cannot be handled at a general cargo terminal but require separate berths (probably jetty type). These goods are shipped with dedicated chemical tankers as can be found in [2].

The "berth capacity after function rearrange" stands for the new berth capacity in the existing port. This capacity is thought to increase according to the government master plan due to more efficient cargo handling.

With table 5.1 and the following steps the ship movements can be assessed:

- For bulk carriers and general cargo ships, add the volumes of the different commodities attached to this type of ship. Do this separately for the old port and for the new port.
- Calculate the percentages of the total amount of cargo (per ship type) going to respectively the old port and the new port.
- Multiply the percentages and the total number of ships per type:

Number of ships of type x sailing to old port = percentage total cargo of old port * total number of ships of type x Number of ships of type x sailing to new port = percentage total cargo of new port * total number of ships of type x

• Add the values of the different types of vessels to obtain the total number of ship movements for the old and the new port.

Some commodities are not mentioned in table 5.1. The division in old port and new port for these commodities is made, using the ratio given for the type of commodity from which the unknown type is part:

- Rough wood and wooden articles use the lumber ratio.
- Other general cargo, refrigerated goods and chemical products use the general cargo ratio.
- Oil products and liquefied gases use the liquids' ratio.

UNIT: 1000 TONS	Classification	2011	2020
	Required Facility	1589	1682
Grain	Unloading Capacity after Function rearrange	2495	2495
	New Port Cargo	0	0
	Required Facility	3493	4598
Cement	Unloading Capacity after Function rearrange	2903	2903
	New Port Cargo	590	1695
	Required Facility	2436	3049
Coal	Unloading Capacity after Function rearrange	3024	3024
	New Port Cargo	0	25
aawaa aaaaaa aa aaaaa	Required Facility	2759	3247
Lumber	Unloading Capacity after Function rearrange	891	891
	New Port Cargo	1868	2356
<u></u>	Required Facility	51	59
Iron Ore	Unloading Capacity after Function rearrange	0	0
	New Port Cargo	51	59
	Required Facility	0	0
Scrap Iron	Unloading Capacity after Function rearrange	0	0
·	New Port Cargo	0	- 0
	Required Facility	7345	8334
Steel-made	Unloading Capacity after Function rearrange	4665	4665
Product	New Port Cargo	2680	3669
	Required Facility	6797	6124
Vehicle	Unloading Capacity after Function rearrange	15120	15120
	New Port Cargo	0	0
······································	Required Facility	1517	1994
Sand	Unloading Capacity after Function rearrange	1037	1037
	New Port Cargo	480	957
	Required Facility	10382	16937
Other Iron	Unloading Capacity after Function rearrange	2759	2759
Ore	New Port Cargo	7623	14178
	Required Facility	23337	32750
General	Unloading Capacity after Function rearrange	13365	14613
Cargo	New Port Cargo	9972	18137
	Required Facility	79899	105816
Liquid	Unloading Capacity after Function rearrange	114159	114159
Cargo	New Port Cargo		0
	Required Facility	133761	158783
Crude Oil	Unloading Capacity after Function rearrange	62370	62370
	New Port Cargo	71391	96413
	Required Facility	438	648
Container	Unloading Capacity after Function rearrange	0	0
(1000 TEU)	New Port Cargo	438	648

Table 5.1The division of the cargo for the old and the new port.



5.2. The liquid cargo problem.

It is not likely that the future liquid cargo can in total be handled by the existing Ulsan and Onsan berths and SPM's, as stated in table 5.1. This will certainly be the case when tanker length restrictions are prescribed for the SPM's. The immense increase in capacity as shown in table 5.1 is justified in [3]. The statements made in this reference assume that a massive increase in throughput is possible for the present berths, by means of increasing the low berth occupancies. It should be noted that the use of these berths is strictly exclusive. It is not possible for an arbitrary company to make use of these berths. Second, only dedicated commodities can be handled at this type of berths. The only increase in berth occupancy can be achieved by expansion of the berth-owners' production. Even this cannot be an unlimited growth, as it seems unlikely that the companies, operating liquid berths at present, have invested in a large unused excess capacity of their berths.

Therefore the assumption is made that 2/3 of the liquid cargo increment (compared to 1995 values) will be handled in the new port, and that hence 1/3 will be handled at existing facilities, upgraded as required. This assumption is based on the concept that part (1/3) of the future increased traffic will be generated by expansion of existing plants as that of Yukong. The remaining 2/3 of the increase is assumed to be generated by new plants, with their own tanker terminals.

From [4] the liquid cargo forecast can be derived. This liquid cargo comprises oil products and liquefied gases. Subtract the 1995 value for liquid cargo (add the values for oil products and gases from table 4.5) and the increment is found:

2011:	increment in liquid cargo =	79,899,000 - 47,099,000 = 32,800,000 tons
2020:	increment in liquid cargo =	105,816,000 - 47,099,000 = 58,717,000 tons

From these values, 2/3 is handled by the new port, yielding

2011:	21,867,000	tons
2020:	39,145,000	tons

The division in products and gases is made by applying the 1995 ratio between oil products and gases:

2011:	Oil products: 19,202,000 tons	Gases: 2,665,000 tons
2020:	Oil products: 34,373,000 tons	Gases: 4,772,000 tons

5.3. Assessed future ship movements for the new port.

The ship movements table 5.2 is shown on the next page.

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6. ASSESSMENT OF THE NUMBER OF BERTHS PER COMMODITY.

6.1. Berth capacities according to the government master plan.

The annual cargo to be handled in the new port is a measure for the amount of berths necessary. These values are copied from table 5.2. The annual berth capacity per commodity determined in [4] are listed in table 6.1.

Item	Typical vessel	Capacity	Remarks
	(DWT)	(1000 ton)	
Container	20,000	107	Based upon feeder
	,	*1000 TEU	0.55*300 days*16 hrs*2*15*1.5 TEU*0.9
Cement	20,000	1,663	
Lumber	20,000	891	(25T/Time*10*4)*0.55*10*300*0.6*0.9
Steel made product	20,000 -	1,166	2*25*15*0.6*16 hrs*300 days*0.6*0.9
Sand	2,000	518	0.6*300 days*16 hrs*200 ton*0.9
Other ores	20,000	1,152	1*600 T/H*0.5*16 hrs*300 days*0.8
General cargo	20,000	645 - 823	year 1996 - 2020 5% increase
Liquid cargo	20,000	2,064	910 T/H*0.5*24 hrs*300 days*0.7*0.9
Crude oil	300,000	14,742	6,500 T/H*0.5*24 hrs*300 days*0.7*0.9

Table 6.1 Berth capacities according to [4].

It is not clear on what basis the berth capacities are determined. A striking thing is that in [4] the assumption is made that future terminal handling is restricted to 16 hours/day, 300 days/year (except crude and liquid products, handling 24 hours/day). Although questioned, this assumption will be used in the assessment. Various parameters are not named or of obscure nature. The handling equipment is not mentioned, and values for handling capacities have to be assumed. To obtain an objective berth capacity, the queuing theory will be used.

6.2. The queuing theory.

In a complex environment, as large ports are, the chances to encounter delays and congestion are considerable, as not unavoidable. To minimise these costly phenomena, various techniques are available. To name a few:

- Empirical "rules of thumb"
- Queuing theory
- Simulation models

To obtain a reliable port capacity, the simulation model technique is the best alternative. There are some disadvantages however:

- Detailed information is needed as input for the model to be reliable. In the preliminary phase, this information is not yet available.
- The vast amount of time, necessary for testing and working with the model. Developing a simulation model for a port extension as in Ulsan, is a study on its own.

The "rules of thumb" are only suitable for small ports or isolated problems. In a major project like the Ulsan Port development, this method is not applicable.

Using queuing theory is the middle course between the preceding alternatives. It is rather simple to work with (using standard tables) and more reliable than the "rule of thumb" method.

The queuing theory schematises a port as a queue (anchorage) and a discrete number of berths. The inter arrival time distribution of the ships and the service time distribution are assumed to be mathematical expressions. This theory includes customers, requiring a single service before departing from the system. The governing factors in the queuing system are:

- a. Customers arrivals
- b. Service times
- c. Service system (number of berths)

The first two factors are statistically distributed, according to one of the following distribution functions:

M Negative Exponential Distribution (N.E.D.)

probability density function: $f(t) = \lambda \cdot e^{-\lambda t}$, requiring the parameter λ (mean) This distribution is often used for random inter arrival times of the ships

E_k The Erlang K distribution

probability density function: $f(t) = \frac{(k \cdot \mu)^k \cdot t^{k-1} \cdot e^{-k \cdot \mu \cdot t}}{(k-1)!}$, requiring the parameters μ and k.

This distribution is mainly used for service time distribution as they both consist of several stages. The Erlang K distribution exists of K negative exponential distributions with parameter $\mathbf{k} \cdot \lambda$.



D The deterministic distribution

probability density function:
$$f(t) = \int_{0}^{t} f(\mu) \cdot \lambda \cdot \mu = 0$$
 if $t < a$
= 1 if $t > a$

The variate does not change and takes the constant value a on all occasions: $\sigma^2=0$.

G The general distribution

When no assumption is made about the form of the distribution function the general distribution can be used.

The deterministic and general distributions are seldom used, as these functions do not correspond with the reality of ships' arrivals and service times.

Now systems can be assembled using three parameters. The first is the arrival time distribution function, the second is the service time distribution and the last is the number of berths. Example: $M/E_2/2$. The number of berths and the berth occupancy can be determined with the use of standard tables, if the maximum admissible waiting time is assessed.

The parameters needed for the use of the various tables are the following [5]:

- production per year per berth with 100% utilisation: pfull
- annual terminal throughput: t
- ρ=t/p_{full}
- number of berths: n
- berth occupancy ψ=ρ/n
- Assess the acceptable maximum waiting time for the commodity: W

An attempt is made to find the right combination of maximum waiting time and number of berths. This is done by choosing the number of berths, calculating the berth occupancy (or utilisation, the name used in the tables) and use the tables to determine the matching waiting time. If the combination is not satisfactory, it is tried to modify the number of berths and make a new calculation.

The average waiting times valid for the $E_2/E_2/n$ system are described in table D.1 in Appendix D.

For the $M/E_2/n$ system, the average waiting time can be read in table D.2 in Appendix D.

When n=1, the $E_2/E_2/1$ system results. For this system, the berth occupancy must be known, being $\psi=\rho/1=\rho$. With k=2 and l=2, tables D.3 to D.8 in Appendix D can be used.

6.3. New assessment of the berth capacities using the queuing theory.

The queuing theory now can be used to determine the number of berths, later to be expressed in a quay length. In combination with a berth occupancy, the annual handling capacity can be derived. While these calculations are made, it must be kept in mind that the waiting times must be held under control. Not the calculation itself, but the results of this calculation are of interest. Therefore the calculations can be found in Appendix C and only the results are listed in this section (table 6.2).

	2011		2020	
Commodity	Number	Berth capacity	Number	Berth capacity
	of berths	(1000 tons or TEU)	of berths	(1000 tons or TEU)
Other ores	3	2,500	5	2,850
Sand	2	245	3	317
Rough wood	1	230	1	300
Cement	1	604	1	1,693
Refrigerated goods	3	201	3	260
Other general cargo (1)	6	640	10	. 760
(2)	4	622	4	622
Lumber	2	821	3	684
Iron materials	2	1,359	3	1,225
Containers (1)	3	145	3	216
(2)	4	134	5	202
Crude oil	3	23,940	3	32,130
Chemical liquids	2	4,334	3	4,939
Oil products	3	6,350	4	8,554
Gases	1	2,635	2	2,416

 Table 6.2
 The number of berths and berth capacities for the different commodities.

6.4. Decreasing of general cargo and simultaneous increasing container traffic.

The items, marked with (2) in table 6.2, are modified with regard to the original government master plan. In this plan, general cargo is assumed to grow to large proportions, doubling from 3,856,000 to 7,558,000 tons. This is hardly imaginable as the break bulk part of shipments all over the world decreases rapidly, in favour of the container cargo traffic. This is confirmed in [6], where the forecast for Korea and Taiwan shows that the container traffic in 2010 will be tripled with regard to that of 1995. In the second of the following tables 6.3 the general cargo is supposed to be decreased for 2020, while simultaneously the container throughput is increased. This seems to be a more realistic view than the massive increase in break bulk as suggested in table 5.1.



<u>2011</u>

Original container cargo handling (table 4.6): 6,096,000 tons/year. Assume the annual throughput of break bulk decreases in the coming years (most break bulk cargo will be shipped with containers) to 2,500,000 tons/year. This means a decrease in general cargo of 3,856,000-2,500,000=1,356,000 tons/year. The increased container cargo volume now becomes 6,096,000+1,356,000=7,452,000 tons/year. The average weight of one TEU is 13.92 tons (table 4.6). This means a yearly throughput of approximately 535,000 TEU.

<u>2020</u>

Original general cargo forecast: 7,558,000 tons/year. Break bulk will always exist, because not all shipped cargo can be bundled. This is why the assumption is made that the annual throughput of general cargo in 2020 is equal to that of 2011: 2,500,000 tons/year. This means a decrease of 5,058,000 tons/year. This amount is added to the existing forecasted 9,141,000 tons of containerised cargo. An annual throughput of 14,199,000 tons of goods, shipped in containers, results. As the average cargo per TEU equals 14.11 tons (table 4.6), the annual container volume is 1,006,000 TEU.

6.5. Assessing the quay lengths.

For the determination of the quay lengths, various methods are available. One method is to assume a maximum ship. The length of this ship is then used to assess the length of one berth. This method is applied when only one berth is constructed. The berth lengths for these commodities are determined with figure 6.1. It is a summarised investigation into the relation between the quay length and the probability of additional waiting times, due to insufficient quay length [7].



Figure 6.1 Influence of the berth length/ship length ratio on the port time.

It should be noted that this figure originally is ment for general cargo ships. The distribution in length of these ships is probably not the same as for other ship types. The reliability of this figure can therefore somewhat be questioned. Moreover, the figure is 13 years old. Distribution of ship length might be canged over the years.



For preliminary design, as master planning is, the figure still may be used. When detailed planning is involved, additional research must be executed.

When the berth length is chosen equal to the ship length, an extra waiting time of 10% can be expected. To avoid this additional waiting times, the berth length must be chosen 10% longer than the ship length. The average and maximum ship sizes for the different commodities are printed in table 6.6. The berth lengths are listed in table 6.3. The average ship lengths for the proposed dead weight tonnages of the ships are copied from [4].

Commodity	Maximum ship size (DWT)	Matching ship length (m)	b Berth length (m)
Rough wood	20,000	177	195
Cement	50,000	216	240

Table 6.3 Berth length for single berth commodities.

When multiple berths are necessary for one commodity, this method should not be applied for continuous quays, as the length would be excessive. This because it is very doubtful that all the berths receive the ships with maximum length at the same time. This is never the case. One advantage of a continuous quay is that it is very flexible in its berthing capacity: the ships are in general not required to berth at a fixed point. This can however be the case for cement and sand terminals. These terminals are mostly fitted with an unloader and a set of belt conveyors per berth, so flexibility is limited. Another advantage of the straight quay sections is the possibility to change the function of a terminal to that of the adjacent terminal in a fast and simple way.

To avoid over-dimensioning of the quays, another method can be applied. This method does not take the maximum ship as decisive, but works with the average ship size. The average ship sizes for commodities, handled at continuous quays are copied from [4] and printed in table 6.4. The matching berth lengths are again assessed via figure 6.1.

Commodity	Average ship	Matching ship	Average "length
	size (DWT)	length (m)	per berth" (m)
Ores	30,000	186	205
Sand	2,000	81	90
Refrigerated	20,000	177	195
Other general	20,000	177	195
Wooden articles	20,000	177	195
Iron materials	20,000	177	195
Containers	20,000	201	225

Table 6.4 Average berth lengths.

The ore carrier is assumed to be 20,000 DWT average in the government master plan, but this value is adjusted to 30,000 DWT in a later fax from the Sunkyong company.

The jetty type berths for the liquid cargo handling do obviously have to be dimensioned on the maximum ship size that has to be received. These berths consist of a platform with (un)loading arms and several breasting and mooring dolphins, to hold the ship in a steady position during (un)loading operations.



The space between jetties must be somewhat more than that alongside quays. This because the ships' manifolds are not all exactly placed amidships and the tankers must be able to shift along the jetty. It is therefor that the extra length for jetty type berths is 20%. The maximum ship sizes can be found in table 6.5.

Commodity	Maximum ship size (DWT)	Matching ship length (m)	Space required for a jetty-type berth (m)
Chemical liquids	30,000	200	240
Oil products	50,000 ·	230	275
Crude oil	325,000	350	420
Gases	125,000 m ³	280	335

 Table 6.5
 Space requirements for jetty-type berths.

Type of ship		Avera	age shij	2	Maxii	mum sł	nip	
	DWT	L	B	D	DWT	L	В	D
		(m)	(m)	(m)		(m)	(m)	(m)
Ore carrier	30,000	186	27.1	10.9	50,000	216	31.5	12.4
Sand ship	2,000	81	12.7	4.9	5,000	109	16.4	6.8
Log carrier					20,000	177	23.4	10.0
Cement ship					50,000	216	31.5	12.4
Refrigerator ship	20,000	177	23.4	10.0	30,000	186	27.1	10.9
General cargo or	20,000	177	23.4	10.0	30,000	186	27.1	10.9
multi purpose								
ship								
Container ship	20,000	201	27.1	10.6	55,000	285	39.0	11.5
Chemical tanker					30,000	200	25.5	10.8
Product carrier					50,000	230	30.5	12.0
Crude oil carrier					325,000	350	56.0	24.0
Gas carrier					125,000 m ³	280	42.0	11.0

Table 6.6 Average and maximum ship sizes for the different types of ships.

The two tables 6.7.1 and 6.7.2 contain the preceding information and an assessment of the total quay length. The difference between the tables is that in table 6.7.1 the scenario of strongly growing general cargo as drafted in [4] is applied, and in table 6.7.2 the general cargo is kept constant in favour of increasing container traffic.

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7. TERMINAL AREA ASSESSMENT.

7.1. Introduction.

The classification of the terminal areas is a difficult matter. This is especially the case in the master plan phase, when so many factors are still preliminary. Basic design rules can be applied for the determination of terminal areas. Some of them will be discussed below. design must be made in the first phases of a project.

7.2. General cargo terminals.

7.2.1. Introduction.

The general cargo terminals will not all have the same layout. This is due to the origin of the cargo, and the ways of transhipment. As an example, a rough wood import terminal will have a different layout than the refrigerated cargo terminal. The items, necessary on the terminal terrain are sheds, paved roads, offices, workshops, etc. The calculation of the different terminal items will be made now.

The throughput value used in the formula can be that of 2011 or 2020. The throughput, corresponding with the highest berth capacity is chosen, as this value is determinative for the area assessment (resulting in the greatest terminal width). This can even hold for the smaller throughput value. The width of the terminal stays constant when the throughput increases, because the quay length increases proportionally.

7.2.2. Other general cargo terminal.

A brief and crude storage area determination can be achieved with the use of the following formula [7]:

$$O_{SA} = \frac{f_1 \cdot f_2 \cdot T \cdot t_{av}}{m \cdot h \cdot \rho \cdot 365}$$

in which:

 O_{SA} = storage area (m²)

 f_1 = proportion gross/net surface with regard to handling equipment (-)

 f_2 = bulking factor due to stripping and separately stacking of special consignments (-)

T = annual terminal throughput (tons)

 t_{av} = average dwell time of the cargo on the terminal (days)

m = average occupation of the storage area (-)

- h = average stacking height of the cargo (m)
- ρ = average relative density of the cargo as stowed in the ship (t/m³)

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For the "other general cargo" terminal, the values of the different parameters are assumed to be the following:

(The throughput prediction of 2011 is used as base of calculation although the 2020 value has a higher berth occupation. This has been done because there are serious doubts about the validity of this last scenario.)

$f_1 = 1.5$	Relatively large due to fork lift trucks, requiring large working spaces.
$f_2 = 1.3$	Relatively large due to unpacking and repacking of goods.
T = 2,600,000 tons	Assume 1/3 of the handled cargo does not have to be stored but is transported to
	or from the terminal directly.
$t_{av} = 10 \text{ days}$	This is a realistic value for general cargo.
m = 0.65	A relatively low value, but applied to all storage areas.
h = 2 meters	
$\rho = 0.40 \text{ tons/m}^3$	This because the heavy, pre-slung or palletised cargo is not handled at this terminal.

$$O_{SA} = \frac{1.5 \cdot 1.3 \cdot 2,600,000 \text{ tons } \cdot 10 \text{ days}}{0.65 \cdot 2 \text{ metres } \cdot 0.4 \text{ tons } / \text{m}^3 \cdot 365 \text{ days}} \approx 267,000 \text{ m}^3$$

Other components of the terminal have areas that are estimated as follows:

Apron: assume a width of 40 metres, as cargo must have the ability to be temporary parked on the apron after unloading.

The apron area now is (see table 6.6): 1,170 metres*40 metres≈45,000 m²

Shunting yard and additional rail tracks: 50,000 m²

Offices and work shops: 50,000 m²

Miscellaneous: 10,000 m²

The terminal width now becomes 422,000 m²/1,170 m \approx 350 meters.

7.2.3. Rough wood terminal.

The same formula can be used for the assessment of the rough wood terminal, only the values for the parameters must be changed. The 2020 forecast gives the highest berth occupation and is used for the area calculation.

$f_1 = 1.3$	The wood (trunks) is probably shunted with rail mounted gantry cranes into the stock and on trucks and/or trains.
$f_2 = 1.1$	The bulking factor is fairly small as no operations on the wood take place on the terminal and the only extra space results from the compilation of consignments.
T = 300,000 tons	Assume all of the handled cargo has to be stored on the terminal.
t _{av} = 15 days	
m = 0.65	A relatively low value, but the log is imported irregularly and in large quantities at a time.
h = 2 meters	The average height, the trunks are piled up in triangle shaped stocks.
$\rho = 0.75 \text{ tons/m}^3$	Change over value between hard and soft wood.



$$O_{SA} = \frac{1.3 \cdot 1.1 \cdot 300,000 \text{ tons} \cdot 15 \text{ days}}{0.65 \cdot 2 \text{ metres} \cdot 0.75 \text{ tons} / \text{m}^3 \cdot 365 \text{ days}} \approx 18,000 \text{ m}^3$$

Other components of the terminal have areas that are estimated as follows: Apron: take the width 20 metres, as handling of the wood on the apron is restricted to terminal traffic to and from the stacking area. The apron area now is (see table 6.6): 195 metres*20 metres≈4,000 m² Rail tracks: 5,000 m² Offices and work shops: 1,000 m² Miscellaneous: 2,000 m² The terminal width now becomes 30,000 m²/195 m ≈ 150 meters.

7.2.4. Lumber terminal.

As the throughput of wooden articles is rather high (up to 2,000,000 tons in 2020), a dedicated terminal can be designed for the handling of lumber. The throughput value for 2011 is used for the area determination. As this commodity is a type of general cargo, the general formula for the storage areas as mentioned above can again be used:

f ₁ = 1.5	The lumber is shipped in bundles or palletised and will be handled on the quay and in the storage areas by fork lift trucks. This equipment needs large manoeuvre spaces.
$f_2 = 1.2$	Operations on the cargo can be expected and the compilation of consignments increase the bulking factor.
T = 1,550,000 tons	Assume that 95% of the handled cargo has to be stored on the terminal.
$t_{av} = 10 \text{ days}$	
m = 0.70	The storage area must be a sheltered place as the lumber must be protected against the weather. As shed constructions are costly, the rate of occupation must not be too low.
h = 3 meters $\rho = 0.50 tons/m^3$	The bundles can be stacked on each other with the aid of fork lift trucks. Assume that the lumber consists of rather soft wood.

$$O_{SA} = \frac{1.5 \cdot 1.2 \cdot 1,550,000 \text{ tons} \cdot 10 \text{ days}}{0.7 \cdot 3 \text{ metres} \cdot 0.50 \text{ tons} / \text{m}^3 \cdot 365 \text{ days}} \approx 73,000 \text{ m}^3$$

Other components of the terminal have areas that are estimated as follows:

Apron: take the width 30 metres, as handling of the lumber on the apron must be done by fork lift trucks, requiring large manoeuvring spaces and the bundles are temporarily parked on the quay during (un)loading.

The apron area now is (see table 6.6): 390 metres*30 metres≈12,000 m² Rail tracks: 5,000 m² Offices and work shops: 5,000 m² Miscellaneous: 10,000 m²

The terminal width now becomes 105,000 m²/390 m \approx 275 meters.

7.2.5. Iron materials terminal.

This again is a special case of a general cargo terminal. It consists of steel products among which steel plates and bars. The storage area can be assessed, using the general cargo storage area formula and the 2011 throughput value:

$f_1 = 1.5$	The iron materials handled on the quay and in the storage areas by both fork lift trucks and gantry cranes. The combination of equipment needs large manoeuvre spaces.						
$f_2 = 1.1$	No operations on the cargo are expected and only the compilation of consignments are influencing the bulking factor.						
T = 2,680,000 tons $t_{av} = 10 \text{ days}$	Assume that all of the handled cargo has to be stored on the terminal.						
m = 0.70	The storage area must be a sheltered place as the steel must be protected against the weather (only reinforcing steel and metal ingots may remain unsheltered). As shed constructions are costly, the rate of occupation must not be too low.						
h = 2 meters	The bundles can not be stacked too high as a consequence of the high ground pressures they cause.						
$\rho = 2.5 \text{ tons/m}^3$	Assume that the majority of the cargo consists of steel plates and bars.						

 $O_{SA} = \frac{1.5 \cdot 1.1 \cdot 2,680,000 \text{ tons} \cdot 10 \text{ days}}{0.7 \cdot 2 \text{ metres} \cdot 2.5 \text{ tons} / \text{m}^3 \cdot 365 \text{ days}} \approx 35,000 \text{ m}^3$

Other components of the terminal have areas that are estimated as follows:

Apron: take the width 30 metres. The handling of the iron material on the apron must be done by fork lift trucks, requiring large manoeuvring spaces. Second, the bundles are temporarily parked on the quay during (un)loading.

The apron area now is (see table 6.6): 390 metres*30 metres≈12,000 m²

Rail tracks: 25,000 m^2 as the majority of the steel products are transported by train, due to the high weight of the units.

Offices and work shops: 5,000 m²

Miscellaneous: 10,000 m²

The terminal width now becomes 87,000 m²/390 m \approx 225 meters.

7.2.6. Refrigerated cargo terminal.

Refrigerated cargo is perishable general cargo that has to be cooled. Therefor provisions like cold storage rooms have to be made to keep the cargo cooled. The investments for such provisions are considerable and therefor a trend can be noticed to use refrigerated containers, with their own cooling generators. This is probably going to happen in this case too. As a first approximation, the width of the refrigerated cargo terminal is made equal to that of the "other general cargo". This width must be sufficient to be able to function now as a conservative refrigerated cargo terminal and in the future as a refrigerated container terminal.



7.3. General requirements for a container terminal.

As container handling is one of the most dynamic and thus problematic activities in port operations, the design of a container terminal is a difficult task. One of the first things to do is to find a suitable site. Suitable in this manner means with sufficient space for storing and an acceptable soil condition, as the handling equipment causes high loads on the pavement.

The requirements that have to be satisfied during the design are the following:

1. Container flow

Within the terminal, the route of the containers must be logical and undisturbed. This route should be determined keeping in mind the initial and future throughputs, the operator's method of control and the handling and stacking procedures.

2. Container stacking areas

The storage areas are stacks of containers, several containers wide and 1 to 6 high. These stacks are provided with handling equipment, for instance straddle carriers, gantry cranes or forklift trucks. The size of the stacking areas can be assessed, using the following factors:

- The forecasted throughput.
- The average dwell time of the containers in the terminal.

3. The type of handling equipment

The time distribution of containers to be handled (difference in average and peak flows)

4. Container Freight Station (CFS)

The main purpose of a CFS is the unpacking, handling and distribution of cargo, shipped with containers, and conversely the assembly and packing of cargo for a container.

The size of a CFS depends on many factors, for instance dwell times, type of cargo, etc., but as a guideline 10 freight tons per year per m² can be used. The storage of empties should be close to the CFS, for easy access.

5. Ro-ro provisions

Although not mentioned in [4], it is probable that at least one berth is provided with ro-ro facilities.

6. Rail terminal/shunting yard

The site where the new port is planned provides no additional back up land areas. The distribution of container cargo and general cargo will be partly done by rail, requiring a vast amount of space for shunting and waiting. It is noted that space must be reserved for this purpose on the terminal property.

As the most important requirements now are known, an attempt can be made to assess the terminal layout and surface area.

7.4. Stacking areas.

7.4.1. Cargo forecast.

The forecasted throughput for 2011 is 438,000 TEU and is 648,000 TEU for 2020, according to table 4.6. According to table 6.2 these values can increase to 535,000 TEU in 2011 and 1,006,000 TEU in 2020.

7.4.2. Dwell times of the containers on the terminal.

The dwell times are difficult to foresee. Some reference can be made with regard to the container terminal of ECT in Rotterdam. ECT has carried out a study of the dwell times for their Home-Terminal [7]. This resulted in the following formula:

$$\overline{t_d} = \frac{(T + 2)}{3}$$

in which T = maximum dwell time (98% of the containers have left the terminal).

At the ECT terminal the maximum dwell time T = 10 days for import and export containers (common for West European countries). The dwell time for empties is significantly longer. The average dwell time at ECT becomes

$$\overline{t_d} = \frac{(10 + 2)}{3} = 4 \text{ days}$$

Some of the objectives of the Korean Government Master Plan are quoted below to defend the value of T that will be chosen [4]:

'Improvement of the international competitiveness by prompt cargo handling' '...., by providing high quality harbour service' 'Contribute to the national economic development by harbour operations without cargo delay'

Taking these objectives into account, a lower maximum dwell time than the, somewhat dated, maximum dwell time found by ECT must be achieved. So say T = 7 days, the average dwell time becomes

$$\overline{t_d} = \frac{(7 + 2)}{3} = 3$$
 days for fully loaded containers.

A remark to this short dwell time must be made. It should be taken in consideration that 16 hours/day working, 300 days per year is not an example of providing high service. When investments are made to reduce the dwell times, it is recommendable to extend the handling times as well (round the clock working) and reduce the non-working days (50 weeks a year working in stead of 300 days/year).

The average dwell time for empties is assumed to be 10 days.

7.4.3. Cargo handling equipment.

7.4.3.1. Quay side equipment.

The equipment, used for the handling of containers on the terminal, can be various. First the equipment for (un)loading the vessel is discussed. There are various possibilities to (un)load a ship. It can be done with the ship's own gear, a big mobile crane, a multi-purpose crane or a portainer. For a dedicated terminal with high throughputs, only portainers are used nowadays. This is a heavy, shore based gantry crane. Taking into account the increasing ship sizes (with widths of up to 40 m for the Post-Panamax class) which can be expected in the future, the outreach of the portainers should be about 40-45 metres. The space between the legs of the crane is approximately 30 meters, with a backreach capacity of order 15 metres. The crane is mounted on rails, with the outer rail a few metres from the quay wall, to avoid collisions with ship's overhangs. An example of a portainer is shown in figure 7.1.

Surce : Port autonome de Marseille, Eost, Marseille 1981.

Figure 7.1 An example of a large portainer.

The portainer places the containers on the apron between its legs, or direct on trailers, depending on the handling equipment used. The apron is the hardened area behind the quay face where the terminal chassis drive, the containers can be temporarily stored and the hatch covers of the ships are put. The apron width is determined by the type of quay crane. As mentioned earlier, a portainer is used with assumed dimensions [8]:

- Outreach: 40-45 metres
- Setback front crane rail: 5 metres, in connection with danger of collision with the ship's overhang.
- Space between the legs: 30 metres
- Back reach: 15 metres
- Traffic lane: 10 metres

The total apron width now becomes 60 metres.

7.4.3.2. Stacking equipment.

The handling equipment on the stack can be one of the following or a combination [8]:

a. Trailer storage system (chassis system)

This system is used to directly place containers from the ship via the portainer on trailers. The following methods can be applied:

- 1. The trailer is a road trailer and is directly brought to the customer. This method is hardly ever used because of the long queues and the fact that commercial traffic often is prohibited on the terminal.
- 2. The trailer is a terminal trailer and is moved by a tractor to the stacking area where other equipment takes the container off the chassis and further handling takes place.
- 3. The trailers are towed to an assigned position and stored there, until they are picked up by a road truck.

Advantages:

- high flexibility and speed of terminal transport.
- random access to containers as they are stacked only one high.
- simple equipment.

Disadvantages:

- large space requirements.
- storage peaks are difficult to absorb, resulting in long queues.
- b. Straddle carrier system

The straddle carrier is the most versatile piece of container handling equipment. It can be used for transport between quay and storage area, storage area and CFS and as a piece of stacking equipment. The straddle carrier can stack up to 4 containers high.

Advantages:

- good space utilisation
- high flexibility
- ability to absorb peaks in traffic

Disadvantages:

- complicated equipment
- high maintenance and energy costs

At most modern terminals using straddle carriers, the transport of containers is done with a terminal tractor/trailer system.



A drawing of a straddle carrier can be found below:





c. Gantry crane system (transtainer)

A gantry crane is a travelling portal crane, mounted on rails (RMG) or rubber tyres (RTG). The difference between these two designs is the flexibility of the RTG, as it can move between lateral stacks. The consequence of this ability is the reduced span and storage area.

Both types can stack up to 5 or 6 containers high. As the position of a large gantry crane is rather fixed, it often is assisted by straddle carriers, fork-lift trucks or chassis.

Advantages:

- good area utilisation by high stacking
- high reliability, low breakdown percentages
 Disadvantages:
- low flexibility, changes in layout hardly possible

Examples of a RMG and RTG can be viewed in figures 7.3 and 7.4.



Figure 7.3 The rubber tyred gantry crane.



Figure 7.4 An example of a rail mounted gantry crane.

d. Fork-lift truck system

The fork-lift truck system is applied at terminals with relatively low throughputs and terminals where also neo-bulk is handled. In addition the fork-lift truck can be brought in action for the stacking of empty containers.

Advantages:

- inexpensive
- very suitable for stacking empties

Disadvantages:

- moderate throughput capacity
- high area requirements due to manoeuvring space

The selection of the best handling system for this terminal is a weigh of the following local conditions:

- Soil conditions
- Accessibility of the site
- Financing possibilities
- Availability of qualified personnel
- Expected growth rate
- Functional requirements

The terminal will get a vast throughput of at minimum 438,000 TEU per year in 2011 and 648,000 TEU in 2020. The fork-lift truck system alone can be rejected with this information. Further on, the available area of land is restricted as it all has to be reclaimed. This excludes the application of the all chassis system. The sub soil can be sufficiently strong as it consists of fill material. No demands on wheel loads have to be made. To get the best results now, it is likely to apply the transtainer system (probably rubber tyred for greater flexibility), aided by terminal chassis (possibly automatic guided) and large portainers at the quay.

7.4.4. Stacking areas assessment.

The area requirements for the stacking of containers are different for the following respective stacks:

- Import
- Export
- Reefers (not mentioned here, a dedicated reefer terminal is constructed)
- Empties

The calculation of the different areas can be done via various methods, of which one is used in Appendix E. In this section, only the result of this calculation is presented in table 7.1.

Type of stack	2011 438,000 TEU (m ³)	2011 535,000 TEU (m ³)	2020 648,000 TEU (m ³)	2020 1,006,000 TEU (m ³)
Import	25,000	30,000	37,000	57,000
Export	39,000	47,000	56,000	89,000
Empties	63,000	77,000	102,000	148,000

Table 7.1	Stacking a	rea assessment f	for	different	throughputs.

7.5. The Container Freight Station.

As for its feeder status [1], it is likely that the container terminal must have a Container Freight Station (CFS). The function of the CFS is to receive, prepare and handle cargo that is shipped with containers. These operations must be done in a protected environment and therefore a shed has to be constructed. It is important to have as much free space as possible, so as few columns as possible should be used. The size of a CFS depends on many factors, of which the anticipated cargo throughput is the most important. A crude assumption leads to an annual throughput of 25% of the total annual terminal throughput.

2011: C = 25% of 438,000 is 110,000 TEU C = 25% of 535,000 is 134,000 TEU

2020: C = 25% of 648,000 is 162,000 TEU C = 25% of 1,006,000 is 252,000 TEU

The 162,000 value will be used to calculate the dimensions of the CFS. Other factors are:

•	V = space requirements per TEU (m^3)	$V = 29 \text{ m}^3$
٠	$h_a = average CFS$ stacking height (m)	h _a = 2 m
٠	$t_r =$ mean transit time of the cargo in the CFS (days)	t _t = 5 days
٠	$f_1 = \text{gross/net area factor}$	$f_1 = 1.4$
٠	$f_2 = bulking factor$	$f_2 = 1.2$
•	m = acceptable occupancy rate	m = 0.7

All these factors can be combined, forming the following formula [7]:

$$O_{CFS} = \frac{C \cdot \frac{V}{h_a} \cdot t_t \cdot f_1 \cdot f_2}{m \cdot 365} = \frac{162,000 \cdot \frac{29}{2} \cdot 5 \cdot 1.4 \cdot 1.2}{0.7 \cdot 365} = 77,000 \text{ m}^2$$

This is a very large Container Freight Station, but this is not surprisingly, as the throughput is significant.

The CFS is a link in the transport chain, between the stacking areas and quays and the inland transport by truck or rail. The layout of the CFS must be such that the containers can be easily brought in to the CFS by fork lift trucks or chassis and that the other side is in connection with external traffic. Therefore the side of the road traffic has a heightened platform, so the fork lift trucks can drive unhindered into the container, loaded on the road chassis. This platform is for instance 5 metres wide. The loading area should be sufficiently wide for truck manoeuvring, preferable width is 40 metres.

7.6. Ro-ro facilities.

Ro-ro ships carry containers on road truck chassis. The advantage is that the throughput of the cargo can be done with a simpler sequence of cargo handling compared to the normal container cargo. The new port should be able to receive these ro-ro ships, as it has the status of a feeder port. For this reason small consignments are frequently encountered. This is just the type of cargo being suitable for shipping with ro-ro ships. The facilities needed to receive ro-ro cargo are:

- quay side to be able to lower the ramp on
- space for the trucks to manoeuvre
- separated roads for the road trucks, so no interference with terminal traffic can take place.

The quay space need not always be a secluded space in the port. Many modern ro-ro ships are provided with a quarter ramp, making an angle of 45° with the ship's centre line, or with a slewing ramp, being able to rotate over an angle of 65°. In this case, no additional facilities have to be present, as these ships can unload at a straight quay. For the terminal layout, no extra space is reserved, as it falls within the margin.

7.7. Shunting yard.

The shunting yard facilitates both the general cargo terminal and the container terminal, if possible. The dimensions of the shunting yard are difficult to determine, as the layout of the terminal is not yet known. For the terminal area assessment, a space of approximately 35,000 m² will be reserved for rail traffic.

7.8. Offices.

Reserve approximately 10,000 m² for offices and workshops.



7.9. Total area of the container terminal.

The assessed total container terminal area is a simple addition sum of the preceding parts, with an additional amount of square metres for parts of the terminal not mentioned, as parking areas, terminal traffic roads, etc.

The highest berth capacity is reached for the 648,000 TEU throughput in 2020 (see table 6.6). The accompanying length of the terminal is 675 metres. This value is needed to determine the apron area.

- Apron area: 60 m*675 m ≈ 41,000 m²
- Import stack: 37,000 m²
- together, including surrounding spaces: 195,000 m²
- Export stack: 56,000 m²
 Empties stack: 102,000 m²
- Transtainer shifting lanes: assume 15,000 m²
- Container Freight Station, including (un)loading bays for trucks and chassis: 100,000 m²
- Shunting yard and additional rail tracks: 35,000 m²
- Offices and work shops: 10,000 m²
- Miscellaneous: 10,000 m²

The total terminal area becomes approximately 400,000 square metres, resulting in a terminal width of $400,000/675 \approx 600$ m for 2020.

7.10. Dry bulk terminals.

Three dry bulk terminals must be designed, each handling a different commodity:

- Ore terminal
- Cement terminal
- Sand terminal

The throughput of the terminals and the nature of the cargo vary considerably, so three different width calculations will be made here.

7.10.1. Ore terminal.

As the throughput of ores is significant (7,674,000 tons in 2011 and 14,238,000 tons in 2020), high capacity transfer devices will be used for the cargo handling. This is mentioned in Appendix C as well. Big travelling overhead trolley grabbing crane unloaders are used. This device is applicable for all kinds of ore, handled at the terminal. The cargo is brought to the storage areas via a transport system. Commonly, this transport system consists of belt conveyors. With these devices, a few kilometres can be bridged. Advantages of the belt conveyor system are:

- Simple construction
- High efficiency with low driving power
- Low maintenance costs
- Adaptability

Disadvantage of the system is the limited vertical angle the system can operate under. The belts for dry bulk transport are trough-shaped. Special applications are the pipe conveyor and hose belt conveyor.

These are normal trouhged belt conveyors, folded into a U-shape or circle. These devices compose an enclosed, dust free system. Another advantage of this system is the possibility to make rather narrow bends. Conventional conveyors need separate (enclosed) transfer points.

For the ore terminal, it is supposed that provisions must be made to prevent dust problems. This is necessary as the ores, handled at the terminal, can cause severe dust problems.

After the terminal transport phase, the ores are placed in storage areas. Depending on the nature of the materials, three different types of storage can be used:

- 1. Open storage (mostly stockpiles), used for commodities that can be exposed to the weather.
- 2. Shed constructions, used for commodities that suffer from degradation when exposed to rain.
- 3. Silos, used for the storage of relatively dusty commodities with a short storage time, as grain and cement.

The ores can be stored in the open air without problems. It is now important to determine the amount of cargo to be stored, necessary to calculate the areas. When assuming two types of ore, two different stockpiles must be created. The areas on which the stockpiles are going to be made depend on many factors, such as:

- Height and shape of the stockpiles
- Size of the shipload distribution
- Ship arrival distribution
- Through transport distribution
- Ship unloading rate
- Strategic reserves
- Relation gross-net area

In this preliminary stage, most of the above factors are not yet known. For this study, the use of a rule of thumb method is sufficient. For the open storage areas, the capacity must be 4 to 6 times the largest shipload for each commodity. When assuming a maximum shipload of 50,000 tons, the stockpiles have to accommodate 200,000 to 300,000 tons each. The stockpiles are triangularly shaped, cross sectional area b*0.5*h. The legs of the triangle are angled, equalling the angle of repose of the ore, being \pm 40° (see figure 7.5):



Figure 7.5 Stockpile shape.

When choosing the maximum height of the stockpile 10 metres, the base of the stockpile is $2*(10/\tan 40^\circ) \approx 25$ metres.

When choosing the average stowage factor of the ores 0.75 m³/ton, the volume of the stored ores becomes 2*300,000 tons*0.75 m³/ton = 450,000 m³.

The cross section of the stockpiles amounts $0.5*10*25 = 125 \text{ m}^2$, resulting in a stockpile length of 3,600 metres. The net ground area now becomes 3,600*25 = 90,000 m².



The stockpiles are not arranged as one long string, but are divided in separate parts placed next to each other. This is done to limit the track of the storage and retrieving equipment and to work efficiently (stockpiles on both sides). Storing and retrieving equipment are respectively called stackers and reclaimers. Stackers are rail mounted machines with a stacking boom and belt conveyor. Reclaimers are similar machines, but in stead of a stacking boom, the reclaimer has a reclaiming device at the end of its boom. Frequently, this is a bucket wheel, rotating around a horizontal axis. The stacker-reclaimer nowadays is widely used and combines the features of the preceding machines.

Allowing for one access road in the middle of the terminal, two sets of storage areas are made. Allowing a gross-net factor of 1.4 for the railway of the stacker/reclaimers, the gross area of the storage yard becomes 126,000 m². When the width of the road between the storage areas (15 metres) is subtracted from the terminal length in 2011 (the smallest length, requiring the greatest width, because the storage yard is not dependent on the throughput), the depth of the storage areas is found:

L = 615 metres - 15 metres = 600 metres

 $B = 126,000 \text{ m}^2/600 \text{ m} \approx 210 \text{ metres}.$

Allowing an apron width of 30 metres for the crane tracks temporary storage and emergency stock area results in $30*615 \approx 18,500 \text{ m}^2$.

Assuming another 15,000 m² for offices and parking areas and 25,000 m² for rail tracks leads to a total terminal area of approximately 185,000 m².

With the terminal length of 615 metres, the terminal width becomes 300 metres.

7.10.2. Cement terminal.

Cement differs a lot from the ores, discussed in the previous section. It is a very dry and dusty material. Grab cranes are not suitable for the unloading of the cement, as this unprotected procedure would infer severe dust pollution. As for its fine structure, the flow capability of the cement is good. Together with its low specific density, a suitable unloading system seems to be the pneumatic suction conveying system. This system can be made dust free with rubber flaps and the use of an enclosed transport system.

The maximum shipload of cement will be approximately 0.8*DWT of the largest ship to be received [7]. This is a 50,000 DWT ship, so the largest shipload will be equal to 40,000 tons. This commodity is well suited to be stored in silos, as already stated in 7.10.1. Again using a rule of thumb, the silos must be capable to store 2 to 4 times the maximum shipload, so 80,000 to 160,000 tons.

Assume a silo 40 metres high and 10 metres in diameter. The holding capacity is $(\pi/4)*10^2*40\approx 3,150$ m³. With a stowage factor of 0.65 m³/ton, one silo can hold 4,850 tons.

With these amounts, 160,000/4,850 = 33 silos are necessary. Integration of these silos into one processing building, see figure 7.6, leads to a compact terminal. This terminal is fed by one berth, restricting the length of the terminal to 240 metres. Placing the silos in two rows, 17 silos per row, the building will be approximately 200 metres long. The extra length accounts for the transport devices carrying the cement to the silos. There remains enough space to have access to the quay from the landside. The building becomes some 40 metres wide: two silos of 10 metres each and an interspace for control rooms, conveyor systems, loading platforms for trucks or trains, etc. The total storage area becomes $40 \times 200 = 8,000 \text{ m}^2$.

The pneumatic unloaders are placed on the quay, requiring 25 metres apron width, resulting in $25*240 = 6,000 \text{ m}^2$.

Offices and miscellaneous areas like roads and parking places account for $10,000 \text{ m}^2$, so the total terminal area becomes $24,000 \text{ m}^2$.

With a length of 240 metres, the terminal width becomes 100 metres.



Figure 7.6 Example of integrated silos at the port of Kaohsiung, Taiwan.

7.10.3. Sand terminal.

The sand terminal is a small terminal, only used by coastal vessels, ranging to a maximum of 5,000 DWT, averaging 2,000 DWT. Accounting for 4,500 tons maximum shipload, the (open) storage area must be 6*4,500 = 27,000 tons. With a stowage factor of approximately 0.5 m³/ton, the volume of the stored cargo is 13,500 m³.

Assuming stockpiles 5 metres high, triangular of shape and an angle of repose of 35°, the base is $2*(5/\tan 35^\circ) \approx 14$ metres wide, resulting in a stockpile cross section of $0.5*5*14 = 35 \text{ m}^2$. The length of the stockpiles will be 13,500/35 ≈ 385 metres, resulting in a ground area of $14*385 \approx 5,400 \text{ m}^2$. When calculating for the 2011 situation with a quay length of 180 metres, reserving 15 metres of length for roads and a gross-net factor of 1.4 for terminal equipment space, this results in a storage area width of (1.4*5,400)/(180-15) = 46 metres.

Assuming 20 metres apron width and some space for offices and parking space, the total terminal width will fit easily within 100 metres land.



7.11. Summary of the terminal widths.

With the foregoing, the widths of the different terminals are very roughly determined. For completeness sake, the widths are printed in table 7.1 hereafter.

Terminal type	Terminal width	Terminal area 2011	Terminal area 2020
Other general cargo terminal	350 metres	422,000 m ²	280,000 m²
Rough wood terminal	150 metres	30,000 m²	30,000 m ²
Lumber terminal	275 metres	105,000 m ²	160,000 m ²
Iron materials terminal	225 metres	87,000 m²	132,000 m ²
Refrigerated cargo terminal	350 metres	205,000 m ²	205,000 m²
Container terminal	600 metres	535,000 m ²	400,000 m ²
(Other) ore terminal	300 metres	185,000 m ²	307,000 m²
Cement terminal	100 metres	23,500 m²	23,500 m ²
Sand terminal	100 metres	24,000 m ²	36,000 m ²

Table 7.2Terminal widths and areas.

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8. PORT BASIN DIMENSIONS.

8.1. The disciplines involved.

An important part of port planning is the assessment of the required water areas and water depths. There are many factors playing a role in this assessment. These factors can be captured in two main disciplines, being hydro-nautics and hydraulics.

Hydro-nautics is the discipline that investigates the movements of ships in restricted water areas, such as ports and approach channels. The vertical ship movements are of importance for the approach channel and port basin depths, while the horizontal ship movements are decisive in the width determinations. With the knowledge, gained with these investigations, the water areas of new projects can be designed with accuracy.

The hydraulic discipline deals with waves, currents and sedimentation and the effects they have on the functioning of the port.

In the following, these disciplines will be detailed.

8.2. Hydro-nautics.

8.2.1. The behaviour of ships in and near a port.

As stated in 8.1 hydro-nautics is involved in the behaviour of ships in confined waterways and port approach channels. It combines the skills of nautical engineering with that of naval architecture. The parts of this discipline determining the port design aspects will now be dealt with.

The manoeuvring behaviour of ships depends on the so called vessel manoeuvring characteristics. This is the collective noun for the following factors:

1. The rudder efficiency in combination with the reaction on changes of propeller revolutions.

2. The turning ability.

3. The stopping ability.

Sub 1. Rudder efficiency and propeller revolutions.

Large ships react slowly on a rudder deficiency. This is due to the fact that the length-beam ratio is fairly small (≈ 6) and the block-coefficient large (0.9). An increase in reaction can be achieved by a simultaneous (temporary) increase of propeller revolutions.

Sub 2. Turning ability.

When sailing under power in deep water, the turning radii of different types of ships vary from $2*L_{ship}$ for general cargo ships, multi-purpose ships and gas carriers to $4*L_{ship}$ for the larger crude oil and dry bulk carriers and $7*L_{ship}$ for the fast container ships [7]. It is not foreseen that the ships make this manoeuvre inside the port's basins, because the speed inside the port will be restricted to a maximum of approximately 5 knots.

At low speeds, the turning radius will decrease. The use of twin propellers and bow thrusters can further improve the turning capability.

Sub 3. Stopping ability.

Stopping distances depend largely on the size of ship and the relation propulsive powerdisplacement. This ratio is inversely proportional to the ship size. For example, a 10,000 DWT general cargo ship can be stopped from 16 knots in 900 metres and a 200,000 DWT tanker requires 4,500 metres. This is apart from the fact that stopping from these velocities can not be done with course control, due to turbulent flow around the rudder from the astern power of the propeller. This kind of stopping procedure is called the crash stop, only used in emergencies.

Another factor is the initial speed of the ship. When already sailing at low speeds (\approx 5 knots) the stopping distances decrease significantly to 150 metres for the general cargo ship and 900 metres for the tanker. During the approach, the ship will have to maintain a minimum speed of about 3 to 4 knots. For lower speeds, the ship will not react on rudder deficiencies. When encountering cross currents or heavy wave action, the ships are forced to maintain a higher speed for controlled navigation and the stopping distance thus increases.

Large ships and ships carrying dangerous cargo stopping within the port limits, use the following procedure, called the fully controlled stop:

- The ship maintains the minimum speed, required for safe manoeuvring.
- Tugboats make fast fore and aft.
- The ship stops with its own propeller, held on course by the different tug boats.

8.2.2. The effects of shallow water.

When the water depth becomes less than 1.5 times the draught of a ship, the influence on the ship's manoeuvrability becomes significant. Fairways with a depth of 1.5 times the ship's draught or less are therefore called shallow waters.

The effects of shallow water on the behaviour of the ship are:

• Increase in the course stability

These effects result in a more straight course

- Decreasing rudder efficiency
- Increase of the turning radius
- Decrease of the stopping distance due to increased resistance
- Increase of the squat of the ship

The depth of the port's surrounding waters is sufficient for unrestricted navigation. When being close to the coast, the depth decreases, but at this point the speed of the ships will be that far decreased that the water depth is of little influence on the ship's behaviour.

Navigation of ships still is possible when sailing through low density mud (sling mud) with relative density $\gamma \le 1.2$. This may be of interest in this case, as the subsoil consists of soft soil for water depths over 20 metres. After conducting prototype tests in the Port of Rotterdam, the following conclusions were drawn [7]:

- Increase in the resistance, especially for ships with large block-coefficients
- Reduction of the stopping distance due to the increased resistance
- Decrease in squat as the density increases
- Increase in rudder efficiency due to higher propeller revolutions

This situation is not preferable, but with possible sedimentation of the dredged approach channel, it is useful to know that navigation still is possible.



Ships at berth are sensible to wave motion, especially in the next four directions:

- Roll
- Yaw
 Yaw
- SurgeSway
- translation

See also figure 8.1.



Figure 8.1 The ship motions under wave action.

Big motions in either one of these directions can usually be associated with resonance. The frequency of the wave forces becomes equal to the natural period of oscillation of the combined mass-spring system ship-fenders-moorings: $T_{n,s-f-m}$.

With regard to the roll movement, $T_{n,s-f-m}$ almost equals the natural period of the ship in non-restricted conditions. This period is in the order of 14 seconds for a large container vessel, for which cargo handling is very sensitive to wave motion.

The surge and sway movements of a ship are primarily governed by the elasticity of the fenders and mooring lines. $T_{n,s-f-m}$ therefore changes with the type of mooring, from 15 seconds for hard and stiff systems to 150 seconds for elastic systems.

The yaw motion is governed by both the ship's characteristics and the mooring system configuration, so $T_{n,sfm}$ ranges in between the preceding values.

Moored ships can thus encounter the resonance phenomenon due to swell motion. The difficulty is that swell can not be prevented. It is therefore important that the shape and dimension of the port basin are assessed in such a way that swell motion is minimised.

8.3. Hydraulics.

8.3.1. Wave motion inside the port basins.

Waves existing inside the port mostly originate from outside the port. The penetration takes place via the harbour entrance. Overtopping of or transmission through the breakwaters is only allowed when the inner side of the breakwaters is not used for berthing ships.

The problems inside the port, caused by penetrating waves, are harder to deal with when the period of the waves is longer. Taking these matters into account, the design of the entrance of the port is of major importance. The use of a mathematical model to predict wave motion in the surroundings of the port is recommendable. In the government master plan, a diffraction model is applied for the wave height assessment on the layout of the government master plan, resulting in table 8.1:

	파 향 S Wave S								IF S	y e Ve E		
구역	설 계 파 Deyg War			명 상 파 Oralinany war		설계파 Destructure		명 상 피 아나 : : : : : : : : : : : : : : : : : : :		<u>□</u> } 7		
Area	최대 Ma	최소 ^~~~	명국	최대 Mag	최소 사내	명균	최대 //~~	최소 ^	평균 Avr	최대 서~~	최소 ^/-	평균 <i>Avr</i>
A	1.52	0.48	0.77	0.34	0.10	0.19	2.06	0.72	1.41	0.79	0.03	0.38
В	2.08	1.56	1.84	0.58	0.46	0,53	1.64	1.23	1.49	0.80	0.59	0.70
с	1.63	0.91	1.15	0.47	0.39	0,41	1,23	0.76	0.91	0.75	0.51	0.61
D	1.04	0.86	0.92	0.51	0.41	0.46	1.12	0.88	1.00	0.57	0.52	0.54
Е	1.75	0.86	1.54	0.58	0.37	0.47	1.23	0.86	1.03	0.62	0.45	0,54
F-1	1.16	0.71	0.82	0,35	0.13	0,19	1.75	0.90	1.32	0.68	0.44	0.55
F-2	1.14	0.82	0 96	0.21	0.17	0.19	1.54	1.22	1.35	0.60	0.49	0.53
G-1	1.10	0.73	0.88	0.58	0.35	0.43	1.17	0.67	0.87	0.48	0.34	0.41
G-2	1.20	0,94	1.07	0.57	0.35	0.45	0.91	0.72	0.80	0.40	0.33	0.35
G-3	1.17	0.88	0.97	0.57	0.35	0.44	1.02	0.72	0.89	0.48	0.35	0.43
н	1.37	0.87	1.08	0.57	0.39	0.45	1.17	0.70	0.90	0.53	0.33	0.45
I	1.72	1.15	1.46	0.63	0.41	0.53	0.88	0.55	0.66	0.40	0.20	0.29

Table 8.1Wave heights resulting after applying a numerical diffraction model to the final design
in the government master plan.

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8.3.2. Acceptable ship motions at berth.

The acceptable ship motions alongside the quay, with regard to cargo handling, are restricted because of the handling equipment working limits. The motions are caused by waves, penetrating into the port basins via the entrance or via transmission across the breakwaters. The wave height limit is not uniformly valid and unfortunately cannot be applied. This is due to the fact that the wave action is not the limiting factor but the movement of the ship is. This movement is defined by the wave height and period, but also by the berth orientation, mooring configuration, reflection coefficient of the quay, etc. Ports, accommodating ships of 30,000 DWT and more, are confronted with disturbances due to occurring long waves. A rough estimate of the limiting wave height is set up hereafter. The step from wave height to ship motion and mooring forces distribution is in principle a non-linear problem due to damping phenomena of both the ship and the mooring system. Only with the aid of a non-linear numerical model, the ship motions can be assessed [9]. Such a model is not available for usage in this study.

The values for the limiting wave height are valid for deep water waves penetrating in the port basins and having a period of about 7 to 12 seconds. Locally generated waves have a shorter period, less influencing the vertical movements. On the other side are the swell and seiche movements, already of great influence at low wave heights. The values are meant as a comparison of the sensitivity of ships to wave action. Via this guide, the location of the terminals can be chosen such, that commodity handling, suffering the most from wave action are located in the most protected area of the port and visa versa.

Large ships, such as crude oil carriers, are the least sensitive regarding wave action. The size of the ship and the unloading procedure via flexible devices such as flexible loading arms and hoses, make it possible to work during periods with a vertical ship movement in the order 1.5 to 2.0 metres [7].

The unloading of dry bulk carriers is somewhat more restricted, as the unloading device is in contact with the cargo and comes close to the ship's bottom. Beside this, bulldozers are working in the holds to collect the remaining cargo and bring it to the unloader. This results in a 45° to 90° permissible wave height of approximately 0.8 metres and a head or stern on wave height of 1.0 metres [7]. The vertical ship motion the is in the order 1.0 metre.

During the handling of general cargo ships, stevedores are in the holds to attach the crane's hook, and fork lift trucks are rearranging the cargo in the hold. Therefore, the limit to the ship's movement is about equal to that of bulk carriers.

Container ships and ro-ro ships are extremely sensitive to ship motion during operations at berth. Containers are stored in cells, which allow very little movements of the container (\pm 10 cm). Rolling of the ship jams the container in the cell guide. Ro-ro operations are affected by both the ship movement and the ramp movement, so very little wave action is allowed. For the full container ship, the surge motion is restricted to 1.0 metre, the sway motion to 0.6 metre and the roll must be restricted to a maximum of 3° (see figure 8.1 for the different motions). Ro-ro operations are even more sensible for ship movements: maximum surge motion of 0.2 metres, and sway and roll motions are not allowed [7].

8.3.3. Currents in the port basins.

Currents in the port basins can result from entrances at both sides, as is the case in the government layout plan. Due to these currents, yaw motions may cause high forces on the mooring lines. With a slight change in current direction, sway motions may be induced, increasing the mooring line forces. When not prepared for these forces, the mooring lines might rupture, causing the ship to get adrift.

The encountered current in the basin as designed in the government master plan (1 knot) will not be high enough to cause these phenomena. Such a current can although be awkward in case of mooring the ship, this can be controlled by tugs.

8.4. Approach channel design.

8.4.1. General.

The preceding description of hydro-nautics and hydraulics must now be applied to the design of a port's waterways. The knowledge can be used in order to assess the:

- alignment and width of approach channels and port entrances.
- depth of approach channels and port basins
- size and shape of manoeuvring space (turning basins, stopping space, etc.), see section 8.5.

In the master planning phase the approach channel is worked out via the Concept Design process. This process is characterised by a rapid execution and requires only some data input to be efficient. The design of approach channels is focussed on three parameters:

- Approach channel alignment
- Approach channel width
- Approach channel depth

The problem is, that these three parameters are interlinked. Reduced width or depth can be allowed when the channel alignment is changed, additional width can compensate for reduced depth, etc. These links are not very strong although, and under certain conditions, a decoupling between width and alignment on the one side and depth on the other.

8.4.2. Approach channel alignment.

The local circumstances, like bottom topography, are often decisive in the alignment of approach channels. In the Ulsan case, there is ample water depth available nearshore, so different options can be developed. Still some general guidelines can be used [10]:

- 1. When possible, avoid curves in the approach channel, certainly in the surroundings of the port entrance, as this always is a difficult point for navigation.
- 2. It is better to use one curve instead of several small ones. Keep at least 5*L_{ship} between different curves.
- 3. When designing curves, the radius should be such that ships have to use no more than 15° to 20° rudder angle
- 4. Avoid cross current action, especially at the port entrance.
- 5. The alignment of the approach channel should deviate from the prevailing wave direction to prevent severe wave penetration in the port basins.
- 6. The alignment should not deviate too much from the prevailing wave direction, as this would hinder ships attempting to call at port.



8.4.3. Approach channel depth.

The assessment of the approach channel depth can be made by assuming that the influencing depth factors are wave action and squat.

8.4.3.1. Wave action.

Wave action in approach channels causes the design ship to move in a vertical plane. The different ship motions are already mentioned and visualised in figure 8.1. The motions that influence the vertical movements of the ship are the roll motion, the pitch motion and the heave motion. For each of these modes, the ship has its own natural frequency of oscillation. Resonance phenomena may occur when the exciting wave forces have a frequency near the natural frequency of one of these modes. The degree of damping controls the resonance of the ship. Pitch and heave are rather damped motions. The roll motion is the most sensible to resonance. The actual vertical motion of the ship, as a resultant of the roll, pitch and heave displacements is difficult to determine. The natural frequency of the three separate modes must be known for the chosen design ship, just as the determining wave periods as encountered in the approach channel. For the VLCC of 325,000 DWT (the design ship in this study) these values are not known. Therefor an assumption must be made. It is assumed that this ship encounters a maximum vertical movement of 1.5 metres, based on examples found in [7].

8.4.3.2. Squat.

Squat is the collective noun for two phenomena, both decreasing the underkeel clearance. These are a sinkage of the ship as a whole and a trim to the bow or stern. Squat depends strongly on the ships' speed and increases in shallow water areas. There are various ways to determine the squat of a ship. The use of formulas like the ICORELS equation for open water need more input than is known at this moment. For Concept Design, the use of a graphical method is adequate. The chart can be viewed in figure F.5 in Appendix F.

The parameters needed are the ship's speed, the proposed channel depth, the trim of the ship and the ship's length [10].

- The ship's speed is assumed to be maximum 8 knots. This is a high value, but severe weather conditions may prescribe this speed to ensure safe navigation (see 8.5.5).
- The proposed channel depth will be in the order of 26-27 metres, taking in account the movement due to wave action of approximately 1.5 metres and the squat of the ship (to be determined now). A first attempt will be made with a channel depth of 26.5 metres.
- The trim of the ship is not known. A safe assumption is a bow trim, resulting in a higher squat.
- The length between perpendiculars of the ship will be in the order of 325 metres.

From figure F.5 in Appendix F, the squat is assessed to be 0.4 metres.

8.4.3.3. Total approach channel depth.

The total approach channel depth is a sum of the preceding factors, increased with a net underkeel clearance. Adding leads to a minimum approach channel depth of 24 metres (ship's draught) + 1.5 metres (wave action) + 0.4 metre (squat) = 25.9 metres. With a net underkeel clearance of 0.6 metres, the total channel depth becomes 26.5 metres.

There is no need to establish a tidal window for this project, as the tidal difference is only 0.5 metre, and the length of the Ulsan Port approach channels with restricted depth will be as short as metres. This because deep water is available near shore.

The approach channel for the LNG port has a minimum depth of approximately 20 metres, thus having an underkeel clearance of minimum 9.0 metres. This is sufficient at all times.

8.4.4. Approach channel width.

8.4.4.1. Basic manoeuvrability.

A ship never sails in a straight line, even in the absence of wind, waves, currents, etc. This is due to the fact that the responce of both the ship handler to visual position indications and the ship to rudder deficiencies.

The width of approach channels is expressed in multiples of a design ship's beam. The design ship is the ship that is determinative for the approach channel's dimensions. This ship and all other ships sailing the channel must be able to navigate safely. The width depends mainly on the manoeuvrability of the ship (depending on the depth/draught ratio) and the ship handler's ability.

Criteria which the design ship may have to satisfy:

- Poor navigability
- Large ship size in relation to the port operations
- Excessive windage area
- Carrying hazardous cargo

One ship does not have to fulfill all criteria and thus more than one design ship may be necessary.

The factors mentioned in the next sections must be taken in consideration during approach channel width design [10].



8.4.4.2. Environmental factors.

Cross wind

When ships sail at low speed, the effects of cross wind will be of great influence. It drifts the ship sideways, imposing the ship handler to give the ship an angle of leeway. Both of these increase the required manoeuvring width. The path of a ship under cross wind action can be viewed in figure 8.2.



Figure 8.2 Handling of a ship in strong cross winds.

The cross wind effects depend mainly on the following factors:

- The windage area of the ship
- The depth/draught ratio
- The apparent wind direction

Cross current

The cross current effects are similar to that of cross winds. The difference is that, in contrast to cross wind, the cross current effect is of greater influence when the depth/draught ratio approaches unity.

<u>Waves</u>

Obviously waves effect the depth of approach channels via the verical motions, imposed on the ship. The width too may be effected by waves, moving across the channel. These waves cause a yaw motion of the ship and a drift in the wave direction.

8.4.4.3. Other influencing factors.

Aids to navigation

Well-marked channels require less width than poor marked channels. For master planning it is sufficient to grade the adequacy of navigational aid in the categories "excellent", "good", "average, infrequent poor visability".

Type of cargo

When the chosen design ship is carrying dangerous cargo, the approach channel must be given an additional width to reduce the risk of groundings and to ensure sufficient clearance to other traffic.

Passing distance

In two way channels, space must be reserved for safe passage of ships. The interaction between the ships must be minimised. This is achieved by the design of a "central strip" equal to the beam of the larger passing ship in between the manoeuvring lanes of the ships.

The width of the strip is influenced by the traffic density in the fairway as well: the denser traffic, the wider the central strip.

<u>Bank clearance</u>

The interaction of the moving ship with sloping channel edges and shoals can lead to uncontrolled sheering of the ship. Additional channel width must be provided to avoid this bank interaction. The degree of bank interaction depends on the ships' speed and the bank height and slope.

8.4.4.4. Channel width assessment.

The channel width now can be determined, using one of the following formulae, depending on oneway or two-way traffic:

$$w = w_{BM} + \sum_{i=1}^{n} w_i + w_{Br} + w_{Bg} \text{ for a one - way channel}$$
$$w = 2 \cdot w_{BM} + 2 \cdot \sum_{i=1}^{n} w_i + w_{Br} + w_{Bg} + w_p \text{ for a two- way channel}$$

in which: w_{BM} = basic manoeuvring width w_i = additional width for straight channel sections w_{Br} = bank clearance on the "red" (port) side w_{Bg} = bank clearance on the "green" (starbord) side w_n = passing distance for two-way traffic

The values of the different parameters are determined via tables F.1 to F.4 in Appendix F.



Crude oil carrier:

L = 350 metres

 $\begin{array}{l} B = 56 \text{ metres} \\ T = 24 \text{ metres} \\ \end{array} \\ \\ w_{BM} = 1.5^*B = 1.5^*56 = 84 \text{ metres} \\ \\ w_i = 2.8^*B = 2.8^*56 = 157 \text{ metres} \\ \\ w_{Br} = 0.3^*B = 0.3^*56 = 17 \text{ metres} \\ \\ \\ w_p = 0.3^*B = 0.3^*56 = 17 \text{ metres} \\ \\ w_p = 1.7^*B = 1.7^*56 = 95 \text{ metres} \end{array}$

w = 2*84 + 2*157 + 17 + 17 + 95 = 611 metres.

The only other design ship that might need more width for the main approach channel is the container ship, as the factors for this type of ship might be less favourable than for the crude oil carrier.

Container ship:

L = 285 metres B = 39 metres T = 11.5 metres

 $w_{BM} = 1.8*B = 1.8*39 = 70$ metres $w_i = 2.0*B = 2.0*39 = 78$ metres $w_{Br} = 0.0*B = 0.0*39 = 0$ metres $w_{Bg} = 0.0*B = 0.0*39 = 0$ metres $w_p = 1.7*B_{VLCC} = 1.7*56 = 95$ metres

w = 2*70 + 2*78 + 0 + 0 + 95 = 391 metres.

The LNG import takes place in a separate port, so the approach channel for this port must be developed separately as well. The traffic density for this port is light, so a one-way channel will be sufficient.

LNG carrier:

L = 280 metresB = 42 metresT = 11 metres

 $w_{BM} = 1.8*B = 1.8*42 = 75.5$ metres $w_i = 3.2*B = 3.2*42 = 134.5$ metres $w_{Br} = 0.0*B = 0.0*42 = 0$ metres $w_{Bg} = 0.0*B = 0.0*42 = 0$ metres

w = 75.5 + 134.5 + 0 + 0 = 210 metres.

8.5. Size and shape of manoeuvring space and basins.

The layout of a port basin should be so, that wave action is minimised and eventually occurring wave propagation is in the longitudinal direction of moored ships. The latter is prescribed, as this load on the ships has the least influence on the ship motions.

Very often, the port basin behind the entrance is used as a stopping track. As the stopping distance of large ships is rather long, the length of such an entrance basin is accordingly long. This length depends on three factors:

- 1) The ship's speed when entering the port.
- 2) The time necessary for the tugs to make fast and manoeuvre in position.
- 3) The actual stopping length.

Sub 1)

The ships enter the port with a speed of 3 to 4 knots, allowing sufficient rudder control and restricting drift angle. For worsening conditions, with currents and wind, this minimum speed must be increased. This can be up to 7 or 8 knots in a very strong perpendicular current. The maximum tidal current in Ulsan is only 0.8 knots, so this will certainly not be the case in this study. The wind can cause more problems, as wind speeds of 75 km/hour have been reported. This will influence the manoeuvrability of the ship. In this case the ship will have to enter with a speed of approximately 6 knots.

Sub 2)

The time for tying up the tugs is not uniform. It depends on the environmental conditions and the skills of the crews. The time under normal conditions will be in the order of 15 minutes. All this time the ship remains at its entrance speed of 3 to 4 knots. In this time, the ship covers a distance of at least 0.25 hour*3 miles/hour = 0.75 mile = 1,300 metres.

During storms, it is possible that tugs are not able to make fast. There are two limiting factors for tug operation: the speed of the ship must not exceed 6 knots and the wave height must be smaller than 2.0 metres [1]. Therefore the possibility exists that the tug boat operation can be started only when the ship is at an appreciable distance inside the breakwaters, thus lengthening the stopping distance.

On the other hand, knowing the limits for tugs to operate, it may be possible to start the procedure already outside the port entrance, limiting the inner entrance basin length significantly.

It is assumed that the maximum workable wave height for tug boat operations is 1.75 metres (2.0 metres as stated before seems a very high limit). Using now the annual wave height distribution of figure 3.4, it can be concluded that only 4% of the time, being 15 days a year, this wave height is exceeded. This seems an acceptable value to allow for the design of an approach channel with restricted length and tug boat assistance outside the port's breakwaters.

Sub 3)

The stopping procedure after the tugs have tied up only takes 1 to 1.5 times the length of the ship, because the ship can give hard astern power with the tugs keeping the ship on course.

The layout of the inner channel must be adapted to the ships' movements when they enter the port. Before a ship reaches the entrance, it can be exposed to cross-currents and wind loads, resulting in a certain drift angle to counter-balance these forces. As the ship enters the protected basin, the bow is free from currents and the fiercest winds, while the stern is still exposed to these phenomena, resulting in an increase of the drift angle, the ship "over-turns". For this reason, the width of the water area behind the entrance is larger than the width of the entrance itself.

When the inner channel ends, it should be followed by a turning basin. In this turning basin, all vessels of 10,000 DWT and more are accompanied by tugs, turned in the right direction and towed to their berths. The diameter of the turning basin should at least be $2*L_{ship}$ [7].

8.5.1. Layout of the port basins.

Port basins are water areas where two main activities take place: ships are berthed at quays or jetties at the borders of the basin, and ships are towed to and from their berths by tug boats. It should be avoided that these activities coincide. Therefore, the width of the port basins should be sufficient for safe navigation and berthing in the basin.

The foregoing can be expressed in the following port basin width formulae [7]:

general cargo and container ships with turning basin, double sided use: general cargo and container ships without turning, double sided use: VLCC's and bulk carriers (single or double sided use): $B_{basin} = L_{ship} + B_{ship} + 50$ metres $B_{basin} = 5^*B_{ship} + 100$ metres $B_{basin} = 6^*B_{ship} + 100$ metres

It is often thought that basins, longer than 1,000 - 1,500 metres should provide the ability for ships to turn. This seems logic for ships, arriving or departing without tug assistance, as their navigability when sailing astern is very poor.

The decisive ships, on which the basin widths are dimensioned, are not able to navigate without tug assistance. When accompanied by tugs, no difference in navigability will be accounted for these vessels and sailing astern causes no problems.

The smaller crafts, navigating without tug assistance, have sufficient space for turning already, as the width of the basin is assessed for the large decisive ship.

8.5.2. Port basin depth.

The water depths in the port basins are determined by the decisive ship (with regard to draught) entering the port. In this case, various depths can be applied. This is due to the extensive number of berths that has to be created. It might be possible to group related terminals, so ships with the same characteristics use only a part of the port's waterways. The depth of these water areas can be adjusted to these types of ships. The over depth in the port basins must be in the order of 10%, resulting in the next values:

VLCC	$D_{ship} = 24.0$ metres	$D_{port basin} = 26.50 metres$
Product carrier	$D_{ship} = 12.0$ metres	$D_{port basin} = 13.25 metres$
Chemical tanker	$D_{ship} = 10.8$ metres	$D_{port basin} = 12.00 metres$
Bulk carrier (ores)	$D_{ship} = 12.4$ metres	$D_{port basin} = 13.75 metres$
Bulk carrier (cement)	$D_{ship} = 12.4$ metres	$D_{port basin} = 13.75 metres$
Container ship	$D_{ship} = 11.5$ metres	$D_{port basin} = 12.75 metres$
General cargo ship (multi-purpose, rough wood,		
refrigerated goods, lumber, iron materials)	$D_{ship} = 10.9$ metres	$D_{port basin} = 12.00$ metres
LNG carrier	$D_{ship} = 11.0$ metres	$D_{port basin} = 12.50$ metres
Sand carrier	$D_{ship} = 6.8$ metres	$D_{port basin} = 7.50 metres$

With these maximum ship sizes and thus the minimum water depths, a start can be made with the design of the new port, this will be done in the next chapter.

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9. LAYOUT OF THE NEW PORT.

9.1. Terminal locations.

For reasons, already mentioned in 3.3, the five SPM's located near the coast probably have to be removed. This with regard to safety of navigation and continuity of the crude oil supplies to the different refineries.

The location of the different terminals and jetties can not be arbitrarily chosen. When the SPM's are removed, a better solution must result. Therefore, the crude oil jetties and oil product jetties must be located in the vicinity of the refineries, who depend on the crude supply. Pipelines may not be hindered and in turn these pipelines are not allowed to hinder the other port operations. Keeping this in mind, it is obvious that on both the north side and south side of Onsan Port crude oil jetties and oil product jetties and oil product jetties must be developed.

The required LNG import facilities will have to cater for the continuous operation of the powerplants north of Onsan Port. Their location must be planned in the surroundings of these powerplants. Although LNG can be transported through pipelines over significant distances, the higher risks involved with this procedure restrain the application of this solution.

The only suitable space for the development of new commercial industries is available at the outer most south side of the Ulsan Port limits. Here, the new container terminal and general cargo facilities must be sited.

Information about the location of the other commodities is not known, so it is assumed that they can be sited arbitrarily within the Ulsan Port limits.

9.2. Port entrance direction.

Section 8.4.2 indicates that the direction of the approach channel and entrance of the port must fulfil various requirements, of which some may coincide. An important factor is the minimisation of the wave action within the port basins, as these waves increase the down-time of the terminal (cargo handling under significant wave motion can be prohibited). From table 3.2 it appears that the highest waves can be expected from the north-east and south. This should be taken into account when designing the entrance. From the wave direction's point of view, an entrance and approach channel direction to the east-south-east is the best alternative.

An other factor is the wish that the approach channel and entrance are directed perpendicular to the depth lines. By chance, the depth lines in this project are directed in a north-north-east direction. These factors can in this case be combined.

9.3. Inner channel.

The inner channel of the port is the part of the approach channel inside the port entrance, necessary for ships to be able to stop in quiet water. In this project, such an inner channel is hard to design. This is due to the fact that the water depth near shore is large, so the length of the breakwaters must be as short as possible to keep the costs of the project within bounds. Because the required inner channel length amounts 2,000 metres or more (necessary for VLCC's, see section 8.5), the costs for these breakwaters will then be enormous.

It is therefore suggested that the inner channels are designed with shorter length, assuming that tugs are already connecting to the ships outside the port entrance. This can be done under wave conditions up to 1.75 metres (see section 8.5), occurring approximately 4.0% of the time during a year [1].

9.4. Concept A0: Government master plan alternative.

To be able to judge if the concepts, made in this study are better than the concept design in the government master plan, the latter is described here as well. The comparison of the various designs will be made in chapter 10.

The design of the port development is characterised by the three huge detached breakwaters in front of the new quays, see figure G.1 in Appendix G. Between the breakwaters, two entrances are projected. The northern approach channel leads to the New Ulsan Port and the existing Onsan Port. It replaces the old Onsan approach channel. It is directed in east-south-east direction, which is good with respect to wave penetration in the port. The inner channel is long enough for stopping when entering the existing Onsan Port. When entering the New Onsan Port, difficulties in ship manoeuvring might be expected in rough weather due to the limited length of the inner channel. The length in this direction is restricted to 650 metres.

Part of the north Onsan breakwater is merged into new terminal land, while the rest stays working as a breakwater, separating the Onsan Port and New Ulsan Port. This arrangement can lead to dangerous situations because ship's crews might be disturbed by the breakwater head when entering Onsan Port or New Ulsan Port.

The southern approach channel and entrance give access to the new Onsan Port and the 3rd phase of the port development in the outer south part. The entrance is directed in a south-south-east direction, enabling high waves to penetrate. The fairway is separated from the main fairway way down in the south, separating the dense traffic in two parts. At the entrance location, the approach channel makes a 30° bend in northerly direction. This is probably done to increase the stopping length within the port's breakwaters. This does not help the 3rd phase development; stopping and turning in the right direction will be very hard in this case.

The quays behind the breakwaters follow the contours of the coast. Therefore these quays have all kinds of angled shapes.

The terminal areas are not grouped by commodity type. This can be due to the fact that the port development is planned in 3 phases. The idea then is that not the total area that is needed in 2020 of, for instance, the ore terminal has to be developed in the first phase. In the first phase, only the area needed in 2006 is built. The area requirements for 2011 can be met with the building of the second phase, on a new location.

No port space is reserved for crude oil import. The unloading of the crude oil takes place at the five SPM's, which are maintained. The Yukong #1 and #2 buoys, together with the KEPCO and Ssangyong buoys are moved to a slightly different position and all the SPM's have a new pipeline alignment. This is necessary to keep the moored crude carriers out of the fairways and the pipelines in the undisturbed bottom.

For the oil products, derived in the refineries, just as for the crude oil import, no port space is reserved. In the government master plan, the assumption is made that all oil products can be handled by the existing facilities.

The total length of the port basins in 2020 will be approximately 7,000 metres. The total length of the guays in that year will be about 10,000 metres.

9.5. Concept A1: Korean Port Consultants alternative.

A joint venture of Dutch companies (Delta Marine Consultants, DHV Consultants, Delft Hydraulics, ECT and Port of Rotterdam), grouped under the name Korean Port Consultants, have judged the above described government master plan. In their feasibility study, they have come up with their own alternative as well. This alternative is described here, in order to be able to compare it with the concepts of this study in chapter 10. An overview of the Korean Port Consultants alternative is given in figure G.2 in Appendix G.

This concept sticks to the idea of two different entrances. The northern entrance replaces the old Onsan Port entrance. The old northern Onsan breakwater is partly merged with new terminal area and the remaining part is removed to make the new port more accessible. The breakwaters around the port entrance have a shape, permitting ships to deviate from the desired path when they enter the port. This deviation results from interactions with wind and currents, as mentioned in chapter 8. The upper north breakwater is attached to the shore near the Yukong Gas facility. The second breakwater, protecting the energy port zone, is attached to the original south Onsan breakwater, now being converted in to terminal area. A third breakwater extends from the south port limit up to 1,750 metres north of this limit, where it stops and the south port entrance is located. This entrance is exposed to waves from directions ranging south to east. It is rather wide and unprotective.

The deep lying crude oil carriers can approach the energy port zone from the south-south-east, stop within the port's boundaries and berth adjacent to the inner channel. The approach channel (or better: fairway, due to the non-restrictive depth) is situated in water with depths of 26 metres and more. This will guarantee safe navigation, without the risk of grounding. Ships, heading for the industrial port zone, can best approach the entrance from the east-south-east. They can leave the main fairway wherever they like as the depth is sufficient, even beyond the entrance. The stopping distance within the breakwaters is rather limited when approaching from this direction, 1,100 metres.

The layout of the port is designed in such a way that dedicated parts can be recognised. The northern part of the new design will be phase 1 from a total of 3 phases, to meet the 2020 cargo and shipping forecast. This phasing is designed from the idea that three major components can be distinguished in the cargo forecast:

- Commercial port zone: general cargo and containers, connected to an intermodal service centre.
- Energy port zone: designed for the reception of large crude oil carriers and other tankers.
- Industrial port zone: here the bulk berths, oil product jetties and chemical product jetties are planned.

9.6. Concept B. Central entrance design.

The layout of this port development is drawn around a central wide entrance to different port basins. For an overview see figure G.3 in Appendix G. The idea is that the existing Onsan fairway is widened to allow for two-way traffic of the crude oil carriers. This wide fairway leads to Onsan Port and two new basins north and south of Onsan. The major advantage of this concept is the east-south-easterly direction of the (single) fairway.

The design started from the vision that at least part of the north Onsan breakwater has to be removed. The existing entrance is widened to the north side, allowing a turning circle with a diameter of 800 metres. The south Onsan breakwater remains intact and can be used as a starting point for new terminal terrain south of Onsan Port.

The handling of cargo at this terminal may not suffer very much under wave action. This can impose problems, because this location is not very protected. Dry bulk handling is a system that might be right for this location. It is not very sensitive to wave action. Crude oil and oil product handling are even less sensitive, but the disadvantage of these commodities is the hazardous nature of the goods. The location of the exposed terminal imposes a higher collision risk, and therefore the handling of oil and oil products should not take place in this area. Ores, a dry bulk commodity, are very suitable to be handled at the outer terminal, as the unloading is done with grabs, and relatively large vertical displacements of the ships are tolerated.

South of this terminal, other bulk commodities are projected. Adjacent to the ore terminal, the cement terminal will be located. This because the large ships (up to 50,000 DWT) do not suffer much from wave action and the rock layer lies relatively deep at this location (MSL-25 metres) so the necessity for rock dredging is not present.

Sand is imported next to the cement terminal, it is conceivable that these commodities will be combined to produce concrete. There is space available for extensions in the future, both in width and guay length, so functional rearrangements can be executed.

The outer south part of this new port is the most protected location and thus will be used for the handling of commodities who cannot be handled when the ship is moving at berth. Here the container terminal and general cargo terminal are sited.

The port-side of the breakwater in the new south port is used to accommodate the liquid bulk jetties. At this side two crude jetties are constructed, to cater for the KEPCO and Ssangyong refineries south of Onsan Port. Two oil product jetties are made to transport the refined products. Three chemical liquid jetties are also projected in this part of the port.

The commodities are transported to and from the complexes with pipelines and booster stations. The pipes can be placed on top of the breakwater, without the need for space.

The basin has a length of approximately 4,000 metres. This is a long basin and therefore the ability to turn the ships inside the basin must be available. At the end of the basin, near the container terminal, a turning cycle with 600 metres diameter is projected. In the middle of the basin, the width between the berthed ships, available for navigation, is 500 metres. This is sufficient for general cargo ships and smaller tankers to turn safely. Ships berthed in the upper part of this port have to sail astern to the central turning point and turn there.

After removing 750 metres of the north Onsan Port breakwater, a new port can be created north of Onsan Port. The remaining part of the Onsan breakwater will be used as revetment for new terminal terrain. The terminals will handle neo bulk commodities: rough wood, lumber and iron materials. Beside this, refrigerated cargo is handled in this part of the new port.

Just as in the new south port, the liquid bulk jetties are projected adjacent to the breakwater. In this case, two crude berths and one oil product jetty are made.

The entrance has a width of over 600 metres, sufficient for two-way passage, based on the VLCC of 325,000 DWT. The breakwater heads are positioned in a way that most of the wave action will be kept out of the port. The highest waves will come from the north west, so that direction is blocked by the north breakwater. Other waves, from a south direction, are partly blocked by the south breakwater. The entrance position is chosen at east south east, as this direction has the least wave action (see figure 3.4).

A large area of the bottom surface has to be dredged to secure sufficient depth. This is caused by the locations of the large crude receiving jetties, requiring deep water, in rather shallow water. At the container terminal, some soil must be removed as well. The layout has been chosen such, that only small amounts of rock dredging have to be carried out. This must be avoided as much as possible because this is very expensive. All other dredging is of very soft soil, causing no problems for the dredgers.

Adjacent to the north part of the new port, a separate LNG import port is created. This has been done to assure the safety, continuity and efficiency of the port operations. The hazardous LNG transhipment is now isolated from other port related activities. Reason for the chosen location is the nearness of the powerplants. The berthing facility consists of a finger jetty with two adjacent berths, an arrangement frequently used for the receiving of LNG carriers.

9.7. Concept C: Separate ports, two entrances design.

The main difference between this concept and the preceding concept is the entrance and layout of the new south port basin, see figure G.4 in Appendix G. The entrance of this basin is completely isolated from the other dense traffic in the Onsan and Ulsan Main fairways. This envisages a safer traffic, as many ships are now freed from crossing the Ulsan Main fairway at the Onsan branch. Another advantage is, that the arriving ships approach almost parallel to the length of the basin, so that stopping length is available within the ports' boundaries.

In this concept the traffic is split, so the large amount of ship movements can be divided over two entrances. The location of the port stays roughly the same: one part south of the existing Onsan Port facilities and one part north of Onsan. The south part of the port now has its own entrance in the most southern corner, bounded by the port limits. The direction of the entrance is not optimal. Apart from the north east directed waves, the south incoming waves are the most frequent (11% of the time) and can enter the port's basins without disturbance. On the other hand, 75% of the time that the waves are directed south, the wave height is <1.0 metre see figure 3.4.

When entering the port by passing the breakwater heads, four liquid berths are situated on the left side neighbouring the south breakwater. These are two crude jetties and two product jetties. The position of the entrance and the port basin have been chosen such, that the inner basins can be used for stopping space. When the weather is good and the waves are low or moderate, tugs tie up outside the port and manage to stop the crude carrier in the first turning cycle. Then it is turned and berthed. When the weather is worse, with higher waves, the tugs can not stop the ship outside the breakwaters (4% of the time). In this case the ship can stop in the basin, is towed back to the first turning basin, is turned and berths. There is sufficient water depth (without dredging) for a 1,600 metres long inside stop for the VLCC's.

This scenario can also be applied to the ore carriers, berthing at the peninsula opposite to the liquid jetties. The place of the ore terminal is not arbitrarily chosen. The location of the ore terminal still is relatively exposed, when southerly winds blow. The unloading of the ore with grabs permits relatively large vertical motions of the ship, as already mentioned in section 8.4.

At the protected side of the peninsula, the container terminal is located. The container ships can sail straight to the second turning basin with a diameter of 700 metres. The stopping distance inside the breakwater heads is 1,900 metres.

At the land side, opposite to the container terminal, the general cargo terminal is projected. This to bundle the break bulk facilities and the possibility to change the general cargo terminal partly into a container terminal. The basin for the container and general cargo ships does not have a turning cycle at the end. The reason for this is that the length is only 1,150 metres. The ships can manoeuvre out of the basin astern (with tug assistance) and turn in the turning cycle in the main basin. The width of the container/general cargo basin can now be restricted to 300 metres, corresponding to 5 times the width of the largest container ship plus 100 metres (double sided use), see 8.5.1.

Beside the general cargo terminal, the refrigerated cargo terminal is placed. The idea is that refrigerated cargo will be transported more and more in containers with refrigerator gear, so the location should be close to that of the container and general cargo terminals.

The next terminals are the cement and sand terminal. These terminals are coupled because it is thought that these commodities together are used in the concrete industry. Another common aspect is the relatively small width of the terminals. The latter is the reason to locate the terminals here. A spit of land reaches in to the sea here, and to minimise the offshore distance of the terminals, the ones with the least width are chosen.

The remaining neo bulk terminals for lumber, iron materials and rough wood are located in the (blocked) upper part of the southerly port. At the end, a turning cycle 500 metres in diameter is drawn, allowing the multipurpose ships of lengths ranging to 200⁺ metres to turn.

The existing Onsan fairway is widened to 600 metres, necessary to accommodate the VLCC's and allowing two-way traffic. The south leg of the entrance is the same breakwater as that of the new south port. The north leg extends offshore to obtain a protected stopping length of 1,400 metres. This is probably not enough to stop a VLCC but with tug assistance just outside the port it can be managed. In the turning basin (diameter 800 metres), ships can be turned to enter the new north port, only facilitating the liquid bulk commodities being crude oil, oil products and chemical liquids. On the south-east side of the port, two crude jetties for the 325,000 DWT VLCC's are created adjacent to the breakwater. The oil product and chemical liquid berths are located in the north-west side, connected to the land through a landing stage or pier and the breakwater. This landing stage is used to keep the ships away from the shallow water near the shore. The bottom at that location consists of hard rock, inferring high costs for rock dredging.

North of this part, the LNG port is built. It uses the breakwater of the north port and is protected by a second breakwater in the north. Again the berthing facility consists of a finger jetty.

9.8. Concept D: Deep water breakwaters design.

In this concept, two ports, not connected in any way, are designed, see figure G.5 in Appendix G. One port is designed to be a commercial port, facilitating general cargo, containers, dry bulk and neo bulk commodities. Again, some liquid bulk facilities are situated south of Onsan, to secure the crude flow to the refineries. The other port is a purely industrial port, receiving only liquid bulk. As with the other concepts, a LNG port is located neighbouring the KEPCO powerplant.

The south port is designed to avoid dredging when possible. Therefore, the crude receiving facilities are projected at the most seaward end of the port. The water depth here is approximately 30 metres. A disadvantage of this design is the limited protected stopping distance available for large crude carriers, only 900 metres. The port basins have a relatively good protection against wave action from the prevailing directions.

The terminal areas are located on a large artificial peninsula, extending 2,650 metres from the land. The north-east corner of this peninsula is the most exposed so the ore terminal is projected in this corner, for reasons already mentioned in the preceding sections.

Neo-bulk commodities as rough wood, iron materials and lumber complete the north side of the peninsula. The terminal widths of these north side terminals are constant with a value of 350 metres, resulting in ample space for extension. In accordance with this large width, the length of the terminals is also larger than required for the year 2020.

The south side of the peninsula is occupied by the general cargo and container terminal, situated adjacent to each other. The length of the two terminals together equals 2,300 metres, leaving space for extension after the target year 2020. Because the mix of general cargo and containers in the future is not very clear, as mentioned in 6.4, function rearrangements of the container and general cargo terminal must be possible. Therefore, the width of these terminals is the same and equals that of the container terminal, being approximately 600 metres.



At the east end of the peninsula, the refrigerated cargo terminal is located, being 600 metres long and 350 metres wide. The tendency is to transport the refrigerated cargo with containers, equipped with refrigerating gear. When necessary, the terminal can be combined with the container terminal, located adjacent to the refrigerated cargo terminal.

The north breakwater is located as such that a turning basin of 800 metres diameter can be made. Therefore the remaining space inside the breakwater is large. This space can be used to develop new terminals in the future. The first terminals to be located there already in 2011 are the sand and cement terminals.

At the south breakwater, facilities are designed to receive the crude oil and to export the refined oil products.

When entering the port, a turning cycle of 800 metres in diameter is designed. Here the VLCC's can turn south to berth at the south breakwater. General cargo ships, container ships and product tankers also use this turning cycle. These ships sail around the peninsula, using another turning basin, 600 metres in diameter. The ships then berth. When leaving the port, turning in the southerly basin is achieved by a basin with a diameter of 600 metres for container ships and oil product carriers and a basin, 400 metres in diameter, for general cargo ships to turn. These facilities are necessary, as the length of the basin is 3,000 metres. The width of the south basin is 450 metres, sufficient for navigation of the ships in the basin.

The basin width of the north basin is 500 metres, decreasing to 430 metres when the development areas are reclaimed. A turning cycle of 450 metres in diameter is designed, letting ships of 225 metres length (50,000 DWT cement carrier) turn safely.

The north port is situated adjacent to the Onsan Port north breakwater, using this breakwater as a south-west boundary. At this breakwater, chemical liquids are handled and transported via pipelines over the breakwater heads. A north-east breakwater is newly built, facilitating two crude oil jetties and two product jetties. The protected stopping distance for the crude carriers is only 1,050 metres when waves are directed from the north-east. When waves approach from the south, the breakwaters of the south port reduce the wave action significantly. In this case, the protected stopping distance becomes 5,000 metres.

To turn the ships, so they can berth with the bow seaward, a turning basin 800 metres in diameter is designed. A ship with the bow turned seaward, can easily unberth in case of an emergency.

The approach channel and port basin have to be dredged to obtain sufficient water depth for the ships.

As in the preceding two concepts, again a separate port for the receiving of LNG is designed. The protected stopping distance equals 700 metres when the waves originate from a north east direction. This is not very much. Another disadvantage of this plan is that with north easterly waves, the breakwater of the liquid bulk port can impose high reflection coefficients, resulting in higher waves than expected.

The LNG port is projected at the same location as the preceding concepts B and C. The finger jetty alignment is 90° shifted, to achieve a more protected environment.

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10. EVALUATION OF THE CONCEPTS.

10.1. Introduction.

After designing the various concepts, it is now necessary to make a comparison between the alternatives. After this evaluation, one concept is chosen. When all the concepts have a poor score, possibly a combination of the concepts or adjustment of one of the concepts may result in a better design. It must be kept in mind that the perfect solution is hardly ever applicable. There will always be contradictions between different design aspects. The important issue is to choose the concept with the fewest disadvantages.

It is difficult to make an objective evaluation as the various criteria, applied to the designs, are not comparable. Some criteria may be of quantitative nature and are fairly easy to apply, while other criteria are qualitative and therefore not very easy to work with. To complicate the matter, the quantitative and qualitative criteria have to be reduced to the same denominator for evaluation purposes. This infers that the qualitative criteria have to be quantified.

The techniques available for making a good evaluation are the following [7]:

- 1. Check list approach.
- 2. Numerical system or multi-criteria analysis.
- 3. Monetary system.

The first method is hardly used. The method is too simplistic to obtain good results, especially for large projects.

The monetary system is a good method, as all criteria are expressed in money. This applies to the qualitative criteria as well. The advantage is that the majority of subjective judgement is banned with this method. Disadvantage of the method is the time consuming and difficult approach needed to be able to express all criteria in money. It is often necessary to execute risk analysis, for instance to quantify the difference in safety of alternative approach channels.

The multi-criteria analysis can be applied with greater ease and the results are still reliable, so this method is applied here.

10.2. How to carry out a multi-criteria analysis.

The multi-criteria analysis as an evaluation method can be executed with various techniques [7]:

- Measured success index technique
- Expectation value technique
- Concordance/discordance technique

For this project the simplest one, being the measured success index technique, is used. This technique consists of a framework of criteria, ranging from primary criteria to tertiary criteria. All these criteria are given a specific weight, being for instance a number from 1 to 10. This weighing can give rise to problems regarding the validity of the analysis. When working with different levels of criteria, the importance of primary criteria which have many secondary and tertiary criteria becomes much larger than that of primary criteria without secondary and tertiary criteria, even when the latter is given a higher weigh value. The cause of this is that the sum of the tertiary and secondary criteria score is incorporated in the total score of the primary criterion.



A different approach must therefore be adopted. A proposal is the following technique: Weigh the different levels of criteria separate, beginning with the primary criteria, and take care that the sum of the weigh factors is equal to 100. In this case, all criteria are valued as a percentage of a total of 100%. For each primary criterion, the accompanying secondary criteria are again given weigh factors which form 100% when added. An example: with two secondary criteria attached to a primary criterion, the sum of the weigh factors of the secondary critera must equal 100, so that the mutual values can express their relative importance (for instance 20-80, 40-60, etc.). When three secondary criteria are attached to the primary criterion, their mutual values can express the primary criteria. When no tertiary or secondary criteria are present for a primary criterion, the full 100 points must be given, to keep the balance with the other criteria.

The working of this method is demonstrated in table 10.5. The concept marked as "Case 0" will demonstrate the working of the method. In this case all criteria score the maximum 5 points (see section 10.5.1). A set of tertiary criteria attached to one secondary criterion then scores 500 points. When no tertiary criteria are attached to a secondary criterion, the score given for the virtual tertiary criterion again is 500 points.

This is valid on a higher level for the secondary criteria, attached to a primary criterion. Each sum of secondary criteria per primary criterion is awarded 50,000 points. The maximum score per primary criterion is in the end depending on the relative importance of the criterion. The maximum possible score for a concept is 5,000,000 points. The advantage of this method is that no matter how many secondary or tertiary criteria are attached to a primary criterion, the relative importance of the primary criterion will always be the same and depending on the importance of the primary criterion with respect to the other primary criteria.

When working in a project team, which normally is the case, the relative weights (norm values) of the primary criteria are determined by a panel, representing all disciplines envisaged in the project. This is not possible in this case, as the project team consists of only one person.

The secondary and tertiary criteria are weighed by the representative of the discipline involved. Again, there is only one person involved in this study, so the secondary criteria are also weighed by one individual.

After weighing of all criteria, each criterion will be given a score, applied on the different concepts. The final score of each concept is obtained by the following process:

1. Multiply the score per tertiary criterion and the relative weigh factor for this criterion.

- 2. Add the tertiary results, and multiply this value with the weigh factor of the secondary criterion.
- 3. Repeat these actions for the secondary results and primary weigh factors.
- 4. Add the results of the primary criteria to find the total score of the concept.

In this way, every concept gets a quantitative judgement, and the concept with the highest value will be chosen as the final design.

10.3. Elements of the multi-criteria analysis.

10.3.1. Primary criteria.

The different criteria are labelled as primary, secondary or tertiary and are given a relative weigh factor. In this section the primary criteria are assessed. Criteria may only be used when their application leads to different values for the different concepts.



The following items may be marked as primary criteria:

- 1. Costs
- 2. Port technology
- 3. Physical planning
- 4. Morphology

The validation of the primary criteria ranges from 1 to 100 points, provided that the sum of the weigh factors equals 100 points.

The determination of the norm values now is a bit arbitrarily, as no complete project team is available. Costs as criterion is of major importance, because the cheapest solution is always attractive to a principal. The primary criterion costs therefore is weighed with the value 40.

Port technology is the criterion concerning the way of operating the port. This one is second in the norm value range, it is given a value of 35.

Physical planning concerns the way the port is built, does the "built in phases" principle hold, etc. Another issue is the mobilisation of the building equipment. This criterion is given a norm value 15. Morphology is the least important criterion, because this item is dealing with the accretion of the approach channels and relocation of the currents, which do not play a significant role in this study. The norm value of this criterion will be set to 10.

When added it is correct that the total of the weigh factors is 40+35+15+10 = 100 points.

10.3.2. Secondary criteria.

In this section the secondary criteria are designated and weighed. The secondary criteria are given a weigh factor ranging from 1 to 100 and the sum of secondary criteria attached to one primairy criterion equals 100 points, just as with the primary criteria.

1. Costs (40).

Costs are the sum of all construction costs, maintenance costs, market value, procurement of equipment and materials, etc. The value for maintenance costs is difficult to establish, so this item is not used in the evaluation. For ease of calculation the costs of equipment and materials are dealt with by the construction costs.

Construction costs

- a. Breakwaters
- b. Dredging
- c. Reclamation/fill
- d. Removal of old structures
- e. Removal of land
- f. Additional structures

The secondary criteria are weighed again from 1 to 100 (sum equals 100), making a distinction between the more costly parts and the relatively cheap ones.

The costly parts have to be rewarded with a high weigh factor, in this way enabling to make a greater distinction between the different concepts. The cheaper parts do not make the difference in the first place, so they can relatively be granted with a lower norm value.



Sum	:100
Removal of land	: 5
Additional structures	: 10
Removal of old structures	: 10
Reclamation/fill	: 20
Breakwaters	: 25
Dredging	: 30

2. Port technology (35).

- a. Nautical and hydraulic criteria
- b. Flexibility
- c. Passive safety
- d. Layout
- e. Building time

The safety criterion is the most important, closely followed by the nautical and hydraulic criteria. The former deals with the hazardous cargo handling, etc. while the latter concerns the ship handling nearby and inside the port. The safety criterion is given a norm value of 30 and the nautical and hydraulic criteria are given 25.

Flexibility is awarded with a norm value of 20, as flexibility in port operations is often one of the demands of potentially new terminal operators.

The building time of the port is related to costs. This has a twofold reason: -

- 1. The longer the building time, the higher the fixed costs and thus the total project costs are higher.
- 2. The longer the building time, the longer it takes for clients to operate from the port and thus the longer it takes to receive rent and redemption.

The norm value is set at 15.

The layout of the port, how does the plan look on paper, is given the norm value 10.

The sum of the weigh factors is 25+20+30+10+15 = 100.

3. Physical planning (15).

The physical planning is concerned with the way the port is built. The following aspects of physical planning are taken into account for determining the awards in the multi-criteria analysis:

- Possibility to build the port in phases.
- · Amount of time, necessary to build the port.
- Amount of equipment and personnel working on the project.

The amount of time, necessary to build the port is the most important criterion. The reason for this is of economic nature. The sooner the work is done, the sooner the port is able to receive customers and will make money. This is important because the investments in a port development are very high. This aspect is already dealt with in criterion 2.e.

The possibility of phasing is also a factor that must not be overlooked. Again for economic reasons, because when the port can be built in phases, the investment does not have to be done at once, but can be spread over several years. Another advantage of a phased execution of the works is the possibility to adapt the original plans to the demands of the market at that time.

The amount of people working on the project must be as constant as possible. The benefit of this system is that only slight changes in the number of personnel occur, without dismissing many people, who then have to be put on half-pay.



4. Morphology (10).

Morphology is the science regarding sedimentation and erosion of the seabed, phenomena that are trying to reach a state of equilibrium. For this project, the important issue concerning morphology is the accretion problems in approach channels. As there exists a constant longshore current (see section 3.7.2), a continuous soil supply is present.

10.3.3. Tertiary criteria.

Some of the secondary criteria are in turn divided into tertiary criteria. The numbering of the tertiary criteria is as follows: the first number refers to the primary criterion, the next letter is assigned to the secondary criterion and the last number refers to the tertiary criterion. The weigh factor of the tertiary criteria ranges from 1 to 100, with the sum of tertiary criteria attached to one secondary criterion equalling 100 points. When there is no tertiary criteria attached to a secondary criterion, the weigh factor is set at 100 and counts in the secondary criterion score calculation. This is done because otherwise the secondary criteria where tertiary criteria are present score relatively higher than the criteria where this is not the case.

1.a.1 1.a.2	Soft soil dredging Hard rock dredging	Sum:	20 80 100
2.a.1 2.a.2 2.a.3 2.a.4 2.a.5 2.a.6	General location of the approach route(s). Stopping length inside the port's breakwaters. Manoeuvring space in port. Overall nautical safety. Wave penetration in the port. Wave action in front of the port (approach channel, entrance area).	Sum:	5 20 15 25 20 15 100
2.b.1 2.b.2	Possibility of extension of the port. Possibility of functional rearrangements inside the port boundaries.	Sum:	60 40 100
2.c.1 2.c.2	The position of possible dangerous areas in relation to the local environment The possibility to handle occurring disasters effectively.	Sum:	55 45 100

10.4. Cost aspects.

10.4.1. Breakwater costs.

The costs of a breakwater are very high because it is a complex structure with various parts, combined to form a coherent wave and current protection system. The demands for the new Ulsan Port project are very stringent. The water depth in the port's vicinity increases rapidly to 20 metres and more. This is a large depth for the realisation of a breakwater. Another important factor is that the sub soil consists of very weak silty clay on which no breakwater can be founded.

There exist various options for breakwater design of which the most frequently used are summed below:

• Rubble mound breakwater.

The rubble mound breakwater is a construction made of different layers of granular material. The size of this granular material can vary from sand to concrete blocks of (more than) 40 tons each. The configuration of a rubble mound breakwater can be various:

- a. Placed armour units in a precise pattern.
- b. Several layers of randomly placed stones.
- c. Pell-mell artificial armour units (randomly placed armour units on layers of stone).
- Monolithic caisson on a rip-rap foundation.

A monolithic caisson is a concrete structure with a hollow interior. It is a prefab construction, floated to its position and then sunk by filling the hollow space (usually with sand). The foundation consists of rock from the quarry, that is not suitable as armour stones (rip-rap). This type of breakwater is frequently used in Asian countries. The different configuration possibilities are:

- a. Vertical monolithic structure.
- b. Porous front monolithic structure, reducing the wave impact and reflection.
- c. Sloping front monolithic structure, reducing the wave impact and reflection.
- Composite breakwater.

A composite construction is a combination of the preceding alternatives. It consists partly of a monolithic structure, and partly of rubble mound. Again there are several compositions possible:

- a. Composite, rubble mound front. This is a vertical monolithic breakwater, fitted with a sloping rubble mound front at the exposed side.
- b. Composite, vertical monolithic top. This is a structure with a rubble mound base and a monolithic structure placed on top of it.

There appear to be a lot of possible solutions for the design of a breakwater. There are however some major disadvantages to all of the alternatives.

- A. A rubble mound structure has a trapezium profile, with a relative narrow crest, sloping sides and a wide bottom profile. This bottom profile is depending on the water depth because the other parameters, slope and crest width, are fixed. When the water depth increases for instance with a factor 2, the amount of material necessary to build the breakwater increases with a factor $(2)^2 = 4$. A major disadvantage of the rubble mound structure thus is the large amount of material necessary, especially in large water depths as is the case in this study.
- B. In agreement with the preceding disadvantage is the fact that, due to the large amounts of used materials, the rubble mound breakwater is not very suitable to be built on a subsoil with poor strength, like the silty clay in this project.
- C. Monolithic structures need an even bottom to be founded on. This type of bottom is not everywhere available along the coast near Ulsan.
- D. The monolithic elements are very sensitive to settlements. With only small settlements, the structure might be damaged. Unless measures are taken, this might be expected in this project.
- E. When the design conditions are exceeded, the monolithic structure is severely damaged and might even fail.
- F. The monolithic structure reflects a part of the incoming wave energy, resulting in higher waves in front of the breakwater that might be hindering nearby traffic in the Ulsan Main fairway or other approach channels.



Positive aspects of the various alternatives are the following:

- 1. Rubble mound breakwaters are very durable and flexible, these structures are able to adapt well to settlements, which will most certainly occur in the Ulsan region.
- 2. When encountering an irregular bathymetry, a rubble mound structure can well be used.
- 3. Rubble mound breakwaters are designed to absorb the maximum of incoming wave energy.
- 4. Monolithic breakwaters use relatively little material compared to rubble mound structures and might therefore be more economical than the rubble mound structure.
- 5. Monolithic structures use relatively little space compared to rubble mound structures.
- 6. Quay facilities are easily provided on the lee-side of monolithic structures, also pipelines can be easily led over the top of the structure. Advantageous for the proposed crude and product jetties.
- 7. Composite structures have the advantage of using even less costly materials.

To make a choice between the various alternatives is not easy. In this part of the study it is not even necessary. The only basis on which a rough cost estimate can be made is the required length of the breakwaters and the bathymetric data of the breakwater's location. These data are summarised in table 10.1.

Concept	Total breakwater length (m)	Section length (m)
A0	9,350	
0-10 m water depth		900
10-20 m water depth	•	1,475
20-25 m water depth		2,825
25-30 m water depth		. 4,150
30-35 m water depth		0
A1	11,100	4.050
0-10 m water depth		1,650
10-20 m water depth		2,600
20-25 m water depth		3,925
25-30 m water depth		2,925
30-35 m water depth		
B	0.075	
D 0.10 m water depth	9,973	1 350
10 20 m water depth		2 750
20.25 m water depth		3 625
20-25 III water depth		2 250
30-35 m water depth		-
50-00 m water deput		
С	11,525	
0-10 m water depth		1,000
10-20 m water depth		4,325
20-25 m water depth		2,325
25-30 m water depth		3,875
30-35 m water depth		-
n	12 075	
0-10 m water denth	12,070	1.650
10-20 m water denth		2.650
20-25 m water depth		1.350
25-30 m water denth		4,275
30-35 m water depth		2,150

Table 10.1 Length of the breakwater(section)s for the difference	ent concepts.
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According to table 10.1 the use of a purely rubble mound breakwater type will not be economical. This results from the large portions of breakwater located in water depths of 20 metres and more (for all concepts 50% or more). The amount of material necessary to build the breakwater becomes excessive. Therefore a monolithic structure will at least be part of the final breakwater design.

When choosing for the monolithic breakwater, the first problems encountered are foundation problems. The subsoil consists of materials with insufficient bearing capacity to found the monolith on. The options open to increase the bearing capacity are all costly, from a rubble mound underlayer to a complete replacement of the subsoil with high-quality foundation material.

One expensive other option is the use of open bottom caissons. These breakwaters are very costly, but can be the best alternative in deep water with soil conditions too poor for even a rubble mound breakwater [11].

To reduce the size of the expensive caissons, it is possible to construct a rubble mound underlayer, resulting in a vertically composite breakwater. This type of breakwater can only be used in water with non-breaking waves. The water depth on the spot is sufficient to prevent the breaking of the waves, so this type is suitable. The danger accompanying this solution is that because of the underwater mound the water depth is decreased in a way that the waves are still forced to break [9].

Concluding it is obvious that ample problems may arise with the design, building and operation of the breakwaters. The thing all alternatives have in common is that they are all very expensive, due to a combination of large water depths and poor subsoil.

For an indication of the breakwater costs of the different concepts, the following division is made:

Water depth 0-10 metres: f 40,000.- per m breakwater length Water depth 10-20 metres: f 60,000.- per m breakwater length Water depth 20-30 metres: f 75,000.- per m breakwater length Water depth > 30 metres: f 85,000.- per m breakwater length

These indicative figures are only for comparison's use. They are not intended to be realistic values for the breakwaters to be built in this project.

The resulting costs per concept are summarised in table 10.2.

Water	Concept A0	Concept A1	Concept B	Concept C	Concept D
aepin (m)					
0-10	f 36,000,000	f 66,000,000	f 54,000,000	f 40,000,000	f 66,000,000
10-20	f 89,000,000	f 156,000,000	f 165,000,000	f 260,000,000	f 159,000,000
20-30	f 523,000,000	f 514,000,000	f 440,000,000	f 465,000,000	f 422,000,000
> 30	f 0	f 0	f 0	f 0	f 183,000,000
Total	f 648,000,000	f 736,000.000	f 659,000,000	1765.000.000	f 830,000,000
costs					

 Table 10.2 Indication of the costs of the breakwaters for the different concepts.

10.4.2. Dredging costs.

With all concepts, a certain amount of dredging is necessary. To be able to provide sufficient depth for ships in the port, the water depth has to be increased. The reason for dredging is the compromise between the avoidance of costly dredging and the minimisation of fill material costs for the new terminals.

A differentiation between soft soil dredging and hard rock dredging has to be made. This because the dredging techniques and the accompanying costs are completely different. The soft clay soil is easily removed with a Trailing Suction Hopper Dredger (TSHD), covering large areas in a relatively short time, unloading its cargo on a dumping terrain.

The hard rock on the other hand, can not easily be removed. Even a Cutter Suction Dredger (CSD) fitted with a cutterhead with chisels can not remove types of hard rock with compressive strengths over 20-50 MN/m² in an economical sense. This is probably the case in this situation although no substantial data is available.

The path to follow in these cases is that holes are drilled in a regular pattern, these holes are filled with explosives and the rock is blasted. The rock fragments now can be removed with normal dredging equipment (CSD). Because the latter bore and blast method is much more labour intensive, it is very expensive. This method is approximately 10 times more expensive then soft soil dredging. Guidelines regarding costs are:

Soft soil dredging with a TSHD:	- f 10 per m ³
Rock dredging with bore/blast method and CSD:	f 100 per m ³

Again, these figures are only meant to indicate the difference between the methods and to come to a quantitative difference between the various concepts. These are not the actual costs for the dredging in this project.

With the aid of charts for water depth and rock layer depth, for each concept the amount of rock dredging and soft soil dredging is determined, being summarised in the next table 10.3.

	Type of dredging	Amount (1,000 m ³)	Total costs (indicative)	Sum of the dredging costs (indicative)
Concept A0.	Soft soil	500	f 5,000,000	f 205,000,000
	Hard rock	2,000	f 200,000,000	
Concept A1.	Soft soil	15,500	f 155,000,000	f 1,255,000,000
	Hard rock	11,000	f 1,100,000,000	
Concept B.	Soft soil	10,000	f 100,000,000	f 725,000,000
	Hard rock	6,250	f 625,000,000	
Concept C.	Soft soil	11,000	f 110,000,000	f 1,310,000,000
	Hard rock	12,000	f 1,200,000,000	
Concept D.	Soft soil	7,500	f 75,000,000	f 925,000,000
	Hard rock	8,500	f 850,000,000	

Table 10.3 Amounts and costs of dredging works for the different concepts.



10.4.3. Fill material costs.

In each concept, the terminals are built on reclaimed land, consisting of material, suitable to sustain relatively high loads. This is necessary because terminal equipment such as quay cranes and stacking of heavy cargo imposes high loads on the sub-soil. Suitable materials are sand and rock fragments. Sand is not available in the Ulsan vicinity. It has to be imported (a sand terminal is going to be developed) and this is a costly operation.

Rock fill might be a better solution. The inland sub-soil mainly consists of hard rock so that ample material is available. Another beneficial point is that for the building of the breakwaters, quarries have to be opened to provide stones for the foundation and possibly (in a composite breakwater) for armouring.

The stone seizes, used in the breakwater amount to a maximum of only 50% of the total quarry production. The remnant of the quarry run can be used as fill material for the terminal areas. This is probably not sufficient, as the amount of fill is very large. Therefore, one or more of the quarries must be dedicated to rock fill production only.

From the same water depth chart as used for the dredging costs' calculation, the amount of fill necessary to develop the terminal areas is assessed. In this calculation, an extra height of 2.5 metres above sea level is included. The results are admitted in table 10.4.

As an indication for quantitative comparison, the price per m^3 is set at f 7.50.

Concept	Amount of (rock) fill	Costs (indicative)
A0	42,500,000 m ³	f 318,750,000
A1	39,000,000 m ³	f 292,500,000
В	28,200,000 m ³	f 211,500,000
С	24,000,000 m ³	f 180,000,000
D	56,500,000 m ³	f 423,750,000

Table 10.4 Amount and cost of the fill for the terminal areas of the different concepts.

10.5. Applying the MCA to the different concepts.

10.5.1. Cost criterion.

The preceding sections, in which the elements of the multi-criteria analysis (MCA) are allocated and given a weigh factor, are now summarised in table 10.5. This table also contains the score of the different concepts on each criterion. This score consists of a number in the range 1 to 5. The last row of the table projects the total score of the different concepts. The "best" solution is the concept with the highest score.

A brief explanation of the awarded values to the different concepts will be presented now.

The primary criterion costs is divided in six secondary criteria of which the dredging costs are the most important, because these costs are the largest. Especially rock dredging is very expensive, so scoring good on this criterion must be rewarded with a lot of points for the total.



Soft soil dredging.

With table 10.3. Concept A0 is by far the cheapest solution, dredging need of only 0.5 million cubic metres. It is therefore given a validation 5.

The other concepts ranging from 7.5 - 15.5 million cubic metres, being at least a factor 15 more. These concepts are therefore rewarded maximum 3.

Rock dredging.

Again concept A0 is the absolute winner, with 2.0 million cubic metres to dredge, against 6.3 to 12.0 million cubic metres for the other concepts. The validation is further made according to the mutual differences.

Breakwater costs.

Validation made with reference to table 10.2. To accentuate the largest differences, the validation is chosen a bit extreme: the large gap between the two concepts A0 and B and the concepts A1 and C (\approx 1,500 metres, especially in the deeper parts of the ocean) is accentuated with a three points' difference. Concept D finishes last with 1 point.

Reclamation costs.

Largely dependent on the amount of fill material needed. With regard to table 10.4 it is obvious that the concepts C and B score the best at this criterion, the least amount of fill material is used for these designs. The concepts A0 and A1 score about equal, but 15 million cubic metres more than the preceding concepts. Concept D uses the largest amount of fill material due to its extension into deep water and is therefore rewarded with only 1 point.

Removal of old structures.

Comprising mainly the SPM removal and existing breakwaters, next to other facilities such as dismantling of existing facilities at the foreshore, etc. Concept A0 scores best, this is the only design in which the SPM's do not have to be removed. The Onsan north breakwater is maintained. Together these are the most costly removal operations. The validation becomes 5. With all other concepts, the SPM's must be removed. The concepts can therefore only score 3 as the highest validation. Concept D scores 3, as no breakwater removal is planned and the berth on the north Ulsan breakwater (see figure G.5 in Appendix G) can still be used. This is also the case for concept B but here the end of the breakwater must be removed. In the concepts A1 and C the complete Onsan north breakwater, including the berth, has to be removed. With concept A1 the LPG berths in the north at the Yukong Gas location have to be removed because there new terminal terrain is planned.

Additional structures.

Concept A0 scores not very good: relocation of the SPM's with longer pipelines, making a new berth replacing that at the old Onsan north breakwater.

Concept A1 is even worse: the berth of the Onsan breakwater must be rebuilt, together with three berths for the LPG ships of Yukong and new discharge facilities for the KEPCO powerplant. Score: 1.

Concept B and D both score 100% here, no additional structures must be provided. Score: 5. Concept C caters for a long levee for tankers to keep them in deeper water and need two finger jetties for crude and product carriers. Score: 3.

Removal of land.

Concept A1 scores the best here. The only land removal will be the island of Yõnjado, which must be levelled to merge with the new terminal area. The same applies to concepts A0 and D, where an additional amount has to be removed at the north side terminals. Concept B requires the removal of only part of the Yõnjado island, but in turn needs removal of some cliffs in the middle south sector. All three concepts score 3 points. In concept C the island has to be removed together with parts of the hinterland, therefore scoring only 2.

10.5.2. Port technology criterion.

Within the port technology primary criterion, several secondary and tertiary criteria are embedded. They are described hereafter.

NAUTICAL AND HYDRAULIC CRITERIA.

Location of the approach route(s).

This means with regard to obstacles, distance to the coast and marine structures, etc. In this context, concepts B and C score the best. The approach channels lead to clearly visible entrances, without navigation close to obstacles or marine structures. Concept A1 scores well less, mainly because of the vague approach to the outer crude and liquid berths and the fairly close navigation along the breakwaters. Concept A0 scores 2 because the approach channel to the south basin is located only 100-150 metres from the breakwater. The locations of the SPM's do not contribute to a clear insight in approach route direction when entering Onsan port and the new north port.

Stopping length inside the port.

This is a combination of length and accompanying ship size. After investigation of the alternatives, the following conclusions were drawn:

Concept A0 score: 1. Only 250 metres for large container ships to stop and turn into the new north port. This is unacceptable.

Concept A1 score: 5. The minimum stopping length is 900 metres for container vessels. Crude and ore carriers have stopping lengths of 2,150 metres, this is sufficient.

Concept B score: 2. The south bound crude carriers must stop within 900 metres after entering. This is very short.

Concept C score: 4. The crude carriers must stop within 1,100 metres, rather short. The rest of the ships have ample space for stopping (2,000-2,500 metres for container ships and bulk carriers).

Concept D score: 3. Again the crude carriers only have 1,100 metres. The other ships have more, but this can change after the port extension at the new north breakwater of the south port.

Manoeuvring space in the port.

This regards the width of the basins, the amount of bends that have to be made while navigating, the ability to turn the ship, etc. Concept A0 scores very bad. Because the quays are not straight, a lot of bends have to be made during the track. Some parts of the port's basins are small. Navigation behind the northerly entrance is very hard due to the maintained Onsan north breakwater. Concepts A1 and C score better, the width behind the entrance is larger, turning basins are provided, but still turns must be made frequently to reach certain terminals. Some basins are relatively narrow. This is the extra advantage of concept D, which has wide basins at its disposal and therefor scores a bit higher. Concept B gets the full score for its surveyability and broad, straight basins.

Overall nautical safety.

Concept A0 scores low on this criterion, partly due to the shortcomings as described in the preceding criteria. The entrances are not well designed, the navigation routes are disorderly and some passages very narrow. Besides these points are the SPM operations hazardous with regard to collisions. Concept D is not a good solution too. The entrance of the south port is adjacent to the main Ulsan fairway and the industrial port in the north must be approached from an angle (around the south port).

Concept B is better, but the singe entrance might cause dangerous situations in dense traffic periods. Concept A1 and C score the best points, having separate entrance for the north and south port, with a slight advantage to concept A1 because half of the large crude carriers are handled outside the port's breakwaters.



Wave penetration in the port.

Important for this criterion is the direction of the port entrance(s) with respect to the prevailing wave directions. From figure 3.4 can be seen that the prevailing wave directions are south and east-north-east. The designs with entrances projected south are thus disadvantageous. Concept A0 is the worst, because the waves are forced into the south entrance by the middle breakwater. Only concept B and D score good on this criterion. They both have entrances to the east-south-east, the least vulnerable direction with regard to incoming waves. Concept D scores somewhat better because when waves do enter the port, the terminal operations of concept B suffer sooner than that of concept D.

Wave action in front of the port.

This depends on the direction of the breakwaters and the direction and location of the approach channels. Concept A0 scores the fewest points. When entering the south port during east-northeast waves, the breakwater nearby can cause high reflection effects. This applies to some extend to the north entrance as well. Concept A1 has the same problems, although not so severe. The outer port crude and liquid berths might have some trouble from southerly directed waves. Concept B scores the best, all incoming waves are guided along the port entrance without causing reflection. Concept D might have some problems during southerly winds. The north port in this concept is well protected. The entrances of concept C are more exposed and the score is therefore less.

FLEXIBILITY.

Possibility of extension of the port.

The different concepts all project the 2020 situation. After 2020, all concepts will encounter difficulties regarding extensions, because of the existing port limits and the already built breakwaters. Another approach is that also phasing until 2020 is taken into account, then the following values are assigned: Concept A0: 4. Phasing is good, mixed commodities over north and south port, SPM's may reduce extension into deep water.

Concept A1: 2. Phasing is good, but there is no mixing of commodities over the different phases. Extension in deep water possible, but then breakwater relocation is necessary.

Concept B: 3. Phasing can be done because of available terminal area in the north port. In the south port it is more difficult due to breakwater layout. For extension in deep water the breakwaters have to be realigned.

Concept C: 2. Phasing is possible, but commodities are separated over the different ports. Extension can only be done in deep water, inferring the relocation of breakwaters.

Concept D: 4. Phasing is possible, but commodities are separated over the ports. Extension is still possible within the port and extensions can be made with relative small breakwater relocations.

Possibility of functional rearrangements.

Concept A0 scores bad now, the mixing of the commodities is guilty of this. An ore terminal is not easy rearranged in a container terminal. A general cargo terminal can be rearranged in a container terminal, but the reserved terminal width is too small (only 300 metres). Concept A1 scores average, in the north port, rearrangements are possible. In the energy port only liquid commodities are handled. Concept B scores the best, the general cargo terminal is projected adjacent to the container terminal with ample width. In the north port neo-bulk terminals and a refrigerated terminal are designed, enabling the operators to change into container business. Concept C scores less. The container terminal is situated adjacent to the ores terminal, the general cargo terminal is only 350 metres wide. In the north port, only liquid goods are handled, rearrangements in the type of liquids are not so hard. The possibilities for functional rearrangements is quite good. The general cargo terminal is lying adjacent to the container terminal and has the same width.



PASSIVE SAFETY.

Position of dangerous areas/local environment.

With this criterion, concept A0 is the worst. The 5 SPM's in front of the port's breakwaters impose high risks. The ships with chemical liquids sailing to Onsan port might have difficulties with the entrance because the Onsan north breakwater is maintained. Concept A1 is not very good. The relocated LPG berths in the commercial port are lying in a dangerous position. The liquid berths on the west side of the energy port impose danger to the nearby coast and the ship berthed on the first jetty might be collided by other ships. The crude and LNG berths adjacent to the Ulsan main fairway are vulnerable to collisions. When an LNG leakage occurs, a disaster might follow. Concept B scores good, the dangerous goods are all handled as far from the coast as possible and the basins are all very wide. Concepts C and D both score average. Liquid bulk terminals are located fairly near to the coast. To berth, ships must make many manoeuvres.

Possibility to cope with occurring disasters.

Concept A0: good, ships lying at the SPM's can unberth and sail into open sea quickly. Spillage in the port basins is removed by the currents through the basins because they are open. The first remark also applies to the berths along the Ulsan main fairway of concept A1. The ships in the energy port can sail out of the port when the bow is turned to sea before berthing. Concept B and C are not very good, the ships must first be towed to the entrance before being able to sail to open sea. During this period, the entire port is closed for all traffic. Second, the terminals are only a few hundred metres away so escalation might arise. The north port in concept D can be left fast when the bow is already turned in the seaward direction, the basin is very wide. The south port might encounter more difficulties. The liquid bulk carrying ships must make various turns close to other terminals. This is rather dangerous.

LAYOUT.

The way that the port is generally looking from a bird's eye view also is a (rather subjective) criterion. The scores are:

Concept A0: 1	Concept C: 2
Concept A1:4	Concept D: 3
Concept B: 5	

BUILDING TIME.

Concept A0 is built in the shortest time, the breakwaters are relatively short and the crude receiving facilities already are available. Due to phasing, the port can operate very quickly. Only small amounts of soil have to be dredged. Concept A1 scores a low value; Large amounts of soil must be dredged before building can be started. The breakwaters are rather long. Phasing is possible, the first crude can be imported in the north port. The breakwater length of concept B is the second shortest. The amount of soil to be dredged and fill material to be deposited is also small. This concept therefore scores second best. Concepts C and D are both not built in a short time. Concept D takes longer to build because of the complicated breakwater construction in deep water.

10.5.3. Physical planning criterion.

This is somewhat the mean value of the criteria 2.b.1 and 2.e because of the elements in these criteria that are present in the physical planning. The deployment of personnel and equipment must also be taken into account. The following values have been assigned:

Concept A0:4	Concept C: 2
Concept A1:4	Concept D: 3
Concept B: 3	

10.5.4. Morphology criterion.

The assignment of values depends mainly on the direction and depth of the approach channels and entrances. The scores are the following:

Concept A0:1 this is due to the open basins where the water full with sediment can enter easily and to the dredged parts around the SPM's that can fill up with sediment.

Concept A1:3 the dredged part for the crude carriers can gradually fill up due to sedimentation.

Concept B: 5 only a short part of the canal is dredged and the depth of the dredged slice is only 2 metres thick.

Concept C: 4 the depth and length of the dredged slice is somewhat larger than the previous concept.

Concept D: 1 the dredged trench to the north port is long and deep, the current is decelerated because of the south port breakwater and even more accretion occurs.

10.6. Winning concept.

When looking at the total score, it becomes clear that concept B, Central entrance design, is the winning concept. The advantage over number two is more than 20 percent. The criteria where this concept gets its points are costs and port technology. Concept B scores up to twice as high on the primary criterion costs as the concepts A1, C and D. Here a major battle is won. Concept A0 scores even better at the cost criterion than concept B, but with the port technology criterion concept A0 scores very poor, the least of all concepts. When looking at the second most important primary criterion port technology, concept B scores the most points. More than 55% better than concept A0. Almost 30 percent is won over the second best design, concept D.

As a conclusion, the concept with the central entrance is chosen as the final design. This because it is a relatively economic alternative. Only the government master plan alternative (concept A0) is less costly. If a concept is not economical attractive, it will never be realised. It must, on the other hand, be a workable concept too. This certainly is the case with concept B, because it scores the highest points on nautical and hydraulical criteria, flexibility, passive safety and layout. The cheapest solution, concept A0, is not preferable because it scores very poor on the port technology criteria.

Points on which concept B scores less are:

- Costs of rock and soft soil dredging.
- Costs of removal of old structures.
- Costs of removal of land.
- Stopping length inside the port's breakwaters.
- Overall nautical safety.

The dredging costs can not be decreased without changing the concept radically, namely by excluding the crude oil carriers from the port premises. The costs of removing old structures also can not be decreased. These structures must be removed to increase the nautical safety. The costs of removal of land can be decreased by situating the terminals more seaward, but this increases the costs of fill material and breakwaters, so the resulting costs might even be higher. The protected stopping length can only be increased by a new breakwater location, into deep water. This will increase the building costs significantly. The overall nautical safety is scoring only average because of the single entrance. This can impose hazardous situations in case of dense traffic.

The dimensions of the entrance and approach channel are such that ample manoeuvring space is available, even for the largest ships. The turning cycle behind the entrance might impose problems. An improvement could be achieved in combination with a longer stopping length due to breakwater lengthening. The extra costs of this adjustment must be calculated and compared with the nautical advantages.



11. CONCLUSIONS AND RECOMMENDATIONS.

After months of investigation and study, the final design for a new port in the Ulsan region is presented in chapter 10. Of course this design is not the perfect solution. Even when ample personnel and time are available, a perfect design is an utopia. Always a compromise between reducing costs and nautical optimisation has to be found. The solution presented in this study will even be less perfect, because only the major points in master-planning are dealt with. No time and money were available for the use of simulation models or physical model tests to substantiate the posited propositions.

The relation with the hinterland and the hinterland connections are only briefly discussed, because no detailed information was available. The locations of the terminals and jetties could therefore not be determined with certainty.

The cargo forecast was supplied by the Korean government. It is not clear on what basis it is founded. It is recommended that further investigation regarding the future cargo flows is done, to attain a better basis for calculation of future traffic, number of berths and terminal areas. The assessment of the future cargo flows is mainly based on the figures of the Korean government. Not all data matched and some assumptions were made (section 4.3). The validity of these assumptions can be questioned because they are rather crude, although this was insuperable.

The number of ship movements is determined via an average cargo per call in 1995, being the average amount of cargo over all ships. For 2011 and 2020, the average cargo per call is adapted to the forecasted cargo flows in these years. Again this is a rather arbitrary measure, but the consequences of this adaptation are not very significant. The number of ship movements is only meant as an indication of the traffic density.

To determine the number of berths per commodity and the length of the quays, the queuing theory is used. This theory is a simplification of the practical situation in a port. Simulation models give a more realistic view, but could not be applied as explained earlier. The queuing theory uses two statistically distributed parameters, for ship arrival times and service times. These parameters simplify the actual port operations to a regime with two options, resulting in a disturbed representation of reality. To make the prediction even less accurate, an acceptable waiting time must be assumed. This assumption has a great influence on the final calculation of the number of berths. To be able to make a sound assessment of the number of berths, it is recommended to make use of a numerical simulation model. Prerequisite is that the boundary conditions are more specific and detailed.

The assessment of the terminal areas is made with the aid of some general design formulae. Of course the exact terminal area is not found, but at this stage this is not necessary. It is important though, to get an impression of the required terminal width. This width is found by dividing the assessed terminal area by the quay length. Again some assumptions are made regarding equipment for handling cargo, type of storage, etc. Again, only a rough impression of the width is required and found so no adjustments of the used method are necessary.

PIANC guidelines are used to determine the dimensions of the approach channels. These guidelines are the state-of-the-art and it can be expected that their application leads to accurate results. This can not be said of the dimensioning of the port basins. Here some rules of thumb regarding basin width and depth are used. These calculations are only giving the approximate basin dimensions, sufficient for a master planning stage.



After all the ingredients are present, different design concepts have been made. The concepts A0 and A1 are designs, made by the Korean government and Korean Port Consultants (among others DHV Consultants) respectively. These designs are judged in the multi-criteria analysis to compare them with the concepts developed in this study. The development of the concepts was more or less a trial and error exercise. Keeping the requirements in mind, the elements are shoved over the map to create three different but satisfying designs. The thus obtained solutions are very subjective. When another person was asked to make the designs, totally different layouts would appear.

The five alternative designs are all submitted to a multi-criteria analysis. This is not the most distinctive method to determine which alternative is preferable, but it is a good compromise of sufficient accuracy and little time consumption. The advantage of the used measured success index technique is that all criteria are made quantitative, and thus comparable. A disadvantage of the method is that the assigned weigh factors are allocated subjectively. This can result in the winning or losing of an alternative by just changing one weigh factor. Another subjective part is the allocation of scores to the various concepts. Often the person who is executing the MCA already has a favourite design and then allocates weigh factors and scores in such a way that this design comes out as the winner. As mentioned before, less subjective methods do exist but these are far more difficult to use and much more time consuming.

The winning design with the straight breakwaters and central entrance is certainly not an ideal solution, but scores good points on the navigability criteria and combines it with moderate costs. The layout looks fine which is important too. The disadvantage regarding the difficulties of phasing is enclosed in almost all other concepts.

A point of concern with this alternative is the single entrance to both the new north and south part of Ulsan Port and to Onsan Port. This entrance must cater for 60% of all traffic, meaning approximately 36,000 ship movements in 2020. This need not be a problem but 70% of this traffic, being 25,000 ship movements, use the turning cycle behind the entrance to manoeuvre to the new south part of Ulsan Port and to the liquid berths in the new north part of Ulsan Port. In figure 11.1 a figure with the different traffic flows is included. The time that the entrance is blocked while ships are turning in the turning basin will possibly lead to congestion. A further study using a simulation model to assess the congestion of the approach channel, entrance and turning cycle is recommended.

As a conclusion it can be said that the final design is a good compromise between all the important parts that are embedded in the development of a new port.
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	Cernent ship	Full Empty	564	1322	0	o	31333	13490	o	o	18 0	98 0	0 18	0 98	Total arrivals Total departures	116 116
		Cement	564	1322	0	0		<u> </u>			 		L		Total cement ships	232
	Car carrier	Full Empty	0	O	4288	214	0	0	11052	3627	0 390	0 58	388 0	59 0	Total arrivals Total departures	447 448
		Vehicles	0	0	4288	214									Total car carriers	895
	Refrigerator Ship	Full Empty	626	0	0	0	17857	0	o	0	35 0	0	0 34	0	Total arrivals Total departures	35 34
		Fresh fish Other animal/vegetable products	310 316	0 0	0 0	0			-						Total refrigerator ships	69
	General cargo ship	Full Empty	4484	856	1857	1556	2763	1523	1128	2754	1623 0	562 0	· 1646 0	565 0	Total arrivals Total departures	4396 0
		Wooden articles	1150	0	35	0									Total general cargo ships	4396
		Animal/vegetable fats & oils	40	0	1	1										
		Sugar	346	0	49	ů ů										
		Machinery	315	15	494	208										
		Iron materials	892	780	706	283										
		Plastics, rubber, textiles	309	15	542	0										
		Reingerated cargo Other	267	45	22	972										
	Full container ship	Full Empty	20 (*1.000 TEU)	0	18 (*1.000 TEU)	0	39 (TEU)	0	35 (TEU)	0	511 0	0	514 1	0 0	Total arrivals Total departures	1025 1
		Containers	20 (*1.000 TEU)	0	18 (*1.000 TEU)	0									Total full container ships	1026
	Semi-container ship	Full Empty	2 (*1.000 TEU)	0	2 (*1.000 TEU)	o	32 (TEU)	0	31 (TEU)	o	62 0	0	65 0	0 0	Total arrivals Total departures	127 0
		Containers	2 (*1.000 TEU)	0	2 (*1.000 TEU)	0									Total semi-container ships	127
	Crude oil carrier	Full Empty	49281	32	183	238	146343	27	146343	200	337 0	1180 0	1 338	1188 0	Total arrivals Total departures	2706 338
		Crude oil	49281	32	183	238						ļ			Total crude oil carriers	3044
	Product carrier	Full Empty	8735	421	13188	18813	28546	2835	28546	2835	306 461	149 6646	462 306	6636 137	Total arrivals Total departures	7552 7550
		Oliproducts	8735	421	13188	18813									i otar product carriers	10102
	Chemical tankers or other vessels with chemical	Full Empty	5397	556	1548	541	3034	1007	3034	1007	1779 518	552 530	510 1771	537 559	Total arrivals Total departures	3378 3378
	products	Chemical products	5397	556	1548	541							l		Total chemical tankers	6756
	Gas carrier	Full Empty	3941	136	260	1605	30442	2602	30442	2602	129 10	52 615	9 128	617 53	Total arriva ls Total departures	807 806
		Gasses	3941	136	260	1605									Total gas carriers	1613
		Sub-totals	Total Ocean-going import 78247	Total Coastal import 4012	Total Ocean-going export 21986	Total Coastal export 23053					Total Ocean-going arrivals 6434	Total Coastal arrivals 12602	Total Ocean-going departures 6478	Total Coastal departures 12614	Total ship movements	38128
			Tatal								Total					
			containers								movements					
i.		Total	127298								38128					
			Container cargo 740													
			Total cargo													

Table 4.7Extracted 1995 cargo flows and shipping traffic

EA/

			2011			Γ	2011			1	2011			2011	
		IMPO	RT	EXPO	RT	IMPC	RT	EXPC	DRT	IMPC	RT	EXPO	DRT	6 11	to do not
			Volume (1000 tons)			Av	erage cargo pe (tons)	r call			umber of ship	s		Snip movements	in/out
r		Ocean-going	Coastal	Ocean-going	Coastal	Ocean-going	Coastal	Ocean-going	Coastal	Ocean-going	Coastal	Ocean-going	Coastal		
Bulk carrier	Full Empty	14267	1502	74	132	28897	499	20000	350	502 4	3014 377	4 502	377 3014	Total arrivals Total departures	3897 3897
	Cereals	1495	0	0	94	20000 .	o	0	350	75	0	0	269	Total bulk carriers	7794
	Fertilizers	2434	0	0	2	30000	0	0	350	81	0	0	6		
	Iron ore Other ares	51 10260	0	0 74	0 36	20000 30000	0 350	0 20000	0 350	3 342	0 34	0 4	0 103		
	Natural sand	27	1490	0	0	20000	500	0	0	1	2980	0	0		
Log carrier	Full Emply	351	0	0	0	5500	0	o	o	64 0	0	0 64	0	Total arrivals Total departures	64 64
	Rough wood	351	0	0	0	5500	0	0	0		<u> </u>			Total log carriers	128
Cement ship	Full Empty	355	3138	0	0	10000	20000	0	0	36 0	157 0	0 36	0 157	Total arrivals Total departures	192 192
	Cement	355	3138	0	0	10000	20000	0	0		+			Total cement ships	385
Car carrier	Full Empty	236	0	6272	289	10000	0	15000	3500	24 395	0 83	418 0	83 0	Total arrivals Total departures	524 477
	Vehicles	236	0	6272	289	10000	0	15000	3500					Total car carriers	1001
Refrigerator Ship	Full Empty	1082	0	0	0	5000	0	o	0	216 0	0	0 216	0	Total arrivals Total departures	216 216
	Fresh fish Other animal/vegetable products	536 546	0	0	0	5000 5000	0 0	0	0					Total refrigerator ships	433
General cargo ship	Full Empty	7747	3292	1883	5854	4379	2000	1100	3883	1870 0	1646 0	1712 159	1520 126	Total arrivals Total departures	6749 284
	Wooden articles Animal/vegetable fats & oils Prepared foodstuff	2407	0	O	0	3000	0	0	0	802	0	o	o	Total general cargo ships	7033
	Sugar Machinery Iron scrap Iron malerials	0 2952	0 1882	0 1828	0 683	0 5000	0 2000	0 1100	0 3000	0 590	0 941	0 1662	0 228		
	Plastics, rubber, textiles Refrigerated cargo Other	2388	1410	55	5171	5000	2000	1100	4000	478	705	50	1293		
Full container ship	Full Empty	166 (*1.000 TEU)	o	228 (*1.000 TEU)	0	1000 (TEU)	0	1000 (TEU)	0	166 62	0	228 0	0	Total arrivals Total departures	394 62
	Containers	166 (*1.000 TEU)	0	228 (*1.000 TEU)	o	1000 (TEU)	0	1000 (TEU)	0					Total full container ships	456
Semi-container ship	Full Empty	19 (*1.000 TEU)	o	25 (*1.000 TEU)	0	200 (TEU)	0	200 (TEU)	0	95 30	0	125 0	0	Total arrivals Total departures	220 30
	Containers	19 (*1.000 TEU)	o	25 (*1.000 TEU)	o	200 (TEU)	0	200 (TEU)	٥					Total semi-container ships	250
Crude oil carrier	Full Empty	133761	0	0	0	175000	0	0	0	764 0	0 0	0 764	0	Total arrivals Total departures	764 764
	Crude oil	133761	0	0	0	175000	0	0	0					Total crude oil carriers	1529
Product carrier	Full Empty	14277	670	24878	30326	30000	3000	30000	5000	476 829	223 6065	829 476	6065 223	Total arrivals Total departures	7594 7594
	Oilproducts	14277	670	24878	30326	30000	3000	30000	5000					Total product carriers	15187
Chemical tankers or other vessels with chemical	Full Empty	8525	2134	1582	2074	3000	1500	3000	1500	2842 527	1423 1383	527 2842	1383 1423	Total arrivals Total departures	6174 6174
products	Chemical products	8525	2134	1582	2074	3000	1500	3000	1500					Total chemical tankers	12349
Gas carrier	Full Emply	6441	219	490	2592	30000	2500	30000	2500	215 16	88 1037	16 215	1037 88	Total arrivals Total departures	1355 1355
	Gasses	6441	219	490	2592	30000	2500	30000	2500					Total gas carriers	2711
	Sub-totals	Total Ocean-going import 187042	Total Coastal import 10955	Total Ocean-going export 35179	Total Coastal export 41267					Total Ocean-going arrivals 9132	Total Coastal arrivals 15495	Total Ocean-going departures 9132	Total Coastal departures 15495	Total ship movements	49255
	Total	Total cargo excl. containers 274443 Container cargo								Total ship- movements 49255					
		6096 Total cargo													
	Grand-total	280539								I				I	

Table 4.8Assessment of the cargo flows and shipping traffic in 2011.



		r	202)		1	202)		1	2020)		202	0
		IMPC	ORT	EXPC	RT	IMPO	ORT	EXP	ORT	IMPO	DRT	EXP	ORT		<u></u>
			Volume (1000 tons)			Ave	age cargo (tons)	per call			umber of ship	os		Ship movements in/out	
		Ocean-going	Coastal	Ocean-going	Coastal	Ocean-going	Coastal	Ocean-going	Coastai	Ocean-going	Coastal	Ocean-going	Coastal	1	
Bulk carrier	Full Empty	21551	1977	71	123	33835	997	20000	350	637 4	1984 351	4 637	351 1984	Total arrivals Total departures	2975 2975
	Cereals Fertilizers	1588	o	0	94	20000	O	o	350					Total bulk carriers	5951
	Coals iron ore	3048 59	0	0 0 71	1 0 28	35000 20000 35000	0	0	350 0 350						
	Natural sand	27	1967	0	0	20000	1000	0	0	_ _					
Log carrier	Full Empty	414	0	0	0	5500	0	0	0	75 0	0	0 75	0 0	Total arrivals Total departures	75 75
	Rough wood	414	0	0	0	5500	0	0	0					Total log carriers	151
Cement ship	Full Empty	326	4272	0	0	10000	20000	o	0	33 0	214 0	0 33	0 214	Total arrivals Total departures	246 246
	Cernent	326	4272	0	0	10000	20000	0	0	. <u> </u>	<u> </u>			Total cement ships	492
Car carrier	Full Empty	321	0	5476	327	10000	o	15000	3500	32 333	0 93	365 0	93 0	Total arrivals Total departures	491 426
 	Vehicles	321	0	5476	327	10000	0	15000	3500		<u> </u>			Total car carriers	917
Refrigerator Ship	Full Empty	1397	0	0	0	5000	0	o	o	279 0	0	0 279	0	Total arrivals Total departures	279 279
	Fresh fish	693 704	0	0	0	5000	0	- 0	0					Total refrigerator ships	559
General cargo ship	Full Empty	9999	4103	2445	8267	6330	2000	1100	3870	1580 643	2052 85	2223 0	2136 0	Total arrivals Total departures	7990 728
	Wooden articles Animal/vegetable fats & oils Prepared foodstuff	2833	0	0	0	3000	0	o	o					Total general cargo ships	8718
	Sugar Machinery Iron scrap	o	o	o	0	o	0	o	0						
	Iron materials Plastics, rubber, textiles Refrigerated cargo	3374	1822	2060	1077	5000	2000	1100	3000						
	Other	3792	2281	385	7190	10000	2000	1100	4000						
Full container ship	Full Empty	245 (*1.000 TEU)	0	329 (*1.000 TEU)	0	1250 (TEU)	0	1250 (TEU)	0	196 67	0	263 0	0	Total arrivals Total departures	459 67
	Containers	245 (*1.000 TEU)	0	329 (*1.000 TEU)	0	1250 (TEU)	0	1250 (TEU)	0					Total full container ships	526
Semi-container ship	Fuil Empty	27 (*1.000 TEU)	0	37 (*1.000 TEU)	0	200 (TEU)	o	200 (TEU)	0	135 50	0	185 0	0	Totat arrivals Total departures	320 50
	Containers	27 (*1.000 TEU)	0	37 (*1.000 TEU)	0	200 (TEU)	0	200 (TEU)	0					Total semi-container ships	370
Crude oil carrier	Full Empty	158783	o	o	o	175000	0	0	0	907 0	0 0	0 907	0 0	Total arrivals Total departures	907 907
	Crude oil	158783	0	0	0	175000	o	0	0					Total crude oil carriers	1815
Product carrier	Full Empty	17803	852	36296	38550	30000	3000	30000	5000	593 1210	284 7710	1210 593	7710 284	Total arrivals Total departures	9797 9797
·	Oilproducts	17803	852	36296	38550	30000	3000	30000	5000					Total product carriers	19595
Chemical tankers or other vessels with chemical	Full Empty	11457	2665	2050	2930	3000	1000	3000	1000	3819 683	2665 2930	683 3819	2930 2665	Total arrivals Total departures	10097 10097
products	Chemical products	11457	2665	2050	2930	3000	1000	3000	1000					Total chemical tankers	20195
Gas carrier	Full Empty	8032	278	715	3290	30000	2500	30000	2500	268 24	111 1316	24 268	1316 111	Total arrivals Total departures	1719 1719
	Gasses	8032	278	715	3290	30000	2500	30000	2500					Total gas carriers	3438
	Sub-totals	Total Ocean-going import 230083	Total Coastal import 14147	Total Ocean-going export 47053	Total Coastal export 53487					Total Ocean-going arrivals 11568	Total Coastal arrivals 19795	Total Ocean-going departures 11568	Total Coastal departures 19795	Total ship movements	62726
	Total	Total cargo excl. containers 344770 Container cargo 9141								Total ship- movements 62726					
		Total caroo													
	Grand-total	353911													

Table 4.9Assessment of the cargo flows and shipping traffic in 2020.



			NEV	V PORT	0 CFD	PORT		0KI
	Cereals	1589		0	-	682		
	Coals Iron ore	2436 0	,	0 51	ຕ າ	024 0	<u>0</u> 0	u o
	Other ores Natural sand	2759 1037		7623 480	~~~~	759 037	4 6	179 57
	Total	7821		3154	~~~~	502	15:	220
	Percentage	49		51		36	Φ	4
Nr. of bulk carriers		3816		3978	~	(133	8	2
	Rough wood	113		238		114	ē	00
	Percentage	32		68	*****	28		7
Nr. of log carriers		4		87	<u>.</u>	41		<u>6</u>
	Cement	2903		590		2903	1	95
	Percentage	83		17	annan canad			2
Nr. of cement ships		320		<u>65</u>		311		82
	Vehicles	6797		0		5124		
	Percentage	100		0		100		0
Nr. of car carriers		1001		01		917		01
	Refrigerated goods	800	<u></u>	597		623		74
	Percentage	57		43	a a statistic and a statistic a	45		55
vr. of refrigerator ships		248		185		249		9
	Wooden articles	777		1631		777	5	56
	Iron scrap Iron materials Other	0 4665 5169		0 2680 3856		0 4665 5090	~~~~	0 569 558
	Total	10611	<u></u>	8167		1532		283
	Percentage	57		43		46		54
, of general cargo ships		3974		3059		4051	41	<u>667</u>
	Containers	o		394		٥		83
	Percentage	o		100	<u></u> 9	0		00
r. of full container ships		01		456		01	471	26
	Containers	o		44		0		65
	Percentage	0		100		0		00
of semi-container ships		01		250		01		2
	Crude oil	62370		71391		32370	6	3413
	Percentage	47		53		39		61
Vr. of crude oil carriers		713		816		713	-1	102
	Oilproducts	50949		19202		59128	ന്	1373
	Percentage	73		27	****	63		37
Nr. of product carriers		11030		4157		12391		203
	Chemical products	8198	<u> </u>	6116		8523	-	0579
	Percentage	57		43		45		55
Nr. of chemical tankers		7072		<u>5276</u>		9011	-1	1184
	Gasses	7073		2665		7543		1772
	Percentage	73		27	erronan di kilo jarka	61		39
Nr. of gas carriers		1969		742		2106		332
al cargo volume (1000 ton) e	excl. containers	157635		117120		167362		7409
					-			

5. ASSESSMENT OF THE FUTURE SHIP MOVEMENTS.

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Table 5.2Assessed future ship movements for the old and new port.



			0044			T		0000		
		·····	2011					2020		
	Annual	Annual	Number	Typical	Quay	Annual	Annual	Number	Typical	Quay
	"berth	cargo	of berths	vessel	length	"berth	cargo	of berths	vessel	length
	capacity''	volume				capacity"	volume			
COMMODITY	(1,000 tons)	(1,000 tons)		(DWT)	(m)	(1,000 tons)	(1,000 tons)		(DWT)	(m)
	0.500	707/			045	0050	1.000			
Ores (iron + others)	2500	/6/4	3	30000	615	2850	14238	5	30000	1025
Sand	245	480	2	· 2000	180	317	957	3	2000	270
Rough wood	230	238	1	20000	195	300	300	1	20000	195
Cement	604	590	1	50000	240	1693	1695	1	50000	240
Refrigerated	201	597	3	20000	585	260	774	3	20000	585
Other general	640	3856	6	20000	1170	760	7558	10	20000	1950
Lumber (wooden articles)	821	1631	2	20000	390	684	2056	4	20000	780
Iron materials	1359	2680	2	20000	390	1225	3669	3	20000	585
Containers (*1,000 TEU)	145	438	3	20000	675	216	648	3	20000	675
Total dry cargo quays			23					33	-	
Chemical liquids	23940	6116	2	30000		32130	10579	3	30000	
Oil products	4334	19202	3	50000		4939	34373	4	50000	
Crude oil	6350	71391	3	325000		8554	96413	3	325000	
Gas	2635	2665	1	125000 (m3)		2416	4772	2	125000 (m3)	
		447550			4440		170000			
IOTAL	exci. containers:	11/558	32		4440	exci. containers:	178032	45		6305
	container cargo				excl. liquid	container cargo				excl. liquid
	(1,000 tons)	6096			berths	(1,000 tons)	9141			berths
	Total cargo	123654				Total cargo	187173			

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 Table 6.7.1
 Assessment of the number of berths and quay length per commodity, according to [4].

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			2011	igner mit fill date statistication of the	***			2020	to an	
	Annual	Annual	Number	Typical	Quav	Annual	Annual	Number	Typical	Quay
	"berth	cargo	of berths	vessel	length	"berth	cargo	of berths	vessel	length
	capacity"	volume			ľ	capacity"	volume			longar
COMMODITY	(1,000 tons)	(1,000 tons)		(DWT)	(m)	(1,000 tons)	(1,000 tons)		(DWT)	(m)
	0500	7074	0	00000	0.15	0.050		_		
Ores (Iron + others)	2500	/6/4	3	30000	615	2850	14238	5	30000	1025
Sand	245	480	2	2000	180	317	957	3	2000	270
Rough wood	230	238	1	20000	195	300	300	1	20000	195
Cement	604	590	1	50000	240	1693	1695	1	50000	240
Refrigerated	201	597	3	20000	585	260	774	3	20000	585
Other general	622	2500	4	20000	780	622	2500	4	20000	780
Lumber (wooden articles)	821	1631	2	20000	390	684	2056	4	20000	780
Iron materials	1359	2680	2	20000	390	1225	3669	3	20000	585
Containers (*1,000 TEU)	134	535	4	20000	900	202	1006	5	20000	1125
Total dry cargo quays			22					29		
Chemical liquids	23940	6116	2	30000		32130	10579	4	30000	
Oil products	4334	19202	3	50000		4939	34373	3	50000	
Crude oil	6350	71391	3	325000		8554	96413	3	325000	
Gas	2635	2665	1	125000 (m3)		2416	4772	2	125000 (m3)	
ΤΟΤΑΙ	excl containers:	116299	31		4275	evel containers:	173332	<u>/1</u>		5595
	container cargo				evel liquid	container cargo	110002	41		5565 eval lieuid
	(1,000 tons)	7452			berths	(1,000 tons)	14199			exci. ilquid berths
					L					
	Total cargo	123751				Total cargo	187531			

 Table 6.7.2
 Assessment of the number of berths and quay length per commodity, increased container traffic.

					ſ	Case 0						Case A0	1					Case A1	1				
	Primary criteria	Secondary criteria	Tertiary criteria	Norm v	alue	score	som ter	Sec	som sec.	prim.	som prim.	score	som tert.	sec	som sec.	prim.	som prim.	score	som tert.	sec	som sec.	prim.	som prim
	1. Costs	a. Dredging b. Breakwaters c. Reclamation/fill d. Removal of old structures	1. Soft soil 2. Hard rock	40 30 25 20 10	20 80 100 100 100	5 5 5 5 5 5 5	500 500 500 500	15000 12500 10000 5000				5 5 5 3 5	500 500 300 500	15000 12500 6000 5000				1 1 2 3 1	100 200 300 100	3000 5000 6000 1000			
Sum sec. crit. Sum prim. crit.		f. Removal of land		5	100	5	500 500	2500	50000	2000000		3	300	1500	42000	1680000		4	400	2000	18000	720000	
	2. Port technology	a. Nautical and hydraulic criteria b. Flexibility	General location of the approach route(s) Stopping length inside the port's breakwaters Manoeuvring space in the port Overall nautical safety Wave penetration in the port Wave action in front of the port Possibility of extension of the port Possibility of extension routed comparements	35 25 20	5 20 15 25 20 15 5 60	5 5 5 5 5 5 5	500	12500				2 1 1 1 1 1 4	105	2625			-	3 5 3 5 2 2 2 2	355	8875			
Sum sec. crit. Sum prim. crit.		c. Passive safety d. Layout e. Building time	 Possibility of uncludial rearrangements Possibility to cope with occurring disasters 	30 10 15	40 55 45 100 100	5 5 5 5 5	500 500 500	15000 5000 7500	50000	1750000		1 4 1 5	235 100 500	7050 1000 7500	23775	832125		3 2 3 4 2	240 245 400 200	4800 7350 4000 3000	28025	980875	
Sum sec. crit. Sum prim. crit.	3. Physical plannin	g		15 100	100	5	500	50000	50000	750000		4	400		40000	600000		4	400		40000	600000	
Sum sec. crit. Sum prim. crit. TOTAL SCORE	4. Morphology			10 100	100	5	500	50000	50000	500000	5000000	1	100		10000	100000	3212125	3	300		30000	300000	2600875

					Case B	1					Case C	1					Case D	1				
	Primary criteria	Secondary criteria	Tertiary criteria	Norm value	score	som tert	sec	som sec.	prim.	som prim	. score	som tert.	Sec	som sec.	prim.	som prim	. score	som tert.	sec	som sec.	prim.	som prim
Sum sec. crit Sum prim. crit.	1. Costs	a. Dredging b. Breakwaters c. Reclamation/fill d. Removal of old structures e. Additional structures f. Removal of land	1. Soft soil 2. Hard rock	40 30 25 104 20 100 10 10 10 10 10 5 100	2 3 5 5 5 3 5 3 5 3 3 3	280 500 500 300 500 300	8400 12500 10000 3000 5000 1500	40400	1616000		2 1 2 5 2 3 2	120 200 500 200 300 200	3600 5000 10000 2000 3000 1000	24600	984000		3 2 1 1 3 5 3	220 100 100 300 500 300	6600 2500 2000 3000 5000 1500	20600	824000	
	2. Port technology	a. Nautical and hydraulic criteria b. Flexibility c. Passive safety d. Layout	 General location of the approach route(s) Stopping length inside the port's breakwaters Manoeuvring space in the port Overall nautical safety Wave penetration in the port Wave action in front of the port Possibility of extension of the port Possibility of functional rearrangements Possibility to cope with occurring disasters 	36 25 5 20 15 25 20 15 20 15 20 40 40 30 55 45 10 10 10	5 2 5 3 4 5 3 5 4 2 5	370 380 310 500	9250 7600 9300				5 4 3 4 2 3 2 2 3 2 2 2 2	335 200 255 200	8375 4000 7650 2000			2 	1 3 4 2 5 4 3 3 3 3 3	335 360 300 300	8375 7200 9000 3000			
Sum sec. crit. Sum prim. crit.				15 100	4	400	6000	37160	1300250		2	200	3000	25025	875875		1	100	1500	29075	1017625	
Sum sec. crit. Sum prim. crit.	3. Physical plannin	9		15 100 100	3	300		30000	450000		2	200		20000	300000		3	300		30000	450000	
Sum sec. crit. Sum prim. crit. TOTAL SCORE	4. Morphology			10 100 100	5	500		50000	500000	3866250	4	400		40000	400000	2559875	1	100		10000	100000	2391625

Table 10.5Multi-criteria analysis matrix.





Figure 11.1

Traffic flows to the different parts of Ulsan Port in the final layout.



Appendix A. Existing facilities.

			Length	Depth	Mooring Capa		Unloading	
	Wharf					Q'ty	Capa	Remark
	······		. (141)	(191)			1000ton)	
	Total		6,713		546,000	75	19 148	
			(4,207)	\	(1.663.000)		15,140	•
	Main Port	Total	5,643		446,000	61	15 109	
 			(3.099)		(873,000)	<u> </u>	10,100	
	Sum	1	5,643		446,000 -	43	15,109	
		-	(773)		(40,000) ?			
	Coa	l	270	12	40,000	1	1,512	Coal
	#1		149	8	5.000	1	298	Coal
					-,			Fertilizer
	#2		602	9.12	40,000,20,000,5,000	3	1.552	Raw Mat'l for Fert.
					.0,000 20,000 0,000		.,	Cement
	#3_		347	9	10,000×2	2	798	Liquid 🖌
	#4		322	11	20,000, 5,000	2	764	Feed
G	· · ·				20,000 0,000	-	104	Fert.
0	#5		220	11.5	20,000	1	561	Raw for paper
v	έß		750	13	30.000 × 3	3	1 872	General
e	U:.		100	10	30,000 × 3	5	1,017.	Container
r	Gener	al	799	8	5,000×2 1,000×6	8	1,490	General
n	Hyundai I	Dolphin	24	6	1,000	1	-	Barge, Boat
m	Changeser	Pier	108	วี				
e	Changseang	Hansung	60	c	1,000	1	-	Official Boat
n	μο	Со	υö	0				-
t	YK#2(gravi	ty type)	150	7.5	5,000	1		Petroleum
	Hanjin	Co.	190	7	5,000 1,000	2	-	Official Boat
	Yongja	m#1	143	7	3,000	1		Liquid
	Yongja	m#2	20	11	20,000	1		Liquid
	Yongja	m#3	100	7	3,000	1		Raw for Petro-Chem.
	Grai	n	185	13	50,000	1	3,024	Grain
	YKO	3	360	7.5	1,000 3,000 5,000	3		LPG
	Yeom	po	225	5	1,500×2	2	405	General
	Vehic	le	568	11.5	40,000×2	2	2,017	Vehicle
	Whaa	ım	816	7	4,0CƏ×6	6	816	Steel Prod.

	Wharf	Length (M)	Depth (M)	Berth Capa (DWT)	Q′ty	Unloading Capa (1000ton)	Remark
	Sum	(2,326)		(833,000)	18	· · · · · ·	
1	YK #2(pier type)	430	8	3,000×2 4,000 6,000	Ą	3,000	Petro.
	YK #3	130	12	35,000 _,	1.	4,000	Petro.
r	YK #4	-228	10	10,000 4,000×2	3,	3,500	Petro.
i	YK ≠5	798		2,000×2 4,000 5,000 10,000	5	2,600 2.000	Petro.
a	YK #6	347	15	70,000-	1	2000	Petro.
t	YK #7	370	15	70,000	1	2 000	Petro.
e	Dongyang Co.	23	6	1,000 .	1		Raw for Petro-Chem.
	YK Buoy(#1)	1	22	300,000	1	9,000,000	Crude
	YK Buoy(#2)	1	27	300,000	1		Crude
	Onsan Port ttl	860 (1.108)-	- Contraction - Statemark	80,000 (790.000)	13	3,535	-
	Sum	860 (270)		80,000 (40.000)	7	3,535	
G o	Onsan #1	210	11	20,000	1	1,210	(Kyong Ki Co.) Raw for feed
V	Onsan #2	210	11	20,000	1	806	(Lucky Co.) Ores
r	Onsan #3	230	12	20,000	1	847	(Korea Co.) Ores
n.	Onsan #4	210	11	20,000	1	672	(Halla Co.) Cement
	Ssangyong	270	12	20,000×2	2		Petro.
P	Sum	(838)		(750,000)	· 6		
r	Ssanyyong Buoy	1	27	260,000	1		Crude
li	PEDCO Buoy	1	27	300,000	1		Сгиде
v	Ssangvong #2	340	15.5	80,000 10,000	2	500,000	Crude
t	Jeongil Co.	178 -	11	20,000	1	2,500000	Raw for Petro-Chem.
e	Daehan Co. #1	320	12	50,000 30,000	2	11,000,000	Raw for Petro-Chem.
	Mipo Port						
G	ov. Hyundai co. port	210	9	20,000	1	504	Steel, Lumper, Others
	Total (incl. Liquid Bulk)	10,920		2,209.000	75		

Table A. 1 Berthing facilities for the Ulsan and Onsan Ports.







A-3

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Appendix B. Bathymetric data.



Figure B.1 Rock layer plan.



Figure B.2 Water depth plan.



Appendix C. Applying the queuing theory.

The calculation of the berth occupancies, berth capacities and average waiting times as used in table 6.2 is carried out here for the different kind of commodities. At first an assumption must be made concerning the maximum acceptable waiting times (as a percentage of the average service times) for the different commodities.

The dry bulk type commodities are thought to be allowed to have an average waiting time of 25%. The same 25% is applied for the neo bulk and general cargo type commodities. Container ships are allowed to sustain an average waiting time up to 10% of the average service time. This is due to the fact that the costs for shipping companies rise sharply when the large container ships can not be handled fast.

The ships carrying the liquid part of the cargo all have the restriction of an average waiting time being maximal 15% of the average service time. These values are all drawn in the following table:

Commodity	Acceptable average waiting time as
	percentage of the average service time
Other ores	25%
Sand	25%
Rough wood	25%
Cement	25%
Refrigerated goods	25%
Other general cargo (1)	- 25%
(2)	25%
Lumber	25%
Iron materials	25%
Containers (1) 10%
(2) 10%
Crude oil	15%
Chemical liquids	15%
Oil products	15%
Gasses	15%

Table C.1 Acceptable average waiting times for the different commodities.

It should be mentioned that the values in table C-1 are more or less arbitrarily chosen. The percentages are subjectively assessed from emperical data. Moreover, a maximum acceptable waiting time of 10% of the service time is no guarantee for a succesful port. This can be clearified by an example: in less developed countries, the service time for a general cargo ship might be 2 weeks or more. A waiting time of 7% seems attractive but in fact is 24 hours. Modern ports, with average service times of for instance 2 days, may in proportion have a waiting time of 50% (this is also 24 hours).

Other ores.

In table 6.1 the annual berth capacity is calculated as 1,152,000 tons/year/berth. The assumption is made that unloading these ores is done by one grab with a capacity of 600 tons/hour. This is a low value. Most likely these ships will be unloaded with two grabs (or more). Choose two 25 tons grab cranes, rated capacity 1,000 tons/hour, effective capacity 500 tons/hour. Two cranes per berth: total effective 0.8*2*500=800 tons/hour.



The average service time of the terminal can be determined by dividing the average cargo per call from tables 4.8 and 4.9 by the effective hourly unloading capacity: 30,000 tons/800 tons/hour = 37.5 hours. Assuming an (un)mooring time of 2.5 hours leads to a total quay time of 40 hours. This results in a net unloading capacity of 30,000 tons/40 hours = 750 tons/hour.

 p_{full} =16 hours*300 days*750 tons/hour=3,600,000 tons/year. t=7,623,000 tons/year ρ =7,623,000/3,600,000=2.12

As the ores are used as raw material for the heavy industries, the arrivals will be more or less predictable and not random, so the best system in this case is the $E_2/E_2/n$ system.

When applying the $E_2/E_2/n$ system:

Try 3 berths: The berth occupancy ψ =2.12/3=0.71 With table D.1 in Appendix D, the average waiting time becomes 0.25*average service time. This value can just be tolerated.

Annual capacity: 750 tons/hour*0.71*16 hours/day*300 days/year = 2,500,000 tons/year/berth

For 2020, the average cargo per call is increased to 35,000 tons, leading to a total berthing time of (35,000 tons/800 tons/hour) = 43.75 hour + 2.75 hour (un)mooring = 46.5 hour. The effective unloading capacity now becomes 35,000 tons/46.5 hours = 750 tons/hour, just as for 2011:

 p_{full} =3,600,000 tons/year For 2020 the tonnage increases to t=14,238,000 tons/year ρ =14,238,000/3,600,000=3.96

 $E_2/E_2/n$ system: Try number of berths n=5 The berth occupancy ψ =3.96/5=0.79 The average waiting time becomes 0.22*average service time This value is within the 25% limit.

Annual capacity: 750 tons/hour*0.79*16 hours/day*300 days/year ≈ 2,850,000 tons/year/berth

Sand.

The ships transporting sand are relative small ships of 5000 DWT maximum size. They are to be unloaded with one unloader, rated capacity 250 tons/hour, effective capacity 125 tons/hour. The average cargo per call for 2011 is 500 tons (table 4.8), resulting in an average service time of 500 tons/125 tons/hour = 4 hours. With an (un)mooring time of 30 minutes, the total quay time becomes 4.5 hours. This results in a total effective unloading capacity of 500 tons/4.5 hours \approx 110 tons/hour.

 p_{full} =16 hours*300 days*110 tons/hour=528,000 tons/year t = 480,000 tons/year ρ = 480,000/528,000=0.91

According to [2] the arrivals of sand carriers are rather homogeneous in time. This implies that the Erlang distribution fits better than the N.E.D.



Applying the $E_2/E_2/n$ system:

When trying one berth, the utilisation (berth occupancy) ψ =0.91/1=0.91

With table D.8 in Appendix D and with k=l=2, the average waiting time becomes more than 4.36*average service time. This is an unacceptable high value. To keep the waiting times under control, a second berth is necessary.

With two berths, the berth occupancy ψ =0.91/2=0.46. Using table D.1 in Appendix D results in an average waiting time of 0.09*average service time. This value is rather low for bulk cargo, but there is no proper alternative. The only other option is the tripling of p_{full} which is also a costly operation.

Annual capacity: 110 tons/hour*0.46*16 hours/day*300 days/year ≈ 245,000 tons/year/berth

For 2011 this value is sufficient. For the year 2020 the annual throughput is assumed to be 957,000 tons. In this case, the cargo handling capacity is too low. The average cargo per call is increased to 1,000 tons, resulting in a service time of 1,000 tons/125 tons/hour = 8 hours. The total berthing time becomes 8.5 hour when 0.5 hour (un)mooring time is included. The net unloading capacity equals 1,000 tons/8.5 hours = 120 tons/hour.

 p_{full} =16 hours*300 days*120 tons/hour=576,000 tons/year t=957,000 tons/year ρ =957,000/576,000=1.66

E₂/E₂/n system:

The number of berths n=2 The berth occupancy ψ =1.66/2=0.83 The average waiting time will be 1.18*average service time, which is an unacceptable value. With 3 berths The berth occupancy ψ =1.66/3=0.55 The average waiting time will be 0.08*average service time This again is a low value, but the two berth alternative can not be tolerated.

Annual capacity: 120 tons/hour*0.55*16 hours/day*300 days/year ~ 317,000 tons/year/berth

Rough wood.

This commodity cannot be found in [4], so an assumption must be made. The log carriers shipping this commodity are probably unloaded by two shipping cranes, with an effective capacity of 5 tons per cycle. Suppose a cycle takes 4 minutes, thus the capacity becomes 2*75=150 tons/hour. The service time of the log carrier becomes 5,500 tons/150 tons/hour = 36.7 hour. Assume 1.3 hours for the (un)mooring time results in a total quay time of 38 hours. The net effective capacity now becomes 5,500 tons/38 hours=145 tons/hour.

 $p_{\text{full}} = 16 \text{ hours*} 300 \text{ days*} 145 \text{ tons/hour} = 696,000 \text{ tons/year} \\ t = 238,000 \text{ tons/year} \\ \rho = 238,000/696,000 = 0.34$

According to [2] the arrivals of log carriers are rather homogeneous in time. This implies that the Erlang distribution fits better than the N.E.D.

When applying the $E_2/E_2/1$ system: The number of berths n=1 The berth occupancy ψ =0.34/1=0.34 With tables D.5 and D.6 in Appendix D the average waiting time is assessed to be 0.17*average service time. This is within the stated limits of 25%.



Annual capacity: 145 tons/hour*0.34*16 hours/day*300 days/year ≈ 237,000 tons/year/berth

For 2020 the average cargo per call equals the 2011 value, and the predicted tonnage is: t=300,000 tons/year ρ =300,000/696,000=0.43

Applying the $E_2/E_2/1$ system:

The berth occupancy ψ =0.43/1=0.43

With tables D.6 and D.7 in Appendix D the average waiting time W=0.28*average service time. Strictly this value is not allowed. When a second berth is built, the average waiting time drops to approximately 0.01*average service time. This value is extremely low and it is questionable if a second berth can efficiently be exploited. An alternative is a minor increase in the handling capacity of the quay equipment. This would result in a lower utilisation, and thus a smaller value for the waiting time. This alternative is applied here:

For an average waiting time of 0.25*average service time, the utilisation must be reduced to 0.41, leading to a p_{full} of 732,000 tons/year. This is an hourly increase of 7.5 tons.

Annual capacity: 152.5 tons/hour*0.41*16 hours/day*300 days/year ≈ 300,000 tons/year/berth

Cement.

Cement is imported at dedicated terminals. The unloading gear consists of two pneumatic vacuum unloaders, assuming a rated capacity of 1,000 tons/hour, effective capacity 500 tons/hour, total effective 2*0.8*500=800 tons/hour. The service time of a ship is assessed, using the average cargo per call from table 4.8: 20,000 tons/800 tons/hour = 25 hours. The total time at the berth, including 2 hours (un)mooring, amounts to 27 hours, reducing the total unloading capacity to 20,000 tons/27 hours = 740 tons/hour.

 p_{full} =16 hours*300 days*740 tons/hour=3,552,000 tons/year t=590,000 tons/year ρ =590,000/3,552,000=0.17

According to [2] the arrivals of cement carriers are rather homogeneous in time. This implies that the Erlang distribution fits better than the N.E.D.

When applying the $E_2/E_2/1$ system:

The number of berths n=1

The berth occupancy ψ =0.17/1=0.17 With the aid of tables D.3 and D.4 in Appendix D, the average waiting time becomes 0.05*average service time

Annual capacity: 740 tons/hour*0.17*16 hours/day*300 days/year ≈ 604,000 tons/year/berth

For 2011 this value is sufficient, as so many factors are estimated. For the year 2020 the annual throughput is assumed to be 1,695,000 tons. In this case, the cargo handling capacity seems to be too low. But by increasing the berth occupancy, the unloading capacity increases too:

```
t=1,695,000 tons/year
ρ=1,695,000/3,552,000=0.48
```

Applying the $E_2/E_2/1$ system: The number of berths n=1

The berth occupancy $\psi=0.48/1=0.48$

The average waiting time will be 0.36*average service time



This value is not acceptable. Increasing the handling capacity is one option. The berth occupancy then has to be lowered to 0.41, resulting in an increase in p_{full} of 582,000 tons/year. This means that a third crane must be procured. This is an expensive solution. The other option, being the construction of a second berth, is even more expensive. When possible, this option must be avoided. Therefore, it is assumed that when the capacity threatens to become insufficient, a third unloader is installed.

Annual capacity: 860 tons/hour*0.41*16 hours/day*300 days/year ~ 1,693,000 tons/year/berth

Refrigerated goods.

The unloading of refrigerated goods will be done with ship cranes and possibly with fork-lift trucks via side ports. Assume a cargo handling capacity of 800 tons/shift/ship [7]. The service time of the reefer is determined via table 4.8: 5,000 tons/100 tons/hour = 50 hour. With a 2 hour (un)mooring time, the total time at the quay becomes 52 hours. The net effective handling rate now becomes 5,000 tons/52 hours = 95 tons/hour. This means that:

 p_{full} =95 tons/hour*16 hours*300 days=456,000 tons/year. t=597,000 tons ρ =597,000/456,000=1.31

The arrivals of ships with refrigerated goods are almost random, according to the statistics mentioned in [2]. It should therefore be modelled with a negative exponential distribution. The service times are probably Erlang distributed.

An $M/E_2/n$ system will be the right system for refrigerated cargo:

Try the number of berths n = 3 (see figure D.2 in Appendix D)

The berth occupancy ψ =1.31/3=0.44

The average waiting time becomes 0.08^* average service time. This is a very low value. Applying 2 berths is not feasible, as the waiting times are much too high in this case (order 50% of the average service time $\Rightarrow 25$ hours).

Annual capacity: 95 tons/hour*0.44*16 hours/day*300 days/year ≈ 201,000 tons/year/berth

In 2020 the cargo flow will be increased to 774,000 tons/year. In this case $\rho\text{=}774,000/456,000\text{=}1.70$

Using the M/E₂/n system:

Try the number of berths n = 3

The berth occupancy ψ =1.70/3=0.57

The average waiting time becomes 0.18*average service time, which is well within the limit of 25% of the average service time.

Annual capacity: 95 tons/hour*0.57*16 hours/day*300 days/year ≈ 260,000 tons/year/berth

Other general cargo.

The indicated berth capacity in table 6.1 is a reasonable value for neo-bulk cargoes (unitised, palletised or pre-slung general cargo). For the years 2011 and 2020 it is expected that from all general cargo, a high percentage will be neo-bulk cargo.

Executing a calculation for the determination of the berth occupation, the cargo handling capacity is assessed to be 1500 ton/shift/ship = 187.5 tons/hour. This results in an average service time of (see also table 4.8) 5,000 tons/187.5 tons/hour = 26.7 hours.



The (un)mooring time of the general cargo ship will be in the order of 1 hour, leading to a total quay time of approximately 27.5 hours. The total net handling rate equals 5,000 tons/27.5 hours \approx 180 tons/hour. This produces:

 $p_{full}{=}180$ tons/hour*16 hours*300 days=864,000 tons/year t=3,856,000 tons $\rho{=}3,856,000/864,000{=}4.46$

The arrivals of general cargo ships are almost random, according to the statistics mentioned in [2]. It should therefore be modelled with a negative exponential distribution. The service times are probably Erlang distributed.

An $M/E_2/n$ system will be the right system for general cargo.

Try the number of berths n = 5The berth occupancy ψ =4.46/5=0.89 From table D.2 in Appendix D values have to be interpolated. Looking at the other values, it becomes clear that the waiting times will be too high when applying 5 berths. With the number of berths n = 6

The berth occupancy ψ =4.46/6=0.74

From table D.2 in Appendix D values still have to be interpolated. Looking at the other values, the waiting times will be in the order of 15-20% of the average service time.

Annual capacity: 180 tons/hour*0.74*16 hours/day*300 days/year ~ 639,000 tons/year/berth

Two scenarios are possible (see section 6.4) to describe the cargo flows in the future. The first is the predicted increase according to [4]. In this case: t=7,558,000 tons/year ρ =7,558,000/864,000=8.75

M/E₂/n system:

- Try the number of berths n = 10
- The berth occupancy ψ =8.75/10=0.88

When using the table D.2 in Appendix D, again interpolation is required, leading to an assessed average waiting time of 20-25% of the average service time. Ten berths are sufficient.

Annual capacity: 180 tons/hour*0.88*16 hours/day*300 days/year ~ 760,000 tons/year/berth

The second scenario is a decrease in general cargo, simultaneously increasing the amount of container cargo:

t=2,500,000 tons/year (both for 2011 and 2020) ρ =2,500,000/864,000=2.89

M/E₂/n system:

Try the number of berths n = 4

The berth occupancy ψ =2.89/4=0.72

The average waiting time after interpolation becomes approximately 27% of the average service time. This is slightly too high, but as many factors are somewhat arbitrarily chosen, this value is still allowed. If it really is a problem, the possibility to increase the handling rate remains an alternative.

Annual capacity: 180 tons/hour*0.72*16 hours/day*300 days/year ≈ 622,000 tons/year/berth



Lumber.

Lumber can be seen as a specialised sort of general cargo. As a large amount of lumber will be shipped, dedicated terminals can be built. The lumber is shipped in bundles, easy to handle at the quay. The lumber will be unloaded with 2 multi-purpose quay cranes per ship, with a rated capacity of 20 tons, effective capacity 10 tons in a cycle. Suppose a cycle takes 3 minutes, resulting in 200 tons/hour. The total effective capacity per berth will be 0.8*2*200 tons/hour=320 tons/hour. The service time can be determined with the aid of table 4.8 and is equal to 3,000 tons/320 tons/hour = 9.4 hours. Including with an (un)mooring time of approximately 1 hour, the total time at berth becomes 10.5 hours. The net handling rate now becomes 3,000 tons/10.5 hours \approx 285 tons/hour.

 p_{full} =285 tons/hour*16 hour*300 days=1,368,000 tons/year t=1,631,000 tons ρ =1,631,000/1,368,000=1.19

The arrivals of ships carrying lumber are more or less evenly divided over the months, according to the statistics mentioned in [2]. The arrivals should therefore be modelled with the Erlang distribution. This applies for the service times too, as the ships will deliver approximately the same amounts every time.

The $E_2/E_2/n$ system is applied:

Choose the number of berths n=2 The berth occupancy ψ =1.19/2=0.60 The average waiting time becomes 0.22*average service time This is sufficient.

Annual capacity: 285 tons/hour*0.60*16 hours/day*300 days/year ≈ 821,000 tons/year/berth

For 2020 the predicted tonnage is: t=2,056,000 tons/year ρ =2,056,000/1,368,000=1.5

Applying the E₂/E₂/n: Try the number of berths n=2 The berth occupancy ψ =1.5/2=0.75 The average waiting time now is 0.62*average service time This value is not allowed, as the average waiting time may not exceed 25% of the average service time.

With the number of berths n=3 The berth occupancy ψ =1.5/3=0.5 The average waiting time will be 0.05*average service time This is well within the stated limits.

Annual capacity: 285 tons/hour*0.5*16 hours/day*300 days/year = 684,000 tons/year/berth

Iron materials.

Iron materials are, just as lumber, a special sort of general cargo. The vast amount of steel products requires the use of dedicated terminals. The (un)loading of the cargo will probably be done with heavy quay cranes, as this is a fast method and the products are bundled or massive units. Suppose the cranes are multi purpose cranes with a lifting capacity of 40 tons, effective 20 tons. Suppose a cycle time of 3 minutes, the effective capacity per hour will be 400 tons/hour.



If the cargo handling is done by two cranes the total effective crane capacity is 0.8*2*400 tons/hour=640 tons/hour. The average service time becomes 5,000 tons/640 tons/hour = 7.8 hours. The total time at the berth, including 1.2 hour of (un)mooring, amounts 9 hours. The net cargo handling rate equals 5,000 tons/9 hours=555 tons/hour. This leads to:

 p_{full} =16 hours*300 days*555 tons/hour =2,664,000 tons/year. t=2,680,000 tons/year ρ =2,680,000/2,664,000=1.01

As can be seen in [2] the arrivals are rather constant. This can be explained by the fact that the major part of these iron materials consists of semi-finished articles for the steel industry and ship building industry. An Erlang distribution is the suitable distribution for this system. The import of products is very stable, so an Erlang distribution for the service time could be used.

Applying the $E_2/E_2/n$ system yields:

Choose the number of berths n=2 The berth occupancy ψ =1.01/2=0.51 The average waiting time becomes 0.13*average service time This is an acceptable value.

Annual capacity: 555 tons/hour*0.51*16 hours/day*300 days/year ≈ 1,359,000 tons/year/berth

For the year 2020 the prediction yields: t=3,669,000 ρ =3,669,000/2,664,000=1.38

Applying the $E_2/E_2/n$ system yields:

Try the number of berths n=2

The berth occupancy ψ =1.38/2=0.69

The average waiting time becomes 0.39*average service time. This value is not acceptable. With n=3 berths:

The berth occupancy ψ =1.38/3=0.46

The average waiting time becomes 0.04*average service time. This is a very low value, but unavoidable as two berths are not acceptable.

Annual capacity: 555 tons/hour*0.46*16 hours/day*300 days/year = 1,225,000 tons/year/berth

Containers.

Assume 25 TEU's per hour per crane can be handled, with an average cargo of 14 ton/TEU yielding 350 tons/hour. Assume 2 cranes per ship, resulting in 50 TEU/hour. The average cargo per call for 2011 amounts 1,000 TEU. This means a service time of 1,000 TEU/50 TEU/hour = 20 hours. Including an (un)mooring time of 1.5 hour, the total time at berth becomes 21.5 hours. The net handling rate becomes 1,000 TEU/21.5 hours \approx 45 TEU/hour = 630 tons/hour.

 p_{full} =630 tons/hour*16 hours*300 days=3,024,000 tons/year. t=6,096,000 tons ρ =6,096,000/3,024,000=2.02

The arrivals of container ships are rather constant, as the container ships sail with a stringent schedule. It should therefore be modelled with an Erlang distribution. The service times can be modelled with an Erlang distribution.



 $E_2/E_2/n$ system:

With the number of berths n=4 The berth occupancy ψ =2.02/4=0.51 The average waiting time W=0.05*average service time This is well within the stated limits.

Annual capacity: 3,024,000 tons/year*0.51=1,542,000 tons/year/berth=110,000 TEU/year/berth

For 2011 and 2020 two scenarios are possible (see section 6.4). The first is the predicted increase according to [4], for 2020 leading to an annual throughput of 9,141,000 tons/year (648,000 TEU). The average cargo per call is thought to increase for 2020 to 1,250 TEU (see table 4.8). This increases the service time to 1,250 TEU/50 TEU/hour = 25 hour. This value is not acceptable as container ships must be handled within 24 hours. A third crane must be brought into service, increasing the capacity to 75 TEU/hour and reducing the service time to 1,250 TEU/75 TEU/hour = 16,7 hours. The total berthing time becomes approximately 18 hours. The net handling rate now becomes 1,250 tons/18 hours \approx 70 TEU/hour = 1,050 tons/hour. The preceding leads to:

 p_{full} =1,050 tons/hour*16 hours*300 days=5,040,000 tons/year t=9,141,000 tons/year ρ =9,141,000/5,040,000=1.81

 $E_2/E_2/n$ system:

Try the number of berths n=3

The berth occupancy ψ =1.81/3=0.60

The average waiting time W=0.11*average service time

This is so close to the maximum value of 10%, that it is taken as allowable.

Annual capacity: 5,040,000 tons/year*0.60=3,024,000 tons/year/berth=216,000 TEU/year/berth

When comparing the number of berths for 2011 and 2020, a striking thing occurs: the handled amount of cargo increases with more than 200,000 TEU's, but the quay length can be reduced with a quarter. Of course this is due to the commisioning of the third crane per berth. It will be much more economical to purchase one ore two cranes earlier than required according to the preceeding calculation, to avoid the necessity of four berths in 2011. The early procurement of a quay crane is a large investment, but the construction of 225 metres of container quay that will be demobilised ten years later is a waste of money.

It is therefore assumed that the terminal operator decides to an early third crane procurement and that in 2011 only three berths are necessary. Calculation:

25 TEU's per hour per crane, average cargo of 14 ton/TEU yielding 350 tons/hour.

3 cranes per ship = 75 TEU/hour. The average cargo per call for 2011 amounts 1,000 TEU.

Service time is [1,000 TEU]/[75 TEU/hour] \approx 13.5 hours. Including an (un)mooring time of 1.5 hour, the total time at berth becomes 15 hours. The net handling rate becomes 1,000 TEU/15 hours \approx 67 TEU/hour \approx 935 tons/hour.

 p_{full} =935 tons/hour*16 hours*300 days=4,488,000 tons/year. t=6,096,000 tons ρ =6,096,000/4,488,000=1.36

 $E_2/E_2/n$ system: Try the number of berths n=3 The berth occupancy ψ =1.36/3=0.45 The average waiting time W=0.04*average service time

Annual capacity: 4,488,000 tons/year*0.45=2,020,000 tons/year/berth=145,000 TEU/year/berth



The second scenario is a decrease in general cargo, simultaneously increasing the amount of container cargo:

2011: t=7,452,000 tons/year ρ=7,452,000/3,024,000=2.46

 $E_2/E_2/n$ system:

Try the number of berths n=4

The berth occupancy ψ =2.46/4=0.62

The average waiting time is 0.08*average service time. This is an acceptable value, as 0.10*average service time is the maximum value.

Annual capacity: 3,024,000 tons/year*0.62≈1,875,000 tons/year/berth≈134,000 TEU/year/berth

2020: t=14,199,000 tons/year c=14,199,000/5,040,000=2.82

 $E_2/E_2/n$ system:

Try the number of berths n=4

The berth occupancy ψ =2.82/4=0.71

The average waiting time is 0.16*average service time. This is not an acceptable value, as 0.10*average service time is the maximum value.

With n=5 berths

The berth occupancy ψ =2.82/5=0.56

The average waiting time now becomes 0.03*average service time. This is an acceptable low value.

Annual capacity: 5,040,000 tons/year*0.56=2,822,000 tons/year/berth=202,000 TEU/year/berth

Crude oil.

The unloading capacity for crude is too low. A new SPM will have a capacity in the order of 20 million tons/year. The jetty type berths have larger unloading capacities; assuming 15,000 tons/hour capacity for the pumps, 24 hours a day working and 30% downtime (including shift changes). The average service time is, with the aid of table 4.8: 175,000 tons/(0.7*15,000) tons/hour = 16.7 hours. With an (un)mooring time of 3.3 hours, the total time the jetty is occupied equals 20 hours. The net effective hourly unloading capacity becomes 175,000 tons/20 hours = 8,750 tons/hour.

 p_{full} =24 hours*300 days*8,750 tons/hour=63,000,000 tons/year. t=71,391,000 tons/year ρ =71,391,000/63,000,000=1.13

As the crude oil serves as raw material for the refineries, it should be supplied with a constant flow, to keep the storage tanks full. The service time is certainly not random as large crude oil carriers mostly sail fully loaded and thus call at port with an almost constant amount of cargo. It is likely then, that the queuing system can be modelled as an $E_2/E_2/n$ system.



Applying the $E_2/E_2/n$ system:

Try the number of berths n=2

The berth occupancy ψ =1.13/2=0.57

The average waiting time becomes 0.19*average service time

Two berths are not satisfactory.

Try the number of berths n=3

The berth occupancy ψ =1.13/3=0.38

The average waiting time becomes 0.02*average service time. This is extremely low, but satisfactory.

Annual capacity: 8,750 tons/hour*0.38*24 hours/day*300 days/year=23,940,000 tons/year/berth

In 2020 the annual throughput will be increased: t=96,413,000 tons ρ =96,413,000/63,000,000=1.53

 $E_2/E_2/n$ system:

Try the number of berths n=3 The berth occupancy ψ =1.53/3=0.51 The average waiting time becomes 0.06*average service time This is well within the admissible 15% of the average service time.

Annual capacity: 8,750 tons/hour*0.51*24 hours/day*300 days/year=32,130,000 tons/year/berth

With only three berths, a problem might occur. The fact is that Yukong needs at least two crude oil import facilities to cater for the huge oil supply they receive. Two berths will probably be sufficient to compensate for the three existing SPM's, although this is no certainty because the future cargo flows to the separate refineries are not known.

When two jetties are already in use by Yukong, only one jetty is left for the KEPCO and Ssangyong refineries. It is unlikely that these companies agree on a joint use of the jetty. When a VLCC is unloading oil to the KEPCO refinery and a tanker with crude oil for the Ssangyong refinery must wait for several hours, the latter company will be far from happy.

On the other hand, building a crude oil import jetty for ships of 325,000 DWT, with oil transport facilities and the like, is very expensive. When the waiting times are not excessive and the unloading capacity is sufficient, the companies might come to agreement about a joint use.

To be sure, the assumption of four jetties is made. These jetties have to be ready in 2011, because they have to facilitate the refineries in that year.

Chemical liquids.

Chemical liquids are generally shipped with parcel tankers (6,500 - 16,000 DWT). These ships have a central manifold and (un)load with onboard pumps. The capacity of these pumps is much smaller than those of the large crude oil carriers: say 2,000 tons/hour. Assuming 24 hours a day working and 30% downtime (including shift changes) leads to an hourly production of 1,400 tons/hour. The average service time can be determined with the aid of table 4.8: 3,000 tons/1,400 tons/hour = 2.1 hours. With an (un)mooring time of approximately 0.9 hours, the net effective handling capacity becomes 3,000 tons/3 hours = 1,000 tons/hour.

 p_{full} =24 hours*300 days*1,000 tons/hour=7,200,000 tons/year. t=6,116,000 tons/year ρ =6,116,000/7,200,000=0.85

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As the chemicals serve as raw material for the industries, it should be supplied with a constant flow. The service time is certainly not random as can be seen in [2]. It is likely then, that the queuing system can be modelled as an $E_2/E_2/n$ system.

When applying the $E_2/E_2/n$ system:

Try the number of berths n=2 The berth occupancy ψ =0.85/2=0.43 The average waiting time becomes 0.08*average service time Two berths are satisfactory.

Annual capacity:1,400 tons/hour*0.43*24 hours/day*300 days/year ~ 4,334,000 tons/year/berth

In 2020 the annual throughput will be increased: t=10,579,000 tons $\rho=10,579,000/7,200,000=1,47$

 $E_2/E_2/n$ system:

The number of berths n=3

The berth occupancy ψ =1.47/3=0.49

The average waiting time becomes 0.05*average service time

Three berths are satisfactory. The application of only two berths leads to an unacceptable waiting time of 0.58*average service time.

Annual capacity: 1,400 tons/hour*0.49*24 hours/day*300 days/year ~ 4,939,000 tons/year/berth

Oil products.

Oil products are refined liquids and are shipped with product tankers, ranging to 40.000 DWT. The pumps of product tankers have an average capacity of approximately 3,000 tons/hour. Assuming 24 hours a day working and 30% downtime (including shift changes) results in an effective capacity of 2,100 tons/hour. With table 4.8 the average service time is calculated: 30,000 tons/2,100 tons/hour = 14,3 hour. Including an (un)mooring time of approximately 2.2 hours leads to an net effective handling capacity of 30,000 tons/16.5 hours \approx 1,800 tons/hour.

 p_{full} =24 hours*300 days*1,800 tons/hour=12,960,000 tons/year. t=19,202,000 tons/year ρ =19,202,000/12,960,000=1.48

The arrivals and service times are certainly not random as can be seen in [2]. It is likely then, that the queuing system can be modelled as an $E_2/E_2/n$ system.

When applying the $E_2/E_2/n$ system:

Try the number of berths n=3 The berth occupancy ψ =1.48/3=0.49 The average waiting time becomes 0.05*average service time Three berths are satisfactory, with the average waiting time well within the limit of 15% of the average service time. With only two berths, the average waiting time would be much too long and can not be accepted.

Annual capacity: 1,800 tons/hour*0.49*24 hours/day*300 days/year ~ 6,350,000 tons/year/berth

In 2020 the annual throughput will be increased: t=34,373,000 tons ρ =34,373,000/12,960,000=2.65



 $E_2/E_2/n$ system:

Try the number of berths n=4 The berth occupancy ψ =2.65/4=0.66 The average waiting time becomes 0.11*average service time Four berths are satisfactory.

Annual capacity: 1,800 tons/hour*0.66*24 hours/day*300 days/year ≈ 8,554,000 tons/year/berth

The same principle as with the crude oil facility holds for the oil product facilities: jetties are mostly privately owned and therefore are not used by multiple refineries. The four jetties, necessary in 2020 must thus be divided in 2 for Yukong and KEPCO and Ssangyong one each. It will be necessary to achieve this development in 2011 already, for reasons mentioned in the crude oil jetty assessment.

Gasses.

As gas carriers always have to sail fully loaded, the average import is almost constant, this can be verified in [2]. The arrivals are also not random. With this in mind, the appropriate system will be the $E_2/E_2/n$ system.

The unloading will be done with the pumps of the ships. The capacity of these pumps is assumed to be 2,500 tons/hour. This has come about by assuming that the ships are significantly large, but the specific weight of the gasses is rather low.

Assuming 24 hours a day working and 30% downtime (including shift changes) results in an effective capacity of 1,750 tons/hour. The average service time becomes, with table 4.8, 30,000 tons/1,750 = 17.1 hours. Including 2.4 hours of (un)mooring time leads to a net handling capacity of 30,000 tons/19.5 hours \approx 1,525 tons/hour.

 $p_{\text{full}}{=}24$ hours*300 days*1,525 tons/hour=10,980,000 tons/year. t=2,665,000 tons/year $\rho{=}2,665,000/10,980,000{=}0.24$

When applying the $E_2/E_2/1$ system:

Try the number of berths n=1 The berth occupancy ψ =0.24/1=0.24 With tables D.4 and D.5 the average waiting time becomes 0.09*average service time One berth is satisfactory.

Annual capacity: 1,525 tons/hour*0.24*24 hours/day*300 days/year ≈ 2,635,000 tons/year/berth

In 2020 the annual throughput will be increased: t=4,772,000 tons ρ =4,772,000/10,980,000=0.43

 $E_2/E_2/n$ system:

Try the number of berths n=1 The berth occupancy ψ =0.43/1=0.43 The average waiting time becomes 0.28*average service time (with tables D.6 and D.7) One berth is not satisfactory. With the number of berths n=2 The berth occupancy ψ =0.43/2=0.22 The average waiting time becomes 0.07*average service time (with table D.2) Two berths are required.

Annual capacity: 1,525 tons/hour*0.22*24 hours/day*300days/year ≈ 2,416,000 tons/year/berth

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Appendix D. Queuing theory tables.

			<u></u>	Numb	er of Serve	ers (n)			
Utilization (u)	2	3	4	5	6	7	8	9	10
0.1	0.0006	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.2	0.0065	0.0011	0.0002	0.000	0.0000	0.0000	0.0000	0.0000	6.0000
0.3	0.0235	0.0062	0.0019	0.0007	0.0002	0.0001	0.0000	0.0000	0.0000
0.4	0.0576	0.0205	0.0085	0.0039	0.0019	0,0009	0.0005	0.0003	0.0001
0.5	0.1181	0.0512	0.0532	0.0142	0.0082	0.0050	0.0031	0.0020	0.0013
0.6	0.2222	0.1103	0.0639	0.0400	0.0265	0.0182	0.0128	0.0093	0.0069
0.7	0.4125	0.2275	0.1441	0.0968	0.0712	0.0532	0.0407	0.0319	0.0258
0.8*	0.83	0.46	0,33	0.23	0.19	0.14	0.12	0.09	0.09
0. 9 *	2.0	1.20	0.92	0.65	0.57	0.44	0.40	0.32	0.30

AVERAGE WAITING TIME OF CUSTOMERS IN THE QUEUE E2/E/n (IN UNITS OF AVERAGE SERVICE TIME)

Table D.1 Average waiting time for the $E_2/E_2/n$ system.

0

Average waiting time of ships in the queue M/E₁/n (In units of average service time)

A: FOR 1 TO 15 BERTHING POINTS

]	Number	of bertl	ning poir	nts					
Utilizat	ion	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.10		.06	.01	0	0	0	0	0	0	0	0	0	0	0	0	0
0.15		.13	.02	0	0	0	0	0	0	0	0	0	0	0	0	0
0.20		.19	.03	.01	0	0	0	0	0	0	0	0	0	0	0	0
0.25		.25	.05	.02	0	0	0	0	0	0	0	0	0	0	. 0	0
0.30		.32	.06	.03	.01	0	0	0	0	0	0	0	0	0	0	0
0.35		.40	.11	.04	.02	.01	0	0	0	0	0	0	0	0	0	0
0.40		.50	.15	.06	.03	.02	.01	.01	0	0	0	0	0	0	0	0
0.45		.60	.20	.08	.05	.03	.02	.01	0	0	0	0	0	0	0	0
0.50		.75	.26	.12	.07	.04	.03	.02	.01	.01	.01	. 0	0	0	0	0
0.55		.91	.33	.16	.10	.06	.04	.03	.02	.02	.01	.01	.01	0	0	0

						D. POR		JUDEN	(THING	10111						
		Number of berthing points														
Utilizat	ion	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
0.50		0	0	0	0	0	0	0	< 0	0	0	0	0	0	0	0
0.55	•••••	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.60		.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.65	•••••	.01	.01	.01	.01	.01	.01	0	0	0	0	0	0	0	0	0
0.70		.02	.02	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	0	0	0
0.75	•••••	.04	.04	.03	.03	.03	.02	.02	.02	.02	.02	.02	.01	.01	.01	
0.80		.07	.07	.06	.05	.05	.04	.04	.04	.03	.03	.03	.03	.03	.03	
0.85		.14	.13	.12	.11	.10	.09	.09	.08	.07	.07	.06	.06	.06	.05	
0.90		.28	.26	.24	.22	.21	.19	.18	.17	.16	.15	.14	.14	.13	.12	
0.95		.74	.69	.65	.61	.58	.55	.51	.49	.46	.43	.41	.40	.38	.37	

B: FOR 16 TO 30 BERTHING POINTS

Table D.2 Average waiting time for the $M/E_2/n$ system.



-	Value of 1 for the Erlang Service Distribution = $1/v$,										
$v_a = 1/k$			3	4	5	6	7.		. 9.	10	
0.1	0.0010	0.0001	0.0001	0.0004	0.0007	0.0012	0.0018	0.0025	0.0033	0.0040	
0.2	0.0042	0.0010	0.0004	0.0003	0.0033	0.0002	0.0006	0.0015	0.0076	0.0093	
0.3	0.0102	0.0038	0.0023	0.0017	0.0014	0.0012	0.0011	0.0010	0.0010	0.0009	
0.4	0.0189	0.0090	0.0064	0.0052	0.0046	0.0042	0.003*	0.0037	0.0035	0.0034	
0.5	0.0301	0.0166	0.0128	0.0110	0.0100	0.0093	0.00??	0.0085	0.0082	0.0080	
0.6	0.0433	0.0265	0.0214	0.0190	0.0176	0.0167	0.01???	0.0155	0.0151	0.0148	
0.7	0.0582	0.0384	0.0321	0.0291	0.0273	0.0261	0.02??	0.0247	0.0242	0.0238	
0.8	0.0747	0.0520	0.0446	0.0410	0.0389	0.0374	0.03??	0.0357	0.0351	0.0346	
0.9	0.0924	0.0670	0.0587	0.0545	0.0521	0.0504	0.0492	0.0484	0.0477	0.0471	
1.0	0.1111	0.0833	0.0741	0.0694	0.0667	0.0648	0.0639	0.0625	0.0617	0.0611	

AVERAGE WAITING OF CUSTOMERS IN UNITS OF AVERAGE SERVICE TIME, FOR THE SINGLE SERVER QUEUE $E_x/E_y/I$ WITH UTILISATION u = 0.1

Table D.3	Average waiting time for the $E_2/E_2/1$ system for a berth occupancy of 0.1.
Table D.3	Average waiting time for the $E_2/E_2/1$ system for a berth occupancy of 0.1

					u = 0.2							
	Value of 1 for the Erlang Service Distribution = $1/v$,											
$v_{\rm s} = 1/k$	1	2	3	4	5	6	7	8	9	10		
0.1	0.0188	0.0035	0.0013	0.0006	0.0003	0.0002	0.0040	0.0098	0.0109	0.0051		
0.2	0.0353	0.0116	0.0064	0.0044	0.0033	0.0027	0.0024	0.0021	0.0019	0.0017		
0.3	0.0554	0.0243	0.0162	0.0127	0.0107	0.0095	0.0087	0.0081	0.0076	0.0073		
0.4	0.0783	0.0408	0.0301	0.0252	0.0223	0.0205	0.0193	0.0183	0.0176	0.0171		
0.5	0.1035	0.0604	0.0474	0.0412	0.0376	0.0353	0.0336	0.0324	0.0315	0.0307		
0.6	0.1304	0.0825	0.0675	0.0602	0.0559	0.0531	0.0511	0.0497	0.0485	0.0476		
0.7	0.1588	0.1065	0.0898	0.0816	0.0767	0.0735	0.0712	0.0695	0.0682	0.0671		
0.8	0.1883	0.1322	0.1140	0.1049	0.0996	0.0960	0.0934	0.0915	0.0901	0.0889		
. 0.9	0.2187	0.1593	0.1397	0.1299	0.1241	0.1202	0.1174	0.1153	0.1137	0.1124		
1.0	0.2500	0.1875	0.1667	0.1563	0.1500	0.1458	0.1429	0.1406	0.1389	0.1375		

AVERAGE WAITING TIME, IN UNITS OF AVERAGE SERVICE TIME, FOR THE SINGLES SERVER QUEUE E. R.A. WITH UTILISATION

Table D.4Average waiting time for the $E_2/E_2/1$ system for a berth occupancy of 0.2.

	Value of 1 for the Erlang Service Distribution = $1/v$,											
$v_{\rm a} = 1/k$	1	2	3	4	5	6	7	8	9	10		
0.1	0.0714	0.0202	0.0093	0.0054	0.0035	0.0025	0.0019	0. 1	0.0053	0.0045		
0.2	0.1040	0.0415	0.0253	0.0184	0.0148	0.0125	0.0110	0. †	0.0091	0.0085		
0.3	0.1396	0.0679	0.0475	0.0382	0.0329	0.0296	0.0273	0. †	0.0243	0.0233		
0.4	0.1773	0.0980	0.0742	0.0629	0.0564	0.0522	0.0492	0. 1	0.0453	0.0440		
0.5	0.2166	0.1310	0.1043	0.0914	0.0839	0.0789	0.0755	0.0729	0.0708	0.0693		
0.6	0.2573	0.1661	0.1371	0.1229	0.1145	0.1090	0.1050	0.1021	0.0998	0.0980		
0.7	0.2990	0.2031	0.1720	0.1567	0.1476	0.1415	0.1372	0.1340	0.1315	0.1296		
0.8	0.3415	0.2414	0.2066	0.1923	0.1826	0.1761	0.1715	0.1681	0.1654	0.1633		
0.9	0.3848	0.2809	0.2416	0.2295	0.2192	0.2124	0.2075	0.2039	0.2010	0.1988		
1.0	0.4286	0.3214	0.2 1 7	0,2679	0.2571	0.2500	0.2449	0.2411	0.2381	0.2357		

u = 0.3

AVERAGE WAITING TIME, IN UNITS OF AVERAGE SERVICE TIME, FOR THE SINGLE SERVER QUEUE E, A, A WITH UTILISATION

Table D.5Average waiting time for the $E_2/E_2/1$ system for a berth occupancy of 0.3.

BC::::::::::::::::::::::::::::::::::::	Value of 1 for the Erlang Service Distribution = $1/v$,											
$v_{\rm a} = 1/k$	1	2	3	4	-5	6	7	8	9	10		
0.1	0.1679	0.0596	0.0320	0.0207	0.0149	0.0115	0.0093	0.0078	0.0067	0.0059		
0.2	0.2183	0.0979	0.0639	0.0485	0.0400	0.0346	0.0310	0.0283	0.0263	0.0148		
0.3	0.2707	0.1408	0.1018	0.0836	0.0731	0.0663	0.0615	0.0580	0.0554	0.0533		
0.4	0.3247	0.1869	0.1441	0.1236	0.1116	0.1037	0.0982	0.0941	0.0909	0.0884		
0.5	0.3799	0.2355	0.1896	0.1672	0.1541	0.1454	0.1392	0.1346	0.1311	0.1283		
0.6	0.4360	0.2859	0.2374	0.2136	0.1995	0.1901	0.1835	0.1785	0.1747	0.1716		
0.7	0.4929	0.3378	0.2872	0.2622	0.2472	0.2373	0.2303	0.2250	0.2209	0.2176		
0.8	0.5503	0.3909	0.3385	0.3124	0.2968	0.2864	0.2790	0.2735	0.2692	0.2657		
0.9	0,6083	0.4451	0.3909	0.3640	0.3478	0.3370	0.3293	0.3236	0.3191	0.3155		
1.0	0.6667	0.5000	0.4444	0.4167	0.4000	0.3889	0.3810	0.3750	0.3704	0.3667		

AVERAGE WAITING TIME, IN UNITS OF AVERAGE SERVICE TIME, FOR THE SINGLE SERVER QUEUE $E_{\pi}/E_{\pi}/1$ with utilisation u = 0.4

Table D.6Average waiting time for the $E_2/E_2/1$ system for a berth occupancy of 0.4.


		Val	ue of 1 f	or the Er	lang Serv	vice Dist	ribution =	= 1/v,	>	
$v_{\rm x} = 1/k$	1	2	3	4	5	6	7	8	9	10
0.1	0.3246	0.1326	0.0785	0.0545	0.0415	0.0336	0.0282	0.0245	0.0217	0.0195
0.2	0.3962	0.1924	0.1313	0.1029	0.0867	0.0763	0.0691	0.0638	0.0598	0.0566
0.3	0.4692	0,2559	0.1897	0.1581	0.1396	0.1276	0.1192	0.1129	0.1081	0.1043
0.4	0.5432	0.3221	0.2520	0.2150	0.1978	0.1846	0.1753	0,1683	0.1630	0.1587
0.5	0.6180	0.3904	0.3170	0.2810	0.2597	0.2456	0.2356	0,2281	0.2223	0.2177
0.6	0.6935	0.4602	0.3842	0.3467	0.3243	0.3095	0.2990	0,2911	0.2850	0.2801
0.7	0.7696	0.5313	0.4531	0.4142	0.3911	0.3756	0.3647	0.3564	0.3501	0.3450
0.8	0.8460	0.6034	0.5232	0.4833	0.4594	0.4435	0.4322	0,4237	0.4171	0.4118
0.9	0.9229	0.6764	0.5945	0.5537	0.5292	0.5129	0.5012	0.4925	0.4857	0.4803
1.0	1.0000	0.7500	0.6667	0.6250	0.6000	0.5833	0.5714	0.5625	0.5556	0.5500

AVERAGE WAITING TIME, IN UNITS OF AVERAGE SERVICE TIME, FOR THE SINGLE SERVER QUEUE E_{z} /E// WITH UTILISATION u = 0.5

Table D.7 Average waiting time for the $E_2/E_2/1$ system for a berth occupancy of 0.5.

	Value of 1 for the Erlang Service Distribution = $1/v$,									
$v_{\rm a} = 1/k$	1	2	3	4	5	6	7	8	9	10
0.1	4.6603	2.4602	1.7374	1.3800	1.1674	1.0266	0.9267	0.8522	0.7944	0.7484
0.2	5.1421	2.9330	2.2042	1.8424	1.6265	1.4831	1,3811	1.3047	1.2454	1.1981
0.3	5.6241	3.4072	2.6738	2.3089	2.0907	1.9456	1.8422	1.7647	1.7045	1.6564
0.4	6.1061	3.8827	3.1456	2.7783	2.5584	2.4120	2.3076	2.2294	2.1685	2.1199
0.5	6.5883	4.3590	3.6189	3.2497	3.0285	2.8811	2.7760	2.6972	2.6359	2.5869
0.6	7.0705	4.8362	4.0935	3.7227	3.5004	3.3523	3.2466	3.1674	3.1058	3.0565
0.7	7.5528	5.3139	4.5690	4.1969	3.9738	3.8251	3.7189	3.6393	3.5774	3.5279
0.8	8.0352	5.7922	5.0454	4.6722	4.4483	4.2991	4.1926	4.1327	4.0505	4.0008
0.9	8.5176	6.2709	5.5224	5.1482	4.9238	4.7741	4.6673	4.5871	4.5248	4.4750
1.0	9.0000	6.7500	6.0000	5.6250	5.4000	5.2500	5.1429	5.0625	5.0000	4.9500

AVERAGE WAITING TIME, IN UNITS OF AVERAGE SERVICE TIME, FOR THE SINGLE SERVER QUEUE $E_x/E_t/I$ WITH UTILISATION u = 0.9

Table D.8 Average waiting time for the $E_2/E_2/1$ system for a berth occupancy of 0.9.



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Appendix E. Calculation of the stacking areas.

The area assessment of the different container stacking areas is executed in this appendix. The results are printed in table 7.1.

The proportion of empties, related to containers who carry has been estimated with the use of [12]:

- The average amount of arriving empties is 20% of all arriving containers.
- The average amount of departing empties is 10% of all departing containers.

There are several formulae to assess the stacking areas, of which one is used below [7]:

$$O_{n} = \frac{C_{n} \cdot \overline{t_{d,n}} \cdot F_{n}}{r_{n} \cdot 365 \cdot m_{n}}$$

 O_n = required area per type of stack (m²) C_n = number of container movements per year per type of stack (TEU) $t_{d,n}$ = average dwell times per type of stack (days) F_n = required area per TEU incl. equipment travel space per type of stack (m²) r_n = (average stacking height/nominal stacking height) per type of stack m_n = average occupancy rate per type of stack

Import stack

t_{i,n} = 3 days

 $F_i = 10 \text{ m}^2$ (RTG, stacking maximum 4-high) $r_i = 0.65$ (port has a feeder status, so no massive stacking of large consignments) $m_i = 0.75$ (normal in the '80's: 0.6-0.7)

2011 438,000 TEU

C_i = 148,000 TEU

$$O_i = \frac{148,000 \cdot 3 \cdot 10}{0.65 \cdot 365 \cdot 0.75} = 25,000 \text{ m}^2$$

2011 535,000 TEU

Assuming that the ratio between import and export of containers does not change, the amount of imported containers becomes: 226,000 TEU, of which 20% is empty, so 181,000 TEU remains. $C_i = 181,000$ TEU

$$O_{i} = \frac{181,000 \cdot 3 \cdot 10}{0.65 \cdot 365 \cdot 0.75} = 30,000 \text{ m}^{2}$$



2020 648,000 TEU

The amount of arriving containers is 272,000 TEU (table 6)), and with 20% empties: $C_{\rm i}$ = 218,000 TEU

$$O_{i} = \frac{218,000 \cdot 3 \cdot 10}{0.65 \cdot 365 \cdot 0.75} = 37,000 \text{ m}^{2}$$

2020 1,006,000 TEU

Assuming that the ratio between import and export of containers does not change, the amount of imported containers becomes: 422,000 TEU, of which 20% is empty, so 338,000 TEU remains. $C_i = 338,000$ TEU

 $O_{i} = \frac{338,000 \cdot 3 \cdot 10}{0.65 \cdot 365 \cdot 0.75} = 57,000 \text{ m}^{2}$

Export stack.

 $\begin{array}{l} t_{e,n}=3 \mbox{ days} \\ F_e=10\ m^2 \mbox{ (RTG, stacking maximum 4-high)} \\ r_e=0.65 \mbox{ (port has a feeder status, so no massive stacking of large consignments)} \\ m_e=0.75 \mbox{ (normal in the '80's: 0.6-0.7)} \end{array}$

2011 438,000 TEU

 $C_{e} = 228,000 \text{ TEU}$

 $O_e = \frac{228,000 \cdot 3 \cdot 10}{0.65 \cdot 365 \cdot 0.75} = 39,000 \text{ m}^2$

<u>2011 535,000 TEU</u>

Assuming that the ratio between import and export of containers does not change, the amount of exported containers becomes: 309,000 TEU, of which 10% is empty, so 278,000 TEU remains. $C_e = 278,000$ TEU

 $O_e = \frac{278,000 \cdot 3 \cdot 10}{0.65 \cdot 365 \cdot 0.75} = 47,000 \text{ m}^2$

<u>2020 648,000 TEU</u>

The amount of export containers is 366,000 TEU (table 4.6), and with 10% empties: $C_e = 329,000$ TEU

$$O_{e} = \frac{329,000 \cdot 3 \cdot 10}{0.65 \cdot 365 \cdot 0.75} = 56,000 \text{ m}^{2}$$



<u>2020 1,006,000 TEU</u>

Assuming that the ratio between import and export of containers does not change, the amount of exported containers becomes 584,000 TEU, of which 10% is empty, so 526,000 TEU remains. $C_e = 526,000$ TEU

$$O_e = \frac{526,000 \cdot 3 \cdot 10}{0.65 \cdot 365 \cdot 0.75} = 89,000 \text{ m}^2$$

Empties stacking area.

For the empties, other parameter values must be applied. As stated earlier, the dwell time is 10 days. $F_{empty} = 25 \text{ m}^2$ as for the handling empties, large fork lift trucks can be used, capable of stacking 4 high $r_{empty} = 0.9$ (no connection between the containers, random stacking) $m_{empty} = 0.75$

<u>2011 438,000 TEU</u>

The amount of empties is 438,000 - full import - full export, $C_{empty} = 438,000 - 148,000 - 228,000 = 62,000 \text{ TEU}$

$$C_{empty} = \frac{62,000 \cdot 10 \cdot 25}{0.9 \cdot 365 \cdot 0.75} = 63,000 \text{ m}^2$$

2011 535,000 TEU

 $C_{empty} = 535,000 - 181,000 - 278,000 = 76,000 \text{ TEU}$

$$C_{empty} = \frac{76,000 \cdot 10 \cdot 25}{0.9 \cdot 365 \cdot 0.75} = 77,000 \text{ m}^2$$

2020 648,000 TEU

$$C_{empty} = 648,000 - 218,000 - 329,000 = 101,000 \text{ TEU}$$

$$C_{\text{empty}} = \frac{101,000 \cdot 10 \cdot 25}{0.9 \cdot 365 \cdot 0.75} = 102,000 \text{ m}^2$$

2020 1,006,000 TEU

 $C_{empty} = 1,006,000 - 338,000 - 526,000 = 142,000 \text{ TEU}$

$$C_{\text{empty}} = \frac{142,000 \cdot 10 \cdot 25}{0.9 \cdot 365 \cdot 0.75} = 148,000 \text{ m}^2$$



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Appendix F. Approach channel design.

WIDTH Wi	nnel to iter		Inner Channel protected water			
 (a) Vessel speed (knots) fast > 12 moderate > 8 - 12 slow 5 - 8 	0.1 B 0.0 0.0	0.1 B 0.0 0.0		.1 B 0.0 0.0		
(b) Prevailing cross wind (kno	ots)					
- mild ≤ 15 (≤ Beaufor	t 4)	all	0.0		0.0)
- moderate > 15 - 33 (> Beaufort 4 -	fast	0.3	B	-	~
Beaufort 7)		mod	0.4	В	0.4	8 9
- severe > 33 - 48 (> F	Seaufort 7 -	fast	0.6	B		a
Beaufort 9)		mod	0.8	B	0.8	B
		slow	1.0	В	1.0	в
(c) Prevailing cross current ()	(nots)					
- negligible < 0.2	,	all	0.0		0.0)
- low 0.2 - 0.5		fast	0.1	B	-	
		mod	0.2	В	0.1	B
moderate > 0.5 1.5		slow	0.3	В В	0.2	ង
- moresane - 0.0 - 1.5		mod	0.5	B	0.5	в
		slow	1.0	B	0.8	B
- strong > 1.5 - 2.0		fast	0.7	B	-	
		mod	1.0	В	-	
		slow	1.3	B	-	
(d) Prevailing longitudinal cu	rrent (knots)					
$-10w \le 1.5$		all	0.0		0.0	
- moderate > 1.5 - 3		fast	0.0		-	_
1		mod	0.1	8	0.1	B
- strong > 3		fast	0.2	BR	0.2	ы
- 300119 - 5		mod	0.2	B	0.2	в
		slow	0.4	в	0.4	в·
(a) Simificant wave height H	and length à (m)	· ·				
- $H \leq i$ and $\lambda \leq L$	and reagon /c (m)	all	0.0		0.0	
- 3 > H > 1 and λ ≈ I		fast	≈ 2.0	в		
		mod	≈ 1.0	в		
		slow	≈ 0.5	B		
$-H_{1} > 3$ and $\lambda > L$		fast	≈ 3.0	В D		
		slow	≈ 1.5	В		
WIDTH		Outer (Channel	Ĭn	ner Chanr	nel
w,		open	water	pro	HECKEG WA	uer
(f) Aids to Navigation	traffic control		٥		0.0	
- good		01	В		0.1 B	
- average, visual and s	hip board,					
infrequent poor visib	ility	0.2	B		0.2 B	
- average, visual and s	hip board,		6 D			
frequent poor visibili	ty	20	.5 R	ļ	≥ 0.5 B	
(g) Bottom surface		1				
- if depth ≥ 1.5 T		0	.0		0 .0	
- if depth < 1.5 f then		Δ1	B		018	
- smooth or sloping an	0.1	B	0.1 B			
- rough and hard		0.2	B	1	0.2 B	
(h) Depth of waterway		^	۵	. 1 e ·	т	
- 21.51 - 1.5T - 1.25 T		01	B	< 1.5	Г- 1,15 Т	0.0 0.2 B
- < 1.25 T		0.2	B	< 1.15	T	0.4 B
(i) Cargo hazard level						
- low		0	.0		0.0	
- medium		≥ 0.	5 B		≥0.4 B	
- high		≥ 1.0 B		≥0.8 B		

Table F.1Additional widths for straight channel sections.

Ship Manoeuvrability	good	moderate	poor
Basic Manoeuvring Lane, w _{BM}	1.3 B	1.5 B	1,8 B

Table F.2Basic manoeuvring lane width.

PASSING DISTANCE w _P	Outer Channel exposed to open water	Inner Channel protected water
Vessel speed (knots) - fast > 12 - moderate > 8 - 12 - slow 5 - 8	2.0 B 1.6 B 1.2 B	- 1.4 B 1.0 B
Encounter traffic density - light - moderate - heavy	0.0 0.2 B 0.5 B	0.0 0.2 B 0.4 B

Table F.3Additional width for two-way traffic.

WIDTH for BANK CLEARANCE (w _{Br} or w _{Bg})	Vessel Speed	Outer Channel exposed to open water	Inner Channel protected water
Sloping channel edges and shoals :	fast moderate slow	0.7 B 0.5 B 0.3 B	0.5 B 0.3 B
Steep and hard embankments, structures :	fast moderate slow	1.3 B 1.0 B 0.5 B	1.0 B 0.5 B

Note : Referring to the design ship : B = Beam

L = Length

T = Draught

Table F.4Additional width for bank clearance.



Explanation of the tables F.1-F.4.

Table F.1.

- (b). The prevailing cross wind must be taken from the wind data, as experienced in the port site vicinity. It is an hourly average. The value from the wind rose in figure 3.3 must be used.
- (c). The value for currents is taken from the actual current records for the channel site. This parameter is again taken from table 3.1.
- (e). Wave height is taken from the annual wind rose in figure 3.4.
- (h). The depth of the waterway is determined in section 8.5.3.3.
- (i). The cargo hazard can be expressed in terms of:
 - Toxicity
 - Explosive potential
 - Pollution potential
 - Combustion potential
 - Corrosive potential

The commodities are divided in three categories, as can be seen in table F.5 below:

CATEGORY	CARGO
Low	Dry bulk, break bulk, containers, passengers, general freight, trailer freight
Medium	Oil in bulk
High	Aviation spirit, LPG, LNG, chemicals of all classes

Table F.5Cargo hazard categories.

Minimum widths are given, but the width must be increased if imposed by the local conditions.

Table F.2.

A rough guide for the manoeuvrability of a ship are the following considerations:

- 1. Long and slender ships (L/B > 6.5) are more directional stable than short fat ones (L/B < 6). The latter will manoeuvre around tight bends more easily.
- 2. In shallow water (h/T < 1.5) all ships will manoeuvre less readily.
- 3. Low speed manoeuvrability will differ from the service speed manoeuvrability.
- 4. Single-screw/single-rudder ships will manoeuvre quite well, but are encountering screw-bias .
- 5. Ships with single controllable-pitch screws can experience screw-bias, even when the propeller pitch is set for zero thrust.
- 6. Twin-screw/twin-rudder ships have good control and manoeuvrability at all speeds.
- 7. Twin-screw/single-rudder ships may have poor manoeuvrability at low speeds.
- 8. Ships equipped with bow thrusters and/or stern thrusters usually have very good low speed manoeuvrability.



Table F.3.

For the passing distance determination, the beam of the largest passing ship must be used, whether or not it is the design ship. The encounter traffic density can be assessed with the help of table F.6:

CATEGORY	TRAFFIC DENSITY (vessel/hour)
Light Moderate	0 - 1.0 > 1.0 - 3.0
Heavy	> 3.0

Table F.6Encounter traffic density conversion.

Width determination for the 325,000 DWT crude oil carrier.

Table F.1.

Vessel speed: maximum of 8 knots: Outer channel exposed to open water: $w_i = 0.0^*B$

Prevailing cross wind: from figure 3.3 the maximum wind (hourly) is 13.8 m/s, being 27 knots, encountered from all directions throughout the year. This is a moderate wind. As the vessel speed is slow (≤ 8 knots), the additional width becomes:

 $w_i = 0.5 * B$

Prevailing cross current: From table 3.1 the maximum current amounts 0.8 knots. With a slow speed ship, the additional width regarding cross currents is: $w_i = 1.0^*B$

Prevailing longitudinal current: The new port is located adjacent to the existing land. No current is expected from the landside through the port entrance, so the longitudinal current can be classified as low, resulting in an additional width

 $w_i = 0.0^*B$

The significant wave height can be read in the wave height rose in figure 3.4. The prevailing wave direction is east north east, together with south, reaching values of 3.25 metres (the wave height reaches values over 2 metres only 3.5% of the time). For the width determination, it is assumed that the significant wave height H_s lies within the range 1-3 metres, resulting in an additional width of $w_i = 0.5*B$

Aids to navigation: the new port will, just as the existing port, have a Vessel Traffic System at their disposal. The additional width for port with a VTS is $w_i = 0.0^*B$

Bottom surface: the depth of the approach channel varies, but in significant parts, the depth will be less than 1.5 times the ship's draught. The bottom at the site consists of smooth and soft soil, only in the 20 metres water depth region consists the bottom of hard rock. The description "smooth or sloping and hard" is chosen here, resulting in

 $w_i = 0.1 * B$



Depth of waterway: from 8.5.3.3 it follows that the approach channel depth amounts 26.5 metres for the VLCC. This is less than 1.25 times the ship's draught, resulting in an additional width of $w_i = 0.2^*B$

The cargo hazard level can be assessed with table F.5. Crude oil in bulk is categorised as medium levelled cargo hazard. This infers an additional width $w_i = 0.5*B$

The preceding additional widths can now be summed to find the total additional width for the approach channel:

$$\sum_{i=1}^{n} w_i = (0.0 + 0.5 + 1.0 + 0.0 + 0.5 + 0.0 + 0.1 + 0.2 + 0.5)^*B = 2.8^*B$$

Table F.2.

The basic manoeuvrability of a large tanker can be assessed via the guidelines mentioned earlier in this appendix. The value of L/B for this ship amounts 350/56 = 6.25. It can be seen as a fat ship, manoeuvring easier around bends than other ships of this length (having less beam). The shallow water decreases this manoeuvrability. Especially large crude carriers are very difficult to manoeuvre during low speeds, tug assistance is required for speeds of less than 4 knots. The existence of bow thrusters increases the manoeuvrability, but these devices are mainly used during berthing operations. Concluding, the basic manoeuvrability of the large crude oil carrier is poor, resulting in: $w_{BM} = 1.8*B$

Table F.3.

The traffic density in vessels per hour can be assessed via table 5.2. In the year 2020, approximately 30,000 vessels will sail to and from the new port. If one entrance is designed, the traffic density is 30,000/(365*24) = 3.5 ships per hour. A possible solution is a combination of the existing Onsan Port entrance and the new port entrance. The density will then increase to approximately 40,000/(365*24) = 4.5 ships per hour. In all cases, the traffic density is categorised as "heavy" (see table F.6). This results in an additional passing distance width of

 $w_{p} = 0.5 * B$

With the slow speed of the ship, the initial passing distance equals: $w_{\scriptscriptstyle p}$ = 1.2*B

The total passing distance $w_p = 1.7^*B$

Table F.4.

The bank effects are relatively small in this case, and only present in dredged parts of the approach channel. For these dredged parts, the edges of the channel will be sloping, combined with the slow ship speed resulting in an additional bank clearance width of $w_{Br} = w_{Bg} = 0.3^{*}B$

Width determination for the container ship.

Table F.1.

Vessel speed: maximum of 8 knots: Outer channel exposed to open water: $w_i = 0.0*B$

Prevailing cross wind: from figure 3.3 the maximum wind (hourly) is 13.8 m/s, being 27 knots, encountered from all directions throughout the year. This is a moderate wind. As the vessel speed is slow (≤ 8 knots), the additional width becomes: w_i = 0.5*B

Prevailing cross current: From table 3.1 the maximum current amounts 0.8 knots. With a slow speed ship, the additional width regarding cross currents is: $w_i = 1.0^*B$

Prevailing longitudinal current: The new port is located adjacent to the existing land. No current is expected from the landside through the port entrance, so the longitudinal current can be classified as low, resulting in an additional width $w_i = 0.0^*B$

The significant wave height can be read in the wave height rose in figure 3.4. The prevailing wave direction is east north east, together with south, reaching values of 3.25 metres (the wave height reaches values over 2 metres only 3.5% of the time). For the width determination, it is assumed that the significant wave height H_s lies within the range 1-3 metres, resulting in an additional width of $w_i = 0.5*B$

Aids to navigation: the new port will, just as the existing port, have a Vessel Traffic System at their disposal. The additional width for port with a VTS is $w_i = 0.0^*B$

Bottom surface: from 8.5.3.3 it follows that the approach channel depth amounts 26.5 metres for the VLCC. The draught of the container ship amounts 11.5 metres, h/T = 2.3, resulting in an additional width of $w_i = 0.0^{*}B$

Depth of waterway: from 8.5.3.3 it follows that the approach channel depth amounts 26.5 metres for the VLCC. The draught of the container ship amounts 11.5 metres, h/T = 2.3, resulting in an additional width of

 $w_i = 0.0 * B$

The cargo hazard level can be assessed with table F.5. Containers are categorised as low level cargo hazard. This infers an additional width $w_i = 0.0^*B$

The preceding additional widths can now be summed to find the total additional width for the approach channel:

$$\sum_{i=1}^{n} w_i = (0.0 + 0.5 + 1.0 + 0.0 + 0.5 + 0.0 + 0.0 + 0.0 + 0.0)^*B = 2.0^*B$$



Table F.2.

The basic manoeuvrability of a container ship can be assessed via the guidelines mentioned earlier in this appendix. The value of L/B for this ship amounts 285/39 = 7.3. It can be seen as a slender ship, being directionally stable and thus manoeuvring not very easy around tight bends. The water depth is sufficient for this ship to address it as deep water, so no decrease of manoeuvrability will have to be sustained. Container ships, loaded with containers, have a large windage area and are difficult to manoeuvre during low speeds, encountering cross winds. The existence of bow thrusters increases the manoeuvrability, but these devices are mainly used during berthing operations. Concluding, the basic manoeuvrability of the container ship is poor, resulting in: $w_{BM} = 1.8*B$

Table F.3.

The traffic density in vessels per hour can be assessed via table 5.2. In the year 2020, approximately 30,000 vessels will sail to and from the new port. If one entrance is designed, the traffic density is 30,000/(365*24) = 3.5. ship per hour. A possible solution is a combination of the existing Onsan Port entrance and the new port entrance. The density will then increase to approximately 40,000/(365*24) = 4.5 ships per hour. In all cases, the traffic density is categorised as "heavy" (see table F.6). This results in an additional passing distance width of

$$w_{p} = 0.5 * B$$

It must be noticed that the beam of the largest ship, passing through the approach channel must be used, regardless if this is the design ship or not. The ship with the largest beam using the channel is the VLCC, so

 $w_p = 0.5 * B_{VLCC}$

With the slow speed of the ship, the initial passing distance equals: $w_p = 1.2*B$ Again, this is the largest ship beam sailing through the channel, so $w_p = 1.2*B_{VLCC}$

The total passing distance $w_p = 1.7^* B_{VLCC}$

Table F.4.

The bank effects are not present in this case, as the water depth beside the channel is sufficient for the container ship to sail without problems. The additional bank clearance width becomes $w_{Br} = w_{Bg} = 0.0^{*}B$

Width determination for the LNG carrier.

Table F.1.

Vessel speed: maximum of 8 knots: Outer channel exposed to open water: $w_i\,=\,0.0^*B$

Prevailing cross wind: from figure 3.3 the maximum wind (hourly) is 13.8 m/s, being 27 knots, encountered from all directions throughout the year. This is a moderate wind. As the vessel speed is slow (≤ 8 knots), the additional width becomes: w_i = 0.5*B



Prevailing cross current: From table 3.1 the maximum current amounts 0.8 knots. With a slow speed ship, the additional width regarding cross currents is: $w_i = 1.0^*B$

Prevailing longitudinal current: The new port is located adjacent to the existing land. No current is expected from the landside through the port entrance, so the longitudinal current can be classified as low, resulting in an additional width $w_i = 0.0^*B$

The significant wave height can be read in the wave height rose in figure 3.4. The prevailing wave direction is east north east, together with south, reaching values of 3.25 metres (the wave height reaches values over 2 metres only 3.5% of the time). For the width determination, it is assumed that the significant wave height H_s lies within the range 1-3 metres, resulting in an additional width of $w_i = 0.5*B$

Aids to navigation: the new port will, just as the existing port, have a Vessel Traffic System at their disposal. The additional width for port with a VTS is $w_i = 0.0^*B$

Bottom surface: the location of the LNG port will be in the vicinity of the powerplants, using the gas. The water depths in that area are not less than 20-25 metres, resulting in deep water for the LNG ship, with a draught of 11 metres: $h/T \ge 1.8$, resulting in an additional width of $w_i = 0.0^{*}B$

Depth of waterway: $h/T \ge 1.8$, resulting in an additional width of $w_i = 0.0^*B$

The cargo hazard level can be assessed with table F.5. LNG is categorised as highlevel cargo hazard. This infers an additional width of at least 1.0*B. As the channel will be one-way traffic, the width is chosen slightly larger:

 $w_i = 1.2 * B$

The preceding additional widths can now be summed to find the total additional width for the approach channel:

$$\sum_{i=1}^{n} w_i = (0.0 + 0.5 + 1.0 + 0.0 + 0.5 + 0.0 + 0.0 + 0.0 + 1.2)^*B = 3.2^*B$$

Table F.2.

The basic manoeuvrability of a LNG can be assessed via the guidelines mentioned earlier in this appendix. The value of L/B for this ship amounts 280/42 = 6.7. It can be seen as a rather slender ship, being directionally stable and thus manoeuvring not very easy around tight bends. The water depth is sufficient for this ship to address it as deep water, so no decrease of manoeuvrability will have to be sustained. LNG carriers have a large windage area (the cargo is light and the ship lies high on the water). Therefore these ships are difficult to manoeuvre during low speeds, encountering cross winds. The existence of bow thrusters increases the manoeuvrability, but these devices are mainly used during berthing operations. Concluding, the basic manoeuvrability of the LNG carrier is poor, resulting in: $w_{BM} = 1.8*B$



Table F.3.

As only 1,300 ships per year enter the LNG port, no two-way traffic is necessary.

Table F.4.

The bank effects are not present in this case, as the water depth beside the channel is sufficient for the LNG carrier to sail without problems. The additional bank clearance width becomes $w_{Br} = w_{Bg} = 0.0^{*}B$



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Delft University of Technology Faculty of Civil Engineering

Thesis

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CONFIDENTIAL

Safety aspects of LNG import terminals.

The Ulsan Port development plan

Michiel de Jong 404305

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This report is a development of one of the aspects dealt with in the Ulsan Port master plan study. It comprises the hazards, and measures to reduce or minimise them, accompanying the transfer of LNG in ports. The results of the study are applied to the proposed Ulsan Port LNG import terminal. This report is completed under supervision of the following persons:

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SAFETY ASPECTS REGARDING LNG IMPORT TERMINALS.

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1. INTRODUCTION.

Fossil fuels have been used as a source of energy for a long period of time. In the early days the emphasis laid on coal while later on oil products also gained a significant share of the energy market. Only for the last 40 years, natural gas is gaining an important position between the other fossil fuels. In that period, methods have been developed to transport the natural gas in an economic manner, being the transformation in to LNG, which is short for Liquefied Natural Gas. The first application of natural gas has been fuel for heating and cooking in households and heating of industrial complexes.

During the 1980's, the anxiety over the environment gave a new impulse to the interest in natural gas as a fuel gas because of its environment friendly combustion properties, giving it advantages over traditional fossil fuels as coal and oil products. Application in the transport sector with gas powered vehicles result in lower emission of environment damaging products such as CO_2 , SO_x and NO_x .

The fastest growing consumer of natural gas however is the electricity generating market. This has a threefold reason:

- 1. The world's electricity demand is growing fast and therefore power plants are built or extended all over the world.
- 2. The already mentioned environment friendly combustion is a large benefit as regulations with respect to emissions are becoming more and more stringent.
- 3. Because of a recently developed new production technology, gas fired power plants can generate power more cost efficient than their coal fired predecessors.

All these developments have lead to a new interest in transporting natural gas by sea (in the form of LNG). The advantage of LNG is that its volume is 600 times smaller than that of natural gas, making it economical in transportation purposes.

However, various disadvantages are clinging on to the handling of LNG:

- 1. The temperature: LNG must be maintained at a temperature of -162° C to reduce the formation of gas. These temperatures can influence the behaviour of structures that come in contact with the LNG and can injure human beings.
- LNG is very volatile. When spilled on land or water, the LNG evaporates in a few minutes to form a large vapour cloud. This vapour cloud can under certain conditions be flammable, and be ignited when a small amount of energy is added.

Although handled for quite a long time already, there seem to be no generally accepted regulations regarding the handling of LNG. In december 1996, an overall European Standard has been approved which deals with the subject of LNG handling. This Standard is the state-of-the art document in LNG handling available today. It combines terminal design rules from Europe, the USA and Japan.

In the following chapters, the hazards of LNG handling will be discussed and solutions to reduce or eliminate them are put forward.

Chapter 2 describes the properties of natural gas and the chain which is formed between the source and the customer. A brief description of the fundamental equipment used in LNG transport, transfer and storage is also given in this chapter.

In chapter 3, the various causes of LNG spills on an LNG terminal and loss of containment from LNG carrier cargo tanks are discussed.

The succeeding chapter deals with the consequences of these spills. First of all the conditions for ignition of LNG and LNG vapours are described. After that, the different possibilities of behaviour of the LNG -pool formation, vapour cloud formation and dispersion- are pointed out. Specific consequences close this chapter.

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The meaning of the risk that accompanies the handling of LNG in ports and methods to determine the risk levels are inserted in chapter 5.

After the discussions regarding the hazards of LNG handling and possible consequences of LNG spills and natural gas leakages, it is in chapter 6 that measures to reduce and minimise these hazards and consequences are described.

Here the various possibilities for detecting incidents in a preliminary phase will be present, just as the description of emergency shutdown systems and how these are operated. When things get out of hand after all, fire fighting equipment can be used to reduce the consequences.

Chapter 7 deals with the various parts of an LNG import terminal.

In chapter 8 the gained knowledge is applied to a proposed LNG import terminal at Ulsan Port, Korea.

Chapter 9 ends this study with conclusions and recommendations.

2. THE NATURAL GAS CHAIN.

2.1. Origin.

Natural gas is a product, that is rapidly gaining respect as a source of energy. It is used for heating and provides heat for cooking in households, it is used as a fuel for vehicles and as an energy source for industrial processes, with a dominating role for the power industry.

Natural gas is of fossil nature. Its origin is twofold:

- 1. Natural gas is found in the earth, captured between solid layers. This is called unassociated gas.
- 2. Natural gas results as a by-product from oil production in a mixed oil field, therefore it is called associated gas.

The product consists mainly of methane, CH_4 . Other components of natural gas are ethane (C_2H_6) , butane (C_3H_6) propane (C_4H_{10}) and nitrogen (N_2) . The mixture varies considerably according to where and when the gas is found and whether it is associated or unassociated gas. The associated form of natural gas is richer than the unassociated form, because it contains a higher percentage of ethane, butane and propane, all of which having a higher calorific value than methane. Typical values of methane in the mixture are within the range of 65% to 99%. The resulting product is colourless and does not smell. Specific physical properties of the constituents of natural gas are grouped in table 2-1 [1].

	Methane CH₄	Ethane C ₂ H ₆	Propane C ₃ H ₈	Butane C ₄ H ₁₀
Composition of typical Algerian				
LNG (mol%)	87.40	8.40	2.40	0.50
Molecular weight (kg/kmol)	16.04	30.07	44.09	58.12
Boiling point (°C)	-161.50	-89.00	-42.00	-0.50
Melting point (°C)	-184.00	-183.00	-190.00	-135.00
Liquid density at boiling point (kg/m ³)	420	560	580	600
Vapour density (air=1)	0.55	1.04	1.54	2.05
Critical temperature (°C)	-82.50	32.30	96.70	152.00
Critical pressure (atm)	45.80	48.30	42.00	37.50
Evaporation latent heat (Kcal/kg)	122.50	117.00	102.20	92.55
Natural ignition temp. (°C)	537.00	-	466.00	405.00
Heated gas ignition temp. (°C)	1,325.00	-	990.00	990.00
Flammable limit in air (%)	LFL: 5.00	LFL: 3.00	LFL: 2.12	LFL:1.86
	UFL: 15.00	UFL: 12.50	UFL: 9.35	UFL: 8.41
Relative volumes as liquid at				
boiling point and gas at 21°C	630.00	488.00	316.00	108.00

 Table 2-1
 Typical physical properties of constituents of natural gas.



2.2. Present use of natural gas.

Natural gas is no longer considered a low value by-product of oil production, but is growing as an energy source in its own right. Technological developments and innovations give it more importance as a source of energy. A large growth in energy demand is providing one of the most important driving forces to the development of the natural gas industry, because natural gas, as compared to other fossil fuels, imposes a relatively low environmental impact. This is an important feature in a world in which legislation is gradually tightening the emission requirements of fuels.

The present increasing demand for natural gas is provoked by a need for electricity, dictated by industrial expansion and the demand for rural electrification. The power industry therefore moves to a position of a large customer ofnatural gas rather than oil or coal. Another growing group of customers is the transport industry, where gas powered vehicles and aeroplanes are being developed to reduce emissions, both in the public transport (buses and aeroplanes) and private vehicles sector.

As stated before, one of the fastest growing sectors for natural gas consumption is the electricity generating industry. The use of gas-fired power plants is encouraged by their cost-efficiency.

Generally considered to be the cleanest of the fossil fuels, natural gas is able to meet emission requirements more easily. Legislation to be enforced tackles emissions of gases such as carbon dioxide (CO_2), sulphur oxides (SO_2) and nitrogen oxides (No_x) and soot particles. Studies have shown that natural gas can offer superior environmental performance in terms of all these emissions [2] [3] [4]. In addition, natural gas driven power plants use less land space than the coal fired plants and can be built in a shorter period of time. When this is known a weigh must be made keeping the following guidelines in mind:

Coal fired power plant:

- Low variable costs (coal is a cheap fuel).
- High fixed costs.
- High capital costs (various auxiliary equipment such as SO_x and NO_x separation and catching soot particles).

Natural gas driven plant:

- High variable costs (natural gas is a costly fuel).
- Low fixed costs.
- Low capital investment (only a power plant, no auxiliary equipment necessary).

Exploitation of a natural gas driven power plant is likely to become more economical than the coal driven alternative. The conclusion can be that the application of natural gas in the electricity generating industry is one of the most economical and therefore competitive methods of meeting the environmental requirements.

2.3. Gas exploration and liquefaction.

The natural gas reserves are located in many parts of the earth. Most gas fields are located deep under the surface, both under land and sea. The method of gas winning is virtually the same in both cases, although when the gas field is located under the sea, the available work space is limited. The gas is won by drilling pipes through the different bottom layers into the gas field. The gas from the field is under a natural pressure and rises to the surface through the pipes without pumps. This unassociated gas requires minor processing, other than the addition of an odourant to give the gas a distinctive smell for leak detection. The gas is transported to the customer via a high-pressure pipeline network. The pipelines are buried under a layer of backfill (approximately 1 metre thick) and laid along the direct path as much as possible. Diameters of the pipes vary from 80 to 900 mm according to their carrying capacity. The transport of the gas is achieved through centrifugal compressors, pressurising the gas up to 80 bar. Booster stations, being compressors located along the pipeline, compensate for pressure losses due to the gas displacement process. The distance between booster stations is approximately 100 km. At delivery to the customer, the gas is metered and lowered in pressure to between 4 and 16 bar, according to the customer's use [5]. When the gas field is located under the sea bottom, the gas is won from a platform. It is transported to the shore via submerged pipelines.

In case it is not economical to bring the gas to the customer because the distance from the location of production to the customer is too large for pipeline transport or the customer's location is not accessible with pipelines, the natural gas must be transported in discontinuous bulk portions. The common method for transporting natural gas via this method is by ship. For economic reasons, the natural gas then is liquefied, reducing its volume to 1/600 of the original gas. In principle, liquefaction of a gas can be achieved in two manners. One is by increasing the pressure and the second is by decreasing the temperature below the boiling temperature of the gas.

The first method is not applicable for natural gas, because it can only be liquefied by pressure under the critical temperature of -83°C. Above this temperature, liquefaction by pressure is not possible. Combined pressure and cooling (to -83°C) would require an absolute pressure of approximately 40 bars. The transportation in ships would then impose problems with regard to the construction of the containment system [6].

The second method is generally used: liquefaction, resulting in the product LNG (Liquefied Natural Gas), is achieved by cooling the natural gas to approximately -162 -°C (being the boiling temperature). The natural gas from the gas field has to be treated because it contains undesirable constituents for liquefaction purposes. These undesirable constituents are, among others, water, methanol, mercury, carbon dioxide and sulphur compounds, because they solidify on cooling and will cause blockages in the process [7]. The liquefaction takes place via a series of heat exchangers. The heat, given up by the natural gas as it is cooled, is absorbed by a hydrocarbon refrigerant. This refrigerant is cooled by air and sent back into the heat exchangers. During liquefaction, the LNG can be given the properties agreed on with the customer. The operation of the refrigerant cycle is provided by compressors. These operations take place at the LNG export terminal. Export terminals are, by nature, located on the coast.

After liquefaction, the LNG is stored, ready for transportation.

2.4. Storage of LNG.

The liquefied gas is stored in large storage tanks, up to 200,000 m³ per tank [8]. These tanks must meet the following requirements:

- Safe containment of the LNG
- Permit the safe filling and removal of LNG
- Prevention of air or moisture ingress
- Minimisation of heat in leak

There are six types of storage tanks in use. These are [7]:

1. Single containment storage tank.

Approximately 75% of all LNG storage tanks is of this type. The construction consists of two shells. The inner primary tank holds the LNG and is normally made of 9% Ni steel, having adequate notch toughness properties, preventing brittleness. The outer shell, if any, is designed for holding insulation and for vapour containment, not for cryogenic liquid containment. The used insulation normally is perlite. The outer shell is often made of carbon steel, as is the roof construction.

Around the above ground storage tank, a bund wall is provided to contain the LNG in case of a tank failure. In figure A-1 in Appendix A, two configurations of a single containment tank type are given.

2. Spherical storage tank.

This is a special design of a single containment tank. It consists of an unstiffened sphere, that is supported at its equator by a vertical cylinder. Both the sphere and the outer shell are normally made of an aluminium alloy. The concept of the spherical tank is adapted from the cargo widely used spherical cargo tank aboard LNG carriers. The support cylinder is made of concrete, as is the domed cover of the tank. The tank insulation consists of a panel system. LNG and its vapour are contained within the primary spherical tank. This tank type is often used in areas with a high earthquake probability due to the accurate prediction of structural integrity. Again, the above ground spherical tank must be provided with bund walls to contain LNG spills. The concept of this tank type can be found in figure A-2 in Appendix A.

3. Double containment storage tank.

This construction is equipped with two tanks. Both the inner and outer tank are independently capable of containing the LNG. The vapour that is formed however, can not be contained by the outer tank. To avoid formation of a large pool, the outer containment shell must be placed within 6 metres of the inner tank. The outer tank wall is normally made of pre-stressed or reinforced concrete, sometimes provided with an earth embankment, withstanding the impact of the cryogenic liquid when the inner tank wall fails. It is not necessarily as high as the inner tank. The roof construction is made of carbon steel. Examples are showed in figure A-5 in Appendix A.

4. Full containment storage tank.

The cryogenic liquid and accompanying vapours are both independently contained by the inner and outer tank wall and roof construction. The secondary containment system is placed 1 to 2 metres from the primary containment system. The roof construction of the outer tank can be both steel or reinforced concrete (capable of controlled vapour venting), the inner roof construction is made of steel. The insulation system usually consists of a resilient blanket on the outside of the inner tank and perlite powder in the annular space. A carbon steel or epoxy liner protects the inside of the outer tank wall, the steel variant is protected from brittle shock by a polyurethane foam. In new designs, a bottom wall system of insulation (foam glass) and a 9% Ni steel, extending 5 metres above it against the outer tank wall is used. The full containment tank type is shown in figure A-6 in Appendix A.

5. Membrane storage tank.

A membrane storage tank consists of a primary containment, formed by a membrane, gas-tight connected to a steel roof liner, that contains both the liquid gas and vapour under normal conditions, and a pre-stressed concrete outer wall, supporting the membrane. The membrane has no load bearing capacity, this all comes from the concrete outer wall via load bearing insulation. It consists of 1 to 2 mm thick flexible austenitic stainless steel. Expansion and contraction of this membrane is allowed through orthogonal corrugations. The concrete outer tank must be capable of containing all the LNG which is stored within the membrane, and controlled venting of the vapour formed after inner tank leakage. Examples can be found in figure A-3 and A-4 in Appendix A.

6. Cryogenic concrete storage tank.

This tank type is either a double containment or full containment tank. The difference with the described tank configurations is that in this case both the inner and outer tank walls are made of pre-stressed concrete. In figure A-7 in Appendix A outlines of the concept are given.

The LNG is stored slightly above atmospheric pressure. In this case, air entrainment is prevented. The specific pressure depends on the storage tank type. Tank design pressures for tanks with steel roofs and concrete roofs are 140 mbar and 300 mbar respectively (above atmospheric pressure) [9]. The advantage of a higher pressure is that the generation of vapour during the (un)loading process is reduced or eliminated. The tanks are protected against over-pressure by control and relief valves. The tanks normally have top connections only. No connections for pipelines or instruments penetrate the sides or bottom of the tank to ensure mechanical integrity. The filling and emptying of the tank is achieved via pipes through the roof. The LNG is pumped up by an electrical pump, submerged in the liquid.

Most storage tanks are surrounded by bund walls to contain the cryogenic liquid in case of a spill. These bund walls are designed such that the holding capacity is equal to or more than the holding capacity of the storage tank.

2.5. Transport by sea.

When an LNG carrier arrives at the export terminal, the LNG is pumped from the storage tank to the ship via insulated pipelines and loading arms by shore based pumps. The loading arms are of the articulated metallic pipe design, already used in the oil industry. The arm provides six degrees of freedom through swivel joints. This is necessary to maintain the connection between the ship's manifold and the pipeline while the ship is moving at berth.

LNG carriers are ships that transport the liquid product in bulk. It therefore is fitted with one or more cargo tanks, fed by pipelines and a central manifold. The sizes of the ship are expressed in m^3 hold capacity in stead of DWT. The ship sizes vary from 10,000 m^3 up to 135,000 m^3 , with 200,000 m^3 ships to be commissioned before the year 2000. Nowadays, the common ship size is 125,000 m^3 , being a ship with dimensions 280x42x13.5 metres [6].

The cargo tanks on these ships do not need to be able to withstand high pressure, since LNG is transported only slightly above atmospheric pressure (to avoid air entrainment). The key aspect in the design of LNG carriers is the ability to withstand low temperatures. Because of the extremely low temperature of the transported LNG, the ships have special construction features, including:

- Substantial insulation for the cargo tanks to protect the steel of the hull and preventing the LNG cargo from warming up (and thus evaporation en route).
- Special design of the cargo tanks
 - to accommodate large variations in temperature in order to conserve the total amount of heat that reaches the cargo.
 - to withstand the dynamic loading imposed during ocean transits.
 - to reduce the likelihood of liquid leaks from the cargo tank.

Three cargo tank types are in use:

- 1. Membrane system tanks
 - The inner hull of the ship serves as cargo tank. Load bearing insulation (for instance balsa wood) is placed against this hull on the inside, and is provided with a thin membrane of steel with corrugations allowing strain.
- 2. Self supporting rectangular tanks
 - For this tank type, the cargo tank is not combined with the ship's hull. The construction is made of steel, with insulation on the outside of the tank. The tank is kept at its place by insulated supports to prevent heat leak-in.
- 3. Spherical tanks

This tank configuration is like the preceding tank type, with this difference that the tank is spherical.



All modern LNG carriers are provided with double hulls and a double bottom structure. Cryogenic containment is achieved through barriers, separate from the hulls. The enclosed space surrounding the cargo tanks is maintained fully inert under a constant positive pressure of nitrogen. In this way the insulation stays moist free too. With these modern designs, heat in-leak is reduced to a value of approximately 0.1% of the total cargo per day. This means that 0.1% of the volume of the LNG is vaporised in one day [9]. The vapour resulting from the heat in-leak is called the boil-off. This boil-off gas is used to operate the ship's engine (common practice), is re-liquefied or stays in the cargo tank up to unloading. Examples of LNG carriers are given in figures A-8 and A-9 in Appendix A.

2.6. Import terminals: storage, regasification and transport to the customer.

When the LNG carrier arrives at the import terminal, the reverse trajectory from the export terminal is followed: the LNG is pumped from the vessel with ship based pumps via insulated pipelines to storage tanks on the terminal terrain. Here the LNG is stored until it is demanded by the customer. The storage tanks arrangement is the same as described in section 2.4.

The LNG then must be regassified. The regasification of the LNG into natural gas is achieved through the process of vaporisation. This means that the LNG is slowly warmed up from -162°C to temperatures above 0°C. There are several types of vaporisation, but in each the principle is the same: the LNG is lead through a series of tubes or panels which are heated. The two systems which are generally used (80% of all installed vaporiser systems) are:

1. Open Rack Vaporisation (ORV).

The ORV system uses (sea)water to vaporise LNG, which is flowing through tubes. The water is running along the outside surface of these tubes, open to the atmosphere.

2. Submerged Combustion Vaporisation (SCV).

In SCV systems, a fuel -often natural gas- is burnt. The heat is used to warm a water bath in which a coil is located. The LNG passes through the tube-side of the coil and is vaporised.

Once the LNG is vaporised and becomes natural gas, the gas is regulated for correct pressure and then metered and odorised before entering the pipeline supply system to the customer.

2.7. The European gas industry.

With regard to Western Europe, much of the gas production is concentrated in the North Sea. Here major gas reserves are found. The Netherlands, Norway and the United Kingdom are the major producers. The United Kingdom uses the gas for the domestic market, while the Netherlands and Norway export large volumes of natural gas to the rest of Europe. This transport is accomplished by pipelines and booster stations, providing the pressure.

Growing consumption across Europe is depleting the natural gas reserves in the North Sea. Many European countries therefore have alternative supply routes. One of these alternatives is Russia. Russia is the world's largest gas producer and the most extensive natural gas reserves are located in this country. European (and other) countries are considering import of natural gas from Russia. Because of the current unstable political situation in this nation, most countries use multiple import sources, to be sure of a constant supply. Europe therefore will increasingly have to rely on sources in the east (Gulf States) and in Africa [3].
2.8. The Asian gas industry.

In Asia, and specifically Korea, energy sources are demanded even more progressively than in Europe, because of the rapid development of the economy, with an emphasis on growing industrial infrastructure. In countries such as Japan, Taiwan and Korea, natural gas needs are mainly driven by power needs. Up to now, Asia is (relatively) the largest user of oil in the world: 55% of the total energy consumption against 40% in North America and 45% in Western Europe. Natural gas use on the contrary, is relatively small: 8% in Asia against 20% in the western world. This value will increase significantly in the years to come. Because Korea has no domestic natural gas reserves, the gas has to be imported. Currently, contracts are being prepared with Indonesia, Alaska, Australia and the Gulf region [4].

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3. CAUSES OF AN LNG SPILL.

3.1. General.

The transportation and handling of LNG is different from other commodities because of the nature of the product. LNG is a liquid that is classified as "dangerous" and therefore special safety requirements are necessary. The qualification "dangerous" is given for several reasons:

- A. LNG has a temperature of -162°C, a cryogenic product. This means that contact with humans can cause severe injuries and contact with exposed metal structures can change the properties of the metal, an important example is the irreversible brittleness of steel.
- B. LNG is a highly flammable liquid.
- C. LNG, if not directly ignited, vaporises quickly when exposed to ambient air. It then forms a large vapour cloud which again can be flammable, when the vapour/air mixture is within certain limits.

When during transport or terminal handling LNG is accidentally released from its containment, all three aspects must be considered. Escaping LNG is an important safety consideration. When released from its containment, the probability of a fire is significant. Next to this, LNG is a volatile product so direct release in the atmosphere is increasingly to be avoided. Last but not least, the low temperature of the product makes it even more dangerous, with risk for personnel and metallic materials forming the berth and LNG carrier structure. The next chapter deals with these aspects.

First, the different causes of an accidental release of LNG are described. This is an important aspect when terminal design is in discussion. Although hardly tried, it still is not possible to avoid spills of LNG from its containment. When considering the causes of an LNG release, a wide spectrum of possibilities is found. Various possibilities are [10] [11]:

A. Errors in the LNG handling system.

- 1. Storage tank wall failure
- 2. Storage tank roof failure
- 3. Spontaneous rupture of equipment
- 4. Excessive movement of unloading arms
- 5. Fatigue failure of pipework
- 6. Overpressurisation in a pipe
- 7. Pump leakage
- 8. Vaporiser incidents
- 9. Gasket or seal failure
- 10. Management or personnel errors

B. Other technological systems.

- 1. Ramming ship
 - 2. Crashing aeroplane
 - 3. Off-site incidents (for instance fire or explosion near the LNG facilities)
- C. Nature.
 - 1. Earthquakes
 - 2. Climatic conditions (inclement weather)
- D. Physical geographic entourage.
 - 1. Width and depth of approach channel/fairway, bends
 - 2. Shoals and piers
- E. Social environment.
 - 1. External aggression



Not all these causes are equally credible or have a specific effect. For instance external aggression is a rather vague term. It can result in a pipeline rupture, but also multiple storage tanks can be destroyed. Some of these causes can however be analysed in more detail, because the consequences of the cause are more or less predictable or prevention of the cause is possible.

3.2. Storage tank failure.

3.2.1. General.

Over the years, various scenarios comprising accidents caused by storage tank failure are developed. The credibility of these scenarios is under constant change, because the design of the storage tanks evolves with the knowledge gained about the hazards of LNG.

In the early days of LNG storage, the maximum credible accident was the total failure of a storage tank, resulting in the instantaneous spillage of all the tank's contents. This scenario is based on a storage tank that has striking similarities with the traditional oil tank design, provided with one cargo tank wall of steel and a steel roof structure. Total failure could occur due to material failure or small leaks inducing a chain reaction which causes total failure.

Modern storage tank design is specifically focused on the product; equipped to withstand the cryogenic temperatures by developing adapted steel qualities, equipped with double walls of steel or concrete to contain the liquid and/or formed vapour in case of inner tank failure, roof structures in steel or concrete, etc. This double integrity tank configuration makes a total failure not very credible. For the single integrity tank type, still in use today, total failure is still possible, although highly improbable.

Hazards regarding the terminal storage tank can be divided in internal and external hazards. Internal hazards are for instance cracks in the storage tank, roll-over, overpressurisation, vacuum, overfilling and corrosion. External hazards can be a fire in the vicinity of the storage tank, impact from objects and earthquakes [12].

3.2.2. Roll-over.

The roll-over phenomenon in LNG tanks arises in a multi-component mixture, whose boiling point increases due to increasing density. An example of how roll-over can arise will now be discussed.

When a heavier LNG product is added to the bottom of a tank, containing a lighter LNG, gravity strongly retards mixing and the upper layer prevents vaporisation of the lower layer. Energy is transmitted through the tank walls, roof and bottom, hereby vaporising part of the lighter upper layer, thus increasing its density. The lower heavy LNG can neither vaporise, nor mix, but merely warms because it is enclosed by the upper layer. When the density of the lower layer approaches that of the upper layer, the lower cell of LNG quickly rises, and without the confining effect of the upper layer rapidly boils and mixes. When the tank is unable to release the so generated vapours, tank failure might occur.

Roll-over can appear when two types of LNG are stored in the same tank, or when younger LNG is put in the tank with older LNG of the same type. The latter case can be the cause of roll-over because when LNG is ageing, the methane share will decrease (due to vaporisation) [13].

3.2.3. Overpressurisation.

Overpressurisation of a storage tank can be induced by the preceding roll-over phenomenon. Other causes are an external fire near the storage tank, failure of relief valves or personnel errors. The overpressure can be caused by vapour originating from LNG transfer from the ship to the tank or from heat in-leak during storage. Overpressurisation can cause the tank to fail, for instance the roof could be blown away. It should be mentioned that the full containment tank type, with concrete walls and roof, can endure higher overpressures than single- or double containment tank types (with steel roofs).

3.2.4. Overfilling.

Overfilling of a cargo tank can be caused by human error or equipment failure. It might lead to a (relatively small) LNG spill.

3.2.5. External hazards.

A fire in the vicinity of a storage tank can cause severe thermal radiation. The effect of this thermal radiation can be an increased heat in-leak in the tank and accompanying pressure build up due to increased vaporisation. Severe fires can cause a loss of integrity of the tank structure leading to a total failure and the loss of the tank's contents.

Impact must be treated as energy imposed on the tank structure. Impact can be caused by a crashing aeroplane or, for sabotage purposes, a missile with explosive charge. Especially the latter is hard to prevent, the weapon will be selected in order to induce the most critical damage [12].

3.3. Unloading arm failure.

The loading arm arrangement is subject to dynamic influences caused by the LNG carrier movements. This might be one of the reasons why spills from incidents with the transfer arms are among the most common in LNG handling. The flow rate during transfer can be up to 11,000 m³/h, so in a small period of time, a large amount of LNG can be released [14]. The unloading arms are articulated metallic pipe sections, connected through swivel joints. This configuration enables the unloading arm/ship manifold connection point to move with six degrees of freedom within an allowable working space envelope.

There are several reasons why the unloading arm is such a critical item in the LNG handling chain [15]:

- Because it occurs at each transfer, the making and breaking of the connection between the unloading arm and the ship manifold flange presents a large potential opportunity for LNG spillage. Especially because this action interrupts the containment integrity. The main hazard is for people to become injuries from components falling down during the connection or disconnection.
- The coupling of the arm to the manifold in former days was achieved by manual coupling systems. This often presented problems associated with seal positioning and bolt tensioning, frequently resulting in product leakage. Presently quick connect couplers are used, in which no manual force is needed.

3. When the movement of the LNG carrier becomes excessive and thus the movement of the unloading arm exceeds the limits of its working envelope, rupture of the unloading arm might occur. This might cause a relatively large spill of LNG. Attendant damage can be done to the unloading arm structure or ship deck due to the very low temperature.

These points are credible causes for accidents with LNG. There are other scenarios for product release, although with the present knowledge of design and safety, both for terminals and the personnel, these are not as probable as the preceding ones [16]:

- 1. Spontaneous rupture of the unloading arm.
 - In this case, the construction fails due to the presence of an inherent defect.
 - a. Corrosion

The corrosion of stainless steel in a marine environment is certainly possible. When corrosion occurs, this could lead to rupture. It is however assumed that this process is of the type "leak before break" and can be detected before catastrophic rupture is initiated.

b. Failure of swivel joints.

This is a complex structure on which few information is available, regarding the modes of failure. The amount of LNG that is released will be relatively small.

2. Alongside movement due to propulsion.

This seems a very improbable scenario, but has occurred. Errors in this case are of human nature. A particular case has been that maintenance people were working on the engine and started the ship at full speed when it was berthed and connected to the unloading arms.

3. Mooring system failure.

Again a seemingly improbable scenario, though reported more than once. The mooring system can break down due to high winds or heavy sea conditions, or due to internal failure of the mooring line(s).

3.4. Transfer pipeline system failure.

Constructional inhomogeneities can cause leaks in pumps and pipes. A total full-bare failure of a large diameter pipeline can however be disregarded under normal circumstances for a properly engineered, well built, properly maintained and correctly operated LNG terminal. Failures of smaller, less rigid pipes are more realistic to assume. In this light, also failure of gaskets and seals can not be ruled out [13].

The failure of pipes and connection parts due to fatigue is not a very credible scenario. Research on joints, which already had been in service for 17 years and were put to a fatigue test representing 200 years of service, did not lead to fatigue cracks. Only when the design value for movement was exceeded to twice its value, a small crack inducing a pinhole leak occurred [17].

3.5. Vaporiser malfunction.

Malfunctions in vaporisers can lead to LNG loss. For the different vaporiser configurations, these can comprise [11]:

ORV (Open Rack Vaporisation):

- low seawater flow rate
- low outlet gas temperature
- low outlet gas pressure

SCV (submerged Combustion Vaporisation:

• air blower burner failure

- low water bath level
- low water bath temperature
- high fuel gas temperature
- low outlet gas temperature
- low outlet gas pressure
- high outlet gas flow

3.6. Human error.

Human fallibility has often been proved to be the main cause of incident occurrence and their development into accidents. Human errors at an LNG terminal are defined as those elements which negatively influence the efficiency of the terminal's equipment, possibly resulting in incidents or accidents.

The occurrence of human errors can be felt in virtually all operations at the terminal [11]:

- Process start up
- Process shut down
- Control of the process and process equipment
- Alarms
- · Control room computerisation and back up
- General management of the terminal
- Maintenance of the terminal and its equipment

3.7. Damage to the LNG carrier.

3.7.1. General.

Vital elements in port operations are ships and their crews. An LNG carrier can be represented as a dynamic system, in contradiction with the terminal, which is a static structure. When an LNG carrier travels through the water, its horizontal movements can be controlled by rudder and propeller action. Vertical movement is induced by waves and is not controllable. During movement, other moving objects may be encountered and even at berth, the ship can be harmed by other vessels.

In this perspective, it is understandable that the main causes of damage to an LNG carrier are collision with another ship or object and grounding of the ship.

3.7.2. Collision damage.

When the LNG carrier is involved in a collision, there is a chance that the cargo tanks are damaged and LNG is released. This is a serious accident, because the cargo tanks on LNG carriers have large capacities, averaging 25,000 m³ per tank. A collision will not always lead to a leak in the cargo tanks, because the ship has a built in penetration resistance. Parts of the ship that contribute to this penetration resistance are [10]:

• Inner and outer hull, equipped with longitudinal stiffeners.

- The stringers and decks.
- The bulkheads.

The probability for penetration of the cargo tank depends on the cargo tank configuration. The three tank types as described in section 2.5 all have different characteristics regarding penetration resistance [10].

a. Membrane system tanks.

The containment system fails when the inner hull of the LNG carrier is penetrated, because it is assumed that the membrane has no load bearing capacity. This tank type has the least resistance to penetration.

b. Self supporting rectangular tanks.

This system has higher penetration resistance, because the tank wall is placed deeper in the ship than with the membrane tank type. Especially for high speed collisions, the difference is significant.

c. Spherical tanks.

This cargo space configuration possesses the highest penetration resistance. This is due to the fact that only a small part of the tank wall is close to the ship's hull. The penetration of the hull in between two spherical tanks can be large without damaging the tanks, while a collision at the broadest point of the tank (closest to the hull) results in practically the same damage as for rectangular tanks.

Other factors which determine the amount of damage to the LNG carrier and its containment system are the following [10]:

- When the LNG carrier is rammed at the location of a bulkhead, the penetration resistance reaches its maximum value. At these positions, the construction is very strong.
- Non-orthogonal collisions reduce the penetration depth.
- A smaller bow angle from the penetrating ship significantly reduces the penetration depth.

No generally applied rules can be given for critical collision speeds (being the speed of the ramming ship to rupture the LNG carrier containment system). Research on collisions involving LNG carriers in the range of 70,000 m³ to 130,000 m³ capacity has resulted in critical collision speeds for the ramming ship of 8 to 10 knots. Prerequisite is that the ramming ship has a minimum weight of 5,000 to 10,000 DWT and collides with the LNG carrier under 90° at its most vulnerable point [10].

When the LNG carrier is the ramming ship, critical collision speeds are 12 to 15 knots, in this case the forward cargo tank can be ruptured. These speeds are only occurring during ocean voyages, never in ports or port approaches. During berthing, a ship's approach speed is reduced substantially below the critical speed to avoid damage to the hull and the breasting dolphins of the jetty. Passing ships however may very well present hazard to an LNG carrier at berth [10].

From historical data, it appears that 80% of all ship collisions occurs in coastal waters and ports [18]. Ship speeds in these areas are limited because of approach and berthing manoeuvres, the chances of a critical collision are rather small, but not negligible.

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3.7.3. Damage due to grounding.

When a ship runs aground, damage can be sustained, depending on the soil conditions and speed of the ship. This is called primary damage. When the ship is not directly refloated, additional damage from movement over the sea bottom by tide, wind and waves may occur. This is known as secondary damage and can be more worse than the primary damage [10].

Already mentioned in section 2.5, LNG carriers are equipped with double hulls and bottoms. Even when the outer bottom section is penetrated or damaged, the cargo tanks will remain intact. Penetration of the inner hull will result in water in-leak around the cargo tanks with loss of the inert space. Excessive boiling can occur with risk of overpressurisation in the cargo tank.

Only in the most severe groundings, the cargo tanks are directly damaged, for instance by sharp rock peaks. The chance of this situation is very small, because the cargo tank is located several metres above the outer hull.

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4. CONSEQUENCES OF AN LNG RELEASE.

4.1. General.

In the preceding chapter, the main causes of LNG spills are discussed. In this chapter, the consequences of the different spills are determined. The undesirable consequences are caused by one or more of the following properties of released LNG:

- Heat radiation from an LNG fire or direct contact with this fire.
- Pressure effects from a rapidly burning vapour cloud.
- Suffocation in a non-ignited vapour cloud.
- Explosive boiling of LNG on water.
- Low temperature of LNG.

When immediately ignited after release, the LNG forms a burning pool. If not directly ignited, the LNG forms a cold pool and quickly evaporates, forming a flammable vapour cloud. An identification scheme of the spill consequences is given in figure 4-1.

There exist fundamental differences between the behaviour of LNG in the various spill circumstances. The behaviour of LNG after being spilt can be divided in the following components: a) LNG spills on water

- Unconfined
- Confined

b) LNG spills on land

- Confined
- Unconfined

There are other consequences of an LNG release, not related to the preceding categories. Cryogenic embrittlement of the ship's structure through direct contact with the LNG, RPT (Rapid Phase Transition) and injuries to people when in contact with the LNG are such consequences.

4.2. Ignition of LNG.

When discussing the hazards related to LNG, the most dangerous situations seem to occur when the LNG is ignited. It is therefore important to understand the phenomenon of ignition.

LNG is a liquid and, as with all liquids, does not burn itself but only the vapour burns. Because the main component of LNG is methane, this substance is determining the conditions of ignition. Methane in air is a gas-oxidant system, these systems will normally ignite only within characteristic limits of composition. The concept of flammability limits has been proven to be a useful and reliable tool in determining these compositions [18]. In this concept a Lower Flammability Limit (LFL) is derived, being the ratio methane in air in the mixture under which no ignition will occur, and an Upper Flammability Limit (UFL) above which no ignition is possible. The flammability limits usually quoted for a methane/air mixture are concentrations of methane between 5% and 15%.

When within the flammability limits, methane can be ignited, but requires a minimum threshold energy. As long as the methane/air mixture is well within the flammable range, the ignition energy is relatively small. Only at the edges of the flammable range, where the likelihood of ignition is low, does the ignition energy that is required become significant, see figure 4-2.



Figure 4-1 Identification scheme of LNG spill consequences.



Figure 4-2 Ignition energy required to ignite a methane/air mixture.

Impact, accompanied by friction (generally the case in collisions and groundings of LNG carriers) can produce temperatures, approaching the melting points of the materials involved. During impact, fragments may be projected as sparks into the surrounding atmosphere. Surrounding flammable methane may then be ignited in any of several ways [18]:

- Aluminium, magnesium and titanium produce reactive sparks that cause ignition under impact
- Non-reactive sparks are usually cooler than reactive sparks and must therefore be larger to cause ignition.
- Hot surfaces, produced by friction, can ignite methane, depending on the surface area, the force applied, etc. In a test with mild steel on mild steel, methane was ignited under the following conditions:

Surface area: 645 mm² steel cube, pressed against a steel wheel.

Wheel speed: 4.6 m/s

Applied force: 2,000 N

These conditions will undoubtedly be exceeded in ship collisions involving the penetration of the hull.

- Embedded material may react with surrounding material. In particular the reaction between aluminium and rusty steel (iron-oxide) is known to occur and can produce very high temperatures (3,000 °C).
- Friction involving rocks of various types have been investigated. The results of these investigations state that for ignition by rubbing against rock surfaces, quartizitic rock must be present.

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4.3. Pool formation.

After an incident which leads to an LNG release, the liquid will form a cold pool of boiling LNG. The pool spreads until a minimum layer thickness is attained. This thickness depends on the roughness of the surface, the evaporation rate of the LNG and restricting boundaries. Unrestricted surface areas will produce a pool area, directly proportional to the evaporation rate of the LNG. The pool withdraws heat from the surroundings in order to evaporate. Due to the boiling state, any heat transfer does not lead to an increase in pressure, but to vaporisation without a rise in temperature. The main component of LNG is methane, so the arisen gas is essentially methane gas of approximately -160°C. At this temperature, the methane vapour density is higher than that of the ambient air and will therefore flow along the surface. The methane vapour then warms due to mixing with the surrounding air. When the methane vapour is warmed to -100°C the density becomes less than air and the vapour cloud rises [19].

The location of the LNG spill is an important parameter, because it determines the behaviour of the pool and vapour formation. On land, the pool attains its layer thickness due to the roughness of the soil. This layer thickness is assumed to be in the order of 5 mm up to several centimetres [20]. On water, the minimum layer thickness of the pool is determined by the radiation stress of the water. This layer is much thinner than for land spills and therefore the pool diameter is larger.

Another distinction must be made between confined and unconfined spills. Now four alternatives arise: spills on confined land surfaces, spills on unconfined land surfaces, spills on open water surfaces and spills on confined water, see figure 4-1. The behaviour of these spills will now be discussed.

SPILLS ON CONFINED LAND SURFACES.

The layer thickness of the pool is determined by the surface of the confined area and the amount of spilled LNG. In evaporation from the pool, there is a short initial period of very rapid vaporisation due to intense boiling, caused by the large temperature difference between the LNG and the land. When the pool has reached its maximum size, a relatively slow state of vaporisation is initiated. The vaporisation rate is determined by the mixing with surrounding air. This state is so much lower than the initial peak rate that the greatest hazard occurs within the first few minutes after the spill starts [13].

SPILLS ON UNCONFINED LAND SURFACES.

As stated earlier, the layer thickness now depends on the roughness of the underground. On contact with the ground, an initial period of rapid boiling and accompanying vaporisation is induced by the large temperature difference between land and LNG. After the pool has reached its minimum layer thickness, the rate of vaporisation decreases rapidly to a rather low value due to a low heat conductivity of the land. The evaporation rate is determined by the thermal characteristics of the ground and collected heat from the surrounding air [21].

SPILLS ON OPEN WATER SURFACES.

A spill on open water will spread until the minimum layer thickness is attained. This layer thickness is so small that the LNG will be totally evaporated at that time. On contact with water, the LNG boils rapidly due to the large temperature difference between LNG and water. Water has a high heat conductivity and continues to warm the LNG, creating a constant high rate of vaporisation. In turn, the LNG will chill the water directly below. No coherent ice layer is formed on the water, probably due to the vigorous nature of the boiling. The resulting vapour cloud resembles a pancake and has a diameter equal to the maximum pool diameter.

SPILLS ON CONFINED WATER SURFACES.

The initial state of the spill is the same to that on open water. When the total water area is covered with LNG, the spreading stops and only the layer thickness increases. The heat conductivity of the water now causes it to form a coherent ice layer within seconds. The temperature difference between water and LNG decreases during the formation of the ice. The vaporisation rate will decrease and it takes a longer period for the pool to evaporate totally [20].

4.4. Instantaneous ignition of an LNG spill.

In case LNG is instantaneously ignited during or after a spill, a pool fire originates. As is indicated in section 4.2, the LNG itself does not burn, but the vapour does. On open water, LNG has a continuous and high vaporisation rate. Cause of the rapid vaporisation is the rapid boiling due to the large temperature difference between the water and the cold liquid and the additional evaporation due to heat radiation of the flames. A pool fire on water therefore burns very rapidly, producing a high rate of thermal radiation and a large flame height. An LNG pool fire on water can thus be characterised as brief but intense.

A pool fire on land is most often confined, unless the amount of spilt LNG is very small. This is the result of the bund area, containing the LNG in a restricted area. The amount of LNG that is exposed to the air is relatively small and the layer thickness large. Only the part that is in contact with air can burn. Therefore these fires are not as fierce as pool fires on water, but the duration is longer.

4.5. Flammable vapour clouds.

If the released LNG is not instantaneously ignited, it forms a spreading pool and evaporates, as described in section 4.3. The resulting vapour cloud consists of a flammable gas (methane) and air. The vapour cloud can be ignited if the concentration of flammable gas in the cloud is between 5% and 15%. When the vapour cloud is ignited, it can burn or (under certain circumstances) explode. Explosions cause shock waves, able to cause damage in the vicinity of the explosion. Two types of explosion exist: deflagration and detonation. The differences will now be clarified:

DEFLAGRATION.

By adding a small amount of energy (for instance a spark) to the flammable vapour cloud, a continuous reaction will be initiated. As long as the reaction can propagate within an homogeneous mixture, a spherical flamefront originates from the point source of ignition. The reaction products expand due to the released heat and push the not yet reacted mixture forward. The thickness of the reaction zone is in the order of 1 mm and the flame velocity is about 3.0 m/s [10].

DETONATION.

The mechanism of detonation is based on an increase in temperature due to shock waves instead of heat conduction, as is the case for deflagration. When this shock wave is continuously supported by the released heat energy and thus can maintain its strength, the detonation phenomenon occurs. The accompanying flame velocities are supersonic.



Methane is classified as a low reactive fuel when ignited in unconfined spaces. This means that in unconfined spaces, the vapour cloud will only be subject to deflagration [13] [20] [21] [22]. A deflagration causes only small overpressures, with little probability of direct impact on human beings and buildings. Shattered glass can impose injuries to people. The main effects of a deflagration are the thermal effects of the burning of the vapour cloud.

In areas of high congestion and confinement, such as a dense formation of high buildings, mountains, high breakwaters or places where gas pockets can be formed, higher pressures can occur. These overpressures might be able to damage human beings and buildings.

4.6. Dispersion of an LNG vapour cloud.

Dispersion of gases in the atmosphere is defined as the spreading and rarefaction of the gas by a turbulent air stream [20]. When the vapour cloud is not ignited then it will harmlessly disperse in the air. Factors that influence the dispersion of methane vapour clouds in open air are, among others [7]:

- Diameter of the evaporating pool.
- Evaporation rate.
- Nature of the underground (roughness, thermal conductivity, etc.).
- Temperature of the underground.
- Atmospheric conditions (ambient temperature, humidity, wind speed, etc.).
- Atmospheric stability.
- Site topography.

When the vapour is evaporating shortly after the spill, it is still very cold and thus heavier than the surrounding air (reference is made to section 4.3). In this phase the vapour cloud only disperses sideways and only very slowly vertically. When the temperature of the vapour has increased to the point that the vapour is less dense than the surrounding air, vertical dispersion increases fast.

The dispersion behaviour of vapour clouds is assessed by computer models because of the complex subject.

4.7. Other consequences of LNG spills.

4.7.1. General.

The consequences, described in the preceding sections are the most severe consequences. There are other direct consequences regarding the release of cryogenic LNG. These will be discussed in the proceeding sections.

4.7.2. Rapid Phase Transition.

When two liquids at two different temperatures come into contact, rapid transfer of heat into mechanical energy can occur, producing significant overpressures. This phenomenon, called Rapid Phase Transition (RPT) can be induced when LNG is spilled on water. Although no combustion occurs, RPT has all the other characteristics of an explosion. The universally applicable theory, in agreement with experimental results, can be summarised as follows:



RPT is an interfacial phenomenon in which the cold liquid (LNG) undergoes a rapid rise in temperature such that the temperature of the surface layer exceeds the spontaneous nucleation temperature (when bubbles appear in the liquid). Prerequisite is that the temperature of the water (in °K) is greater than 1.1 times the boiling point of the LNG. At clean surfaces, such as that of water, there are no nuclei available so there exists superheating at the liquid-liquid interface. There exists a limit temperature for the superheating state. When the interface temperature is higher than the superheat temperature limit, rapid boiling occurs and the superheated LNG vaporises at an explosive rate (since the vapour volume is 600 times greater than the liquid, high overpressures can occur) [13] [21] [23].

4.7.3. Cryogenic embrittlement of the ship's structure.

LNG can be spilled on parts of the ship's structure for various reasons, for example cargo tank rupture or spills from the (un)loading arms. This induces extra hazards because when the cold LNG comes in contact with steel parts of the ship, this can result in cryogenic embrittlement and brittle fracture of the steel as a result of thermal stresses. Small existing cracks in the steel are able to initiate progressive rupture of the steel. Because of the low general stress level in the deck and hull structure of LNG carriers, crack propagation will be delayed and come to a stop when reaching the edge of the embrittled area [17].

4.7.4. Explosion in the ship's ballast spaces.

LNG spills from the ship's manifold or unloading arm can leak through cracks in the deck of the ship into the ballast spaces around the cargo tanks. The cracks would be the result of brittle fracture due to the cryogenic LNG. The vapour generated from the liquid can cause a confined explosion in the ballast tank, imposing overpressures on the structure well in excess of the bearable pressure [17].

4.7.5. Harmfullness to human beings.

The low temperatures associated with LNG can result in a variety of effect on the human being. If a person is not suitably protected against low ambient temperatures, the person's reactions and capabilities can adversely be affected.

Direct contact with LNG can produce a blistering effect on the skin, similar to a burn. The cold vapours, originated from evaporated LNG are able to cause the same effects. Even when the exposure with the cold vapour is too brief to affect the skin of face and hands, delicate tissues such as eves can be damaged.

Severe or prolonged exposure to cold vapours can cause frostbite. Local pain normally gives warning of freezing, but sometimes no pain is experienced. Prolonged breathing of the extremely cold atmosphere can give cause to lung damage. When the exposure is short, breathing discomfort can be endured. The danger from hypothermia is present in atmospheres up to 10°C.

The contents of the vapour are mainly methane and no carbon monoxide. It is not a toxic gas, the biological effect on human beings is only linked to a decrease of oxygen in the surrounding air. This can lead to nausea or dizziness.

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5. DECISION MAKING AND RISK ANALYSES.

5.1. The decision making process.

During the past decades, the insight in the hazards regarding LNG import terminals has been much improved, as is the knowledge of the construction methods and materials for LNG handling equipment. Still the decision making process regarding the permission to build a terminal at a certain location is very time consuming.

In the early days, these decisions were made without giving insight to the public. Scientists assessed the technological abilities of the terminal and made assumptions regarding the risks involved in the terminal operations. With these assessments, the scientists went to the decision makers (local or national politicians) and they approved the construction of the terminal.

Since the second half of the 1970's, public concern over the hazards related to the transfer of LNG has grown. The reason for this are some serious accidents with facilities processing dangerous goods during this time, a policy to release more information about minor accidents that normally would not been known by the public and a general movement of increasing awareness of the public.

The trajectory nowadays is one of participation. When a project is under consideration, several rounds of participation of all parties involved are made. During this process, all pro's and contras are evaluated before a final decision is made. The decision making process is not only dealing with the risks imposed by the terminal operations, but also involves other factors like visual impact, increasing noise levels, economic developments, environmental impact, etc.

5.2. Risk.

In the decision making process, emphasis is being put on the risk of the proposed activity. The difficulty is that risk is a rather elusive subject. Risk represents a quantifiable term with which uncertain consequences can be weighed. In terms of handling dangerous goods, risk is represented as a the product of two linked factors: the magnitude of the undesirable consequences and their probability of occurrence [10].

Various methods have been developed over the years to obtain values for risks in handling dangerous goods, among which is LNG. These methods are known as risk analyses. A risk analysis is best used as a decision supporting tool. The basic recipe for a risk analysis method depends on the followed methodology. It can be probabilistic and/or deterministic. For the probabilistic approach the steps to be followed are [7]:

- 1. Collection of failure rate data.
- 2. Composition of a list of potential hazards of external and internal origin.
- 3. Determination and classification of the probability of these hazards.
- 4. Determination of the consequences of each hazard and the allocation into classes of consequence.
- 5. Classification of accidents in accordance with their consequences and probability criteria in order to determine the level of risk.
- 6. Verification that no hazard comes within the "unacceptable risk" category.
- 7. Justification of the measures necessary to limit the risks.

Steps for the deterministic approach consist of [7]:

- 1. Composition of a list of potential hazards of external and internal origin.
- 2. Establishment of the credible hazards.
- 3. Determination of the consequences.
- 4. Justification of the necessary safety improvement measures to limit the risks.

It is favourable for the process if the decision makers define the initial targets for the risk analysis. The results of the risk assessment may show that the initial decision criteria have to be amended. When this is done and the risk analysis is adapted to the new targets, this feedback procedure ensures that the results of the risk analysis are in accordance with the real requirements of the decision makers [13].

The fact that risk is elusive is caused by the difficulty to assess the correct probability of occurrence. This is caused by uncertainties in the assessment. These are [13]:

- Catastrophic consequences have extremely low probabilities, which are difficult to assess and interpret.
- The total terminal system is very complex.
- The available data for new projects often is so limited that hypotheses and extrapolations concerning the behaviour of the system is necessary. This can lead to various interpretations of the figures.
- Extremely high safety levels may be only achievable through investments that stand in no relation to the economic dimensions of the product.

To cope with the described problems regarding risk, analyses procedures are developed to estimate the probability of occurrence of undesirable consequences of incidents. In the next sections, some methods that are frequently used in risk assessment are described.

5.3. Acceptability of risks.

When speaking of risk, it is important to have some benchmarks of the acceptability of certain risk levels. This can be done for individuals and for a society as a whole.

The amount of risk that is accepted by an individual person is not only depending on age and personal attitude, but also on the following factors [24]:

- The fact that the risk is voluntary accepted.
- The recognizability of the risk.
- The personal advantage from defying the risk.
- The societal advantage from defying the risk.
- The societal possibilities to reduce the risk.
- Repetition time of the chance incorporated in the risk.

In essence, two risk dimensions can be identified: the extent of a possible accident (irrespective of the probability of occurrence) and the degree of organised protection. This is especially important to now when discussing about the risks of LNG handling, because the risk consists of a very small probability of occurrence, coupled to catastrophic consequences.

In figure 5-1 the acceptance of risk divided in voluntary and non-voluntary activities is made, coupled to examples of these activities. The vertical axis gives the probability of death on a per year basis.



Acceptance of risks regarding the society is a difficult process. It can be established via a mathematic-economic weigh, based on the conversion of all possible risks into a monetary value. In this case a monetary value must be given to the death of a person as well as the economic loss when the facility on which the risk is applied is destroyed [24]. The amount of deaths is now a monetary parameter in the acceptability determination of the risk. The risks can be reduced but this will imply higher investments in the facility and safety measures.

Another method of determining the acceptable risk level is derived from accident statistics. It is then apparent that voluntary risks are on average larger than non-voluntary risks, this was approximately a factor 25 in 1976 [24].



Figure 5-1 Individual risk acceptance.

5.4. Risk levels, individual and societal risk.

In risk analysis methods, risk is defined as a combination of the probability of occurrence of an incident and the extent of the consequences of this incident. The risk is expressed by two parameters [25]:

- Individual risk. This is defined as the chance, on a per year basis, that an unprotected human being present at a location relative to the source of risk is affected by the consequences of an incident.
- Societal risk. This is defined as the relationship between the number of people killed in a single
 accident (N) and the chance that this number is exceeded (F). The size of the affected group of
 people can be taken into account using this parameter.

The fundamental difference between the two parameters is that the individual risk is only depending on the activity, whereas the societal risk incorporates the population density in the vicinity of the activity as well.

The acceptability of the risk is depending on local legislation and interpretation. When using the Netherlands as a reference, the acceptability limit of individual risk is defined as the risk level which increases the risk of death from all other causes with 1 percent [25]. This would imply a maximum acceptable risk level of 10⁻⁶ per year. Risks levels of 10⁻⁸ per year or less are considered negligible [25].

When observing the maximum acceptable societal risk -again with the Netherlands as a referencea risk level of 10^{-5} per year in case of an accident with ten deaths or more is set as standard. The negligible risk is attained for chances of 10^{-7} per year or less, regarding an accident with ten deaths or more [25]. When the number of deaths caused by an accident is increasing, the acceptable chance must be decreasing. When the number of deaths following an accident increases with a factor n, the acceptable chance decreases with a factor n² [25]. This can be visualised by a log-scale figure, called a F,N-diagram. An example of such a diagram is shown in figure 5-2.



Figure 5-2 F,N-diagram for societal risk.

5.5. The MCA method.

This method of risk assessment is one of the pioneers in the risk analyses sector. MCA stands for Maximum Credible Accident which is the definition of the worst acceptable situation. This is a subjective decision made by the expert, not the decision maker.

The procedure in the MCA method starts with the recognition of the potential hazards. Their consequences and influencing factors are determined in detail. Next, from all potential hazards, the ones which can lead to credible accidents (accidents that can reasonably be expected to take place) must be analysed. Out of the credible accidents, the Maximum Credible Accident has to be identified, leading to the worst set of circumstances. In LNG terminal design, the governing accidents are related to a spill of the cryogenic LNG, see chapter 4 [13].

5.6. Quantitative Risk Assessment.

5.6.1. Risk Contours.

Quantitative Risk Assessment (QRA) is used in two fields: one is the use as a tool to determine risk levels for employees and the public surrounding an LNG terminal, the other is the use as a tool in the optimisation in terminal layout and justification of risk reduction measures. The former field of application is described here, in the form of Risk Contours.

Risk Contours are defined as iso-risk lines on the map at which an unprotected human being, for 24 hours per day and without escape, would be subjected to a defined probability of fatal harm due to exposure to hazards induced by the LNG handling activities on a per year basis [26].

Risk Contours are calculated by assessing the consequences from a number of accident scenarios. By adapting criteria such as radiation from fires and explosion overpressure, effect distances can be assessed. Based on incident frequencies and effects from meteorological conditions (wind direction, stability, etc.) the contribution from each scenario to a point at a distance from the LNG terminal can now be calculated. By putting a grid over the considered area and summing the risk contribution from all scenarios for each grid point, a three-dimensional (x,y,risk) picture emerges. By connecting points of equal risk, a two-dimensional (x,y) picture results, which is easy to interpret. An example of such a Risk Contour plot is given in figure 5-3.



Figure 5-3 An example of a Risk Contour plot in two dimensions.

5.6.2. Legislative use of Risk Contours.

The generalised approach to risk embodied in the Risk Contours concept makes it attractive for legislators to use it as a decision making tool regarding the risk tolerability. When the assessed risk is not tolerable, measures can be taken to reduce the risk. The effect of measures can be studied to see whether they bring the risk within tolerable limits. The Risk Contour concept is an inviting concept to use in the decision making process to decide on the tolerability of risks. However, the current state of the used data in the Risk Contour concept makes an accurate result difficult. Two Risk Contour calculations with different computer models and different additional data may result in widely different contour sizes and thus implications for the terminal design [26].

5.6.3. Zoning principle.

QRA can be a useful tool in determining zoning distances. Each zone represents the severity of an incident. The effect distance of the incident must be smaller than the zone edges in which the accident occurs, see figure 5.4 for an example.

The zoning principle is advantageous because beforehand the possibilities are clear, in contrast with the Risk Contours concept which only indicates the risks and does not provide solutions for managing or reducing them [25]. A second advantage of the zoning principle is that it is possible to plan ahead, whereas with the Risk Contour concept this is very hard.



Figure 5-4 An example of different zoning distances, related to effect distances.

5.6.4. QRA used for option selection.

The risks of two alternative designs can be compared to see which of the alternatives imposes the least risks during operation. By quantifying the major contributors to the risk, an understanding can be developed why the risks are different and in what way the risks can be reduced most effectively.

The definition phase is the most important part of a comparing QRA. All that is different between the two alternatives should be integrated in the study. This includes all project phases and not only the operational phase as is often done.

Separation distances are meant to avoid a chain reaction when an incident on one part of the terminal occurs. The basis for the separation distance is often a credible accident scenario. This is an accident that has a relatively high probability of occurrence, like a flange leak or failure of a small pipe [26].

5.7. Formal Safety Assessment.

Besides risk analyses for the LNG terminal, It is desirable that a risk assessment of ship structures is made, taking all risks into account. Formal Safety Assessment (FSA) procedures and regulations inhibit all these risks under one denominator. The design of the FSA is generally the same as the other risk analyses: FSA procedures are [27]:

- 1. Identification of the hazards.
- 2. Assessment of risks associated with hazards.
- 3. Methods of managing identified risks.
- 4. Cost benefit assessment of the options identified in 3.
- 5. Decisions on which options to select.

There exist many kinds of risks in liquefied gas carriers. Basic philosophy of the proposal is to select some accidents that represent all risks in LNG carrier structures and to analyse and assess the selected accidents.

At first it is necessary to assume essential faults and their probabilities of occurrence and to find the correlation between accidents and the essential faults.

Essential faults are assumed to be:

- Failure of the construction and/or equipment of the ship.
- Human error in cargo handling.
- Special fault events.

Secondly, possible accident occurrence on a subject are empirically assessed and analysed by Event Tree Analysis (ETA), Fault Tree Analysis (FTA) and Simple Flow Analysis (SFA). When the probabilities are known, categorised risk levels and accident effects are defined and calculated, an indication is given in tables 5-1 and 5-2 [27].

A standard acceptable risk level is proposed for LNG carriers, deviating only a few percent from the fully assessed result in the total risk analysis. For other accidents, acceptable risk levels will be assessed using the aforementioned analysis methods.

Index	Extent of Accident	Reference : Critical distance for Ref. LPG tanker(70000m ³) and cargo release rate <i>Qr</i> in open area
A	An accident which shall practically no effect to the ship and personal concerned. If not leave as it is, intentionally or ingross negligence. $Xc = in local$ $Q_R < 0.05 kg/s$	
В	An accident which is possible to bring effect such as resulting a slight injury or the ship's damage with a short period of suspension or a serious effect to the environment.	Xc<85m Q _R <10kg/s
С	An accident which is possible to bring a serious injury to the personnel. the ship's damage with long period of suspension or a serious effect to the environment.	Xc<350m Q _R <400kg/s
D	An accident which is possible to bring many deaths or critical injured personnel. Total loss of the ship. or a catastrophic effect to the environment. $Xc>350m$ Q _R <400kg/s	

Table 5-1 Accident effect categories.

Index	Probability of Occurrence per Ship		Reference
1	Extremely _ few	<10 ^{.7} /Y	probability of occurrence of a big disaster (fatalities numbered abt.900) on an atomic power plant = 1.0x10 ⁻⁹ /(Y x Plant) (US)
2	Few, but possible to occur	10 ⁻⁷ ~10 ⁻⁴ /Y	Occurrence rate of L.P.G explosion in the general households = $2.5 \times 10^{-7}/(Y \times Household)$ (Japan.1975)
3	Low	10 ⁻⁴ ~10 ⁻² /Y	Occurrence rate of an engine room fire of the general ships = 4.0×10^{-3} /(Y x Ship)
4	Comparative ly many	<10 ⁻² /Y	Occurrence rate of a serious casualty on the oil tankers = 1.0×10^{-2} /(Y x Ship)

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Table 5-2Accident probability categories.

5.8. Applying threshold values.

Risk analyses not always have to be executed. It must only be applied when the design exceeds certain threshold values regarding consequences. The threshold values are mostly used for heat radiation and overpressure values. The difficulty is that for different countries different values for the thresholds are in use. The values are gained through experiences during tests or are copied from other countries. The threshold values have also changed over the years. Examples are now given.

Research in the Netherlands in 1976 lead to the following thresholds for heat radiation and overpressures [10]:

Heat radiation:

2 - 10 kW/m² This corresponds to a maximum resident time of 1 minute to several seconds for people in the hazard area.

5 kW/m² This corresponds to a resident time of several minutes for people when protective cloths are worn.

Overpressure lasting 1 millisecond:

- 7 bar The lethal threshold.
- 0.35 bar Threshold of ear drum rupture.

0.02 bar Temporary hearing damage.

In this same period, research in the United States came to the following threshold values [23]:

Heat radiation:

18 kW/m^2 This will blister exposed skin in 7 seconds.

5 kW/m² This will impose blister effects after 1 minute and is regarded as the safe limit.

In 1985, PIANC researchers developed other thresholds [13]:

Heat radiation:

1.5 kW/m² For places of high occupancy at the terminal and in residential areas.

 8 kW/m^2 For other areas.

Overpressure:

0.30 bar Heavy damage to constructions and buildings.

0.03 bar Dangerously shattered glass, chances of fatalities.

These values show that no general applicable thresholds have been set for the consequences of ignited LNG. Only this year a European Standard, valid in all European countries, has been validated. This Standard contains the State-of-the-art in LNG safety. When no distinct local threshold values are known or applicable to the development of the LNG terminal, the thresholds of the new European Standards can be used [7]:

- 32 kW/m² For concrete outer surfaces of storage tanks.
- 15 kW/m² For metal outer surfaces of storage tanks and process facilities.
- 8 kW/m^2 For the control room area, laboratories, etc.
- 5 kW/m² For administrative buildings.
- 13 kW/ m^2 For remote areas outside the terminal boundaries.
- 5 kW/m^2 For urban areas outside the terminal boundaries.
- 1.5 kW/m² For critical areas outside the terminal boundaries (being places where people without protective clothing can be required at all times or a place that can not be evacuated at short notice).



5.9. Value of risk analyses.

Risk analysis methods can be a great help to give insight in the nature of hazards, associated to the handling of LNG and the possibility to identify measures that can be taken to reduce risks and assess the effectiveness of these measures. Because it is a systematic approach to highlight potential causes and consequences of (major) accidents, it can be able to prevent these incidents and can prevent the investment in ineffective measures.

A distinction should be made between quantitative and qualitative risk analyses. The efforts to be made in a qualitative assessment are less than in quantitative assessments while the results can already be very good. Especially when specialist knowledge is limited, first a qualitative risk assessment should be made. This qualitative assessment should indicate areas where a subsequent quantitative assessment would be of benefit or where more detailed research is required.

Quantitative risk analyses have recognised problems, including:

- There often is a level of disagreement in criteria for evaluating the acceptability or of the overall risks.
- When assumptions must be made, always conservative values are used. This can lead to serious over-estimates of risks.
- Publication of the details of a quantitative risk analysis can cause needless alarm among the public. This because the attention is focused on the disastrous consequences of major spills, even though the probability of such accidents is extremely low.

Any form of quantitative risk analysis must only be used as an aid in the decision making process. It must not be used as a generator of numerical results when deciding on acceptability. In this way the limitations to produce accurate and independent results of the method are ignored.



6. SAFETY MEASURES IN LNG HANDLING.

6.1. General.

In the preceding chapters, the emphasis was put on things that can go wrong in LNG handling, both on the terminals and during transit. Especially the catastrophic scenarios have been discussed extensively. In this chapter, measures are proposed that can reduce the probability of accidents or the severity of the effects or are able to prevent the accident to occur. The safety measures are implemented during the design of the LNG terminal and for many of these measures, it is difficult to implant them in existing facilities. It is therefore advised that for a proper understanding of the safety measures on the terminal, chapter 7 is consulted for the understanding of the various terminal equipment.

6.2. Set up of a safety control system.

In order for the LNG terminal to be operated economical and efficient in a safe manner, the terminal operators should be able to monitor and control both the gas processing as well as the terminal safety. To be able to do this properly, a process control system and a safety control system are incorporated, giving the operator real-time information and enabling the adjustments of operating parameters. The two systems are interrelated, as they monitor the same installations and can activate measures by transmitting information to each other.

The process control system monitors and controls the main functions of the receiving terminal, among which are [7]:

- Ship unloading.
- LNG storage.
- Boil off gas recovery.
- Vaporisation.
- Gas treatment.
- Natural gas send out.

Control of these main functions can be automatic or semi-automatic. When the system is not working correct, a Process Shut Down (PSD) might be initiated in part of the process or for the terminal as a whole.

The safety control system is designed for loss prevention and detection. The functions of this system are [7] [19]:

- The acquisition of data provided by safety detectors, regarding loss of containment:
 - ♦ LNG spill.
 - Natural gas leakage.
 - ♦ Fire.
- The initiation of Emergency Shut Down (ESD) and, when necessary, PSD in automatic or manual mode, following detection or an operator order.
- The implementation of appropriate protection equipment, following detection or an operator order.
- The monitoring and control of protection equipment.
- Self-diagnosis capabilities.

6.3. Detectors.

To detect an incident on the terminal, the safety control system uses detectors/sensors which give warning of leakage of LNG, natural gas, other flammable liquids or noxious vapours from the LNG terminal and indicate the presence of smoke and flames in case a fire breaks out.

There are a variety of detectors available. They can be divided into 5 groups, according to their purpose:

- Gas detectors.
- Low temperature detectors.
- Flame detectors.
- Smoke detectors.
- Heat detectors.

The principle of the various detectors and their possible locations at the LNG terminal will now be described.

GAS DETECTORS.

The gas detectors are installed to allow fast detection of leaked gas or evaporated LNG. There are three types commonly in use:

- Catalytic combustion sensors.
- Thermal conductivity sensors.
- Semi-conductor sensors.

These detectors are all of the point-sensing type. The catalytic combustion type is very sensitive and only detect flammable gases. They are not affected by water vapour but are vulnerable to catalyst poisoning; if so, sensitivity is decreasing.

Semi-conductor sensors are also very sensitive, but are sensitive to non-flammable gases (such as water vapour or nitrogen dioxide) as well. These detectors have a long life (over three years).

Thermal conductivity sensors have the lowest sensitivity but are allowed to be used over the full range of gas concentration. They can be used in the absence of oxygen [11].

Recently a linear gas detector based on laser technology is developed, able to cover a wide area of the terminal.

The range of gas concentrations to be measured shall be between 0% and the LFL [7].

Gas detectors are often installed near the following units [7]:

- Unloading areas.
- Vaporisers.
- LNG pumps.
- Flanges of pipework.
- Boil off gas compressors.
- Points of possible concentration of LNG in impounding basins.
- Buildings and enclosed spaces where gas can accumulate.
- At the inlet of building heating, venting and air conditioning systems, burners of vaporisers, air compressors, diesel engines, gas turbines and gas engines.

LOW TEMPERATURE DETECTORS.

Low temperature detectors are installed for the detection of LNG leaks. Traditionally these are point-sensing devices based on industrial thermo-couples, resistance thermometers or bi-metallic switches. Recently coldstrip-thermistor and fibre optic detectors have been developed, being able to detect the presence of LNG along their length (linear detector type) [11].



The use of low temperature detectors is recommended at the following locations [7] [11]:

- In the insulation space of LNG storage tanks.
- LNG storage tank impounding areas/bunds.
- LNG impounding collection basins.
- In LNG spillage collection channels.
- Around LNG pumps.
- Around vaporisers.
- Under unloading arms.
- At any low point where LNG is likely to collect.

FLAME DETECTORS.

This type of detector is able to detect radiation from flames very rapidly. These devices are able to view defined areas and are mostly used outdoors. The following types are in use:

- Ultra-violet detectors (UV).
- Infra-red detectors (IR).
- A combination of the above (UV/IR).

These devices are prone to false alarms. UV detectors are sensitive to lightning, while IR detectors can give alarm when receiving radiation from welding. When the detector is of the combined UV/IR type, the false alarms for the two types can be mutually excluded and thus a greater reliability can be achieved [11].

Locations of the flame detectors can be [11]:

- At unloading areas.
- In impounding areas/bunds.
- On storage tank roof tops.
- In the process areas.

SMOKE DETECTORS.

These devices are the second fastest fire responders. Two point-sensing types are in use:

- Ionisation smoke detectors.
- Photo-electric smoke detectors.

The first type responds best to high-energy fires with a high emission of small smoke particles. The latter responds better to low-energy fires producing larger smoke particles. In order to minimise the chances on false alarms, the detectors must be equipped with time delays [11]. Smoke detectors are also very efficient for use in buildings, containing electrical cabinets. Installation shall be at points where smoke is likely to collect.

HEAT DETECTORS.

Heat detectors are the slowest responders to a fire, detection may be delayed minutes. There is no chance for false alarms, which makes them very reliable. Three types are in use:

- High temperature sensors.
- Rate of temperature sensors.
- Fusible elements.

The first two detectors are available in point or line configuration and can be reset after alarm. The last detector type is a point-sensing device and must be replaced after alarm [11].

A certain level of backup, after failure of a detector, is required and depending on the acceptability of the risk accompanying the event. It can be tolerated that a single detector fails if the total detection system ensures to detect the incident [7]. Still it is common practice to install two sets of all detectors (the linear and flame detector types) and three sets in the case of point-sensing detectors. This is mainly to avoid the appearance of false alarms [11].



6.4. Control centres.

6.4.1. Types of control centres.

There are three control centres involved in the handling of LNG and natural gas: the ship's cargo control centre, the jetty control centre and the main control centre.

The ship's cargo control centre is situated on board the LNG carrier. From this room the control of the ship's cargo unloading operation is directed. The following equipment is required in this control centre [28]:

- A communication system with the port authority.
- A communication system for the cargo transfer operation.
- Monitoring equipment for tank level, temperature and pressure.
- Emergency shutdown control devices.
- LNG pump and cargo transfer valve controls.
- Trim and ballast controls.
- Fire alarm monitoring system.

The jetty control centre is situated on or adjacent to the jetty. From here, the unloading operation and specifically the unloading arms are controlled. It is recommended that the jetty control centre contains the following equipment [28]:

- The communications system between the main control centre and the ship's cargo control centre.
- The unloading arms controls.
- The purging control system for the unloading arms.
- The cooling down controls for the unloading arms.
- The emergency uncoupling controls.
- The fire fighting control centre for the jetty head.
- A weather data station.
- Mooring line tension monitoring equipment.

The most important is the main control centre. This is the hart of the LNG terminal, where all orders are given for operation, communication and safety purposes. From this location, the operator must be able to monitor and control gas processing and terminal safety, must be able to exchange information and must be able to be informed about incoming or intruding people. For this purpose, various systems are developed and controlled in the main control centre [7]:

- The process control system.
- The safety control system.
- The access control system.
- The communication network.
- A closed circuit TV system.

The first two are already described in section 6.2.

6.4.2. ESD and PSD.

The operator in the control room is enabled to monitor and control protection equipment and protection auxiliaries, activate all Emergency Shut Down systems (ESD) with the corresponding push button and inhibit the automatic activation of an ESD with a dedicated key.

In the event of a confirmed detection or upon the command of the operator, the automated safety system activates the appropriate ESD, which mainly consists of shutting down equipment and actuating safety isolation valves. In this way, the following Process Shut Downs (PSD's) can be triggered [19]:

- The unloading PSD, which halts the ship's unloading pumps and closes the ship and unloading arm ESD valves.
- The send out PSD, which halts the high and low pressure LNG pumps, stops the boil off gas compressors and decompresses the high and low pressure LNG lines behind the ESD valves.
- Tank filling PSD, which stops the filling of the tank by shutting down the tank filling line ESD valves.
- Vaporiser PSD, which stops the vaporisation process and shuts the vaporiser ESD valves in case of vaporiser excess overpressure. The vapour is relieved directly to the atmosphere, except when this leads to an undesirable situation (for example in case of a fire in the vicinity). In this case the vapour is routed to the flare/vent system. When the temperature of the gas in the outlet is 0° C an alarm is sounded. When the temperature of the gas is -5° C, ESD is initiated. These thresholds are valid both for Open Rack Vaporisers (ORV) and Submerged Combustion Vaporisers (SCV) [7].
- The terminal PSD, which combines the previous PSD's.

In conclusion it can be stated that PSD is often initiated by closure of ESD valves in LNG or gas pipelines. The efficiency of these valves in preventing large LNG spills depends for a large part on the closing time of the valves after the command for shutdown is given.

6.4.3. Communications.

The communication systems between the ship and the port, ship and terminal and mutual between control centres are various. Often used equipment is described hereafter.

The LNG carrier is in contact with the port authority via a VHF radio on a reserved channel. Oral communication with the jetty/terminal and on the ship itself is achieved by portable radios and telephones. To be able to record the situation of the cargo during the unloading operations, a data link is made between the ship's measurement equipment and the terminal's control rooms.

On the jetty, portable radios are available for the oral communication with the ship during mooring and connection operations. The terminal shall install an emergency stand-by oral communication link, probably a VHF radio. A hard wire data link, suitable for transferring data between the ship and the terminal, is provided up to the jetty head. A back-up system for this data link must be available.

6.5. Fire protection.

When a fire breaks out at an LNG terminal, protective actions must be taken to minimise the effects of the fire and to extinguish it. The fire protection systems for protection of the terminal installations and personnel can be either passive or active. Passive systems are permanently present and ready for use. Active systems require activation, either manually or automatically.

Passive fire protection is achieved by an adequate layout and spacing of the terminal and its constituents, flammable liquid conveyor channels and impounding basins, and insulating coatings.

Active fire protection equipment exists in a variety of forms. The terminal should be in possession of a meteorological station, measuring relevant data (such as air temperature, wind speed and direction, humidity, etc.). The obtained measurements enable the determination of the deployment of the appropriate fire fighting equipment. Another factor for the choice of fire fighting equipment is the extent of the fire and the presence of people in the vicinity of the fire. The commonly used fire fighting equipment will now be described:

WATER FIRE FIGHTING EQUIPMENT.

Although seemingly normal as a fire fighting means, water can not be used for the control or extinguishing of LNG fires. For reasons named in section 4.4, water that comes in contact with LNG will increase the evaporation rate of the LNG significantly. The burning rate of the LNG pool-will subsequently increase and thus the application of water on LNG fires will have negative consequences on the control of the fire.

The primary functions of fire fighting water at LNG terminals is the cooling of structures and the reduction of LNG evaporation by setting up water curtains.

The fire fighting water is drawn from the sea or can be extracted from sweet water storage tanks. As a minimum, two fire fighting water pumps must be installed, provided with independent power sources to secure sufficient capacity even when one pump is unavailable [7]. The fire fighting water ringmain is connecting fire fighting water networks around all sections of the terminal containing flammable fluids. All the networks must be kept under a minimum pressure at all points. Special preventions must be taken to avoid damage due to freezing. The system must be at operational pressure when transfer is in progress.

The cooling of storage tanks, equipment subjected to heat radiation and other equipment that could otherwise worsen the LNG fire is achieved via a water deluge system. This system distributes a water flow evenly over the surface of the exposed structure. Deluge systems are designed to prevent the water from coming into contact with LNG. Special drainage facilities must collect the water. When a fire is present in the bund area of a storage tank, this storage tank can not be deluded, because then the water and LNG can come in contact.

Water curtains are used to rapidly lower the gas concentration of an LNG vapour cloud below the LFL. The water droplets transfer heat to the LNG vapour, together with the large quantities of entrained air. Therefore the vapour cloud dilutes rapidly, increasing its buoyancy and thus increasing dispersion of the cloud. To be effective, water curtain systems must be positioned as close as possible to the area of possible spill. They shall be positioned around the impounding areas of LNG storage tanks, thus providing a barrier for LNG vapour clouds. For reasons mentioned earlier, contact between the water droplets and LNG must be excluded. The water originating from the water curtain system must be drained.

FOAM GENERATION.

Fire fighting high-expansion foams are used to reduce the heat radiation and evaporation rate of LNG during fires, rather than extinguishing the fire. The bund areas of storage tanks and other impounding basins are generally equipped with foam generators. The foam is applied in layers that are a few metres thick, so that the heat radiation is reduced with 90% [7] [11].

CELLULAR GLASS.

Cellular glass is used in impounding basins and bund areas as a substitute for foam generators. The bottom of these areas is covered with blocks of the cellular glass, which will -in the event of an LNG spill- float on the LNG layer and reduce the evaporation rate of the LNG and the thermal radiation in case of a pool fire [11]. In designing a cellular glass protection, the following guidelines must be taken into account [7]:

- The cellular glass must be protected from the penetration of moisture, to avoid contact between water and LNG.
- Direct contact between the bottom of the impounding areas and the cellular glass must be avoided. The interspace should at least be 5 cm.
- The thickness of the cellular glass layer must be at least 20 cm, with a minimum of two layers of cellular glass to be effective.

The application of this system is still in its early phase. Only very few terminals are equipped with this system, because their cost-effectiveness is questioned [11].

DRY CHEMICAL POWDER SYSTEMS.

The method for extinguishing LNG fires is the use of dry chemical powder. The powder must be applied above the surface of the liquid without agitating the latter. Agitation of the liquid surface will increase the evaporation rate, just as with water, and thus the burning rate. To extinguish the fire in the most reliable manner, it should be covered with powder at once. Else radiation from remaining flames is able to re-ignite the vaporising LNG [7].

Economically sized powder extinguishers can only operate for a short period of time (7 to 80 seconds) before they need recharging [11]. Therefore application in storage tank bunds is not recommended. Typical locations for powder extinguishers are at the jetty, near LNG pumps, vaporisers and boil off gas compressors.

MOBILE FIRE FIGHTING EQUIPMENT.

The mobile fire fighting equipment is used as a back up facility for the fixed fire fighting systems. They normally consist of self powered trucks, trailer units or trolley units. These units carry either dry chemical powder or fire fighting water [11].

HALON FIRE FIGHTING DEVICES.

To extinguish electrical fires inside buildings at LNG terminals, fixed Halon systems are used. These systems are normally designed to totally flood the space [11].

The described fire fighting methods are directed from the main control room or automatically upon detection. The safety control system will take care of the correct production of fire fighting water, and will provide selective activation of the appropriate fire protection equipment.

In the next sections, safety provisions for specific parts of the LNG transfer and storage process shall be proposed.



6.6. Safety provisions for the LNG carrier.

When speaking of LNG carriers, a distinction must be made between the navigation of the LNG carrier in port approaches and the port itself on the one hand, and the LNG carrier at berth on the other. The total scope of arrival, berthing, cargo handling operations and departure of the LNG carrier require detailed planning and communication between the ship, the port authority and the LNG terminal in case the traffic is dense. In order to secure the safest possible conditions before, during and after cargo transfer, it is important that the ship/shore checklist is used. This checklist must be completed by ship and shore personnel when the LNG carrier is berthed alongside the jetty, but always before the actual transfer is commenced. An example of a ship/shore checklist, as is used in the port of Nantes/St. Nazaire, is included and can be found in Appendix B. It must be stated that this is only for indicative means, and that in other ports and other countries other ship/shore checklists or control means are valid.

When at berth, safety rules on board the LNG carrier direct areas in which the access of nonauthorised personnel is restricted, this is especially the case for the area surrounding the cargo transfer manifold. The access from the jetty to the ship and vice versa must be twofold. One access is provided for escape of personnel and crew in emergency events. It is located near the ship's accommodation units. The second access is provided for operational personnel and must be located away from the manifold vicinity.

The manifold area itself is protected by passive and active protection measures. A passive protection for the ship's deck is provided by a spill collection tray under the LNG transfer connection. Active protection by means of fire fighting equipment consists of portable and/or fixed dry chemical powder units, water hoses and a water deluge system. At least two portable fire extinguishers must be available close to the manifold area. The water deluge system protects the hull from the LNG carrier against heat radiation from a fire and the embrittlement of the steel due to cold shock from the LNG.

In case of an incident in the transfer area, Emergency Shut Down (ESD) is initiated. This ESD must be operational when the connection between the ship and the unloading is made, this is before transfer is commenced. On the ship side, ESD automatically stops the LNG unloading pumps and closes the ESD valves on the manifold. The ESD can be initiated manually from each of the described control centres or automatically. An extensive description of the ESD function will be given in section 6.7.

Safety in navigation of the LNG carrier in port approach and within the port is mainly achieved via operational procedures. Hereafter several possibilities of operational procedures are described. It is stressed that these procedures are dependent on the local circumstances, either legislative and topographic.

To avoid collisions between LNG carriers and other ships when approaching the port, a separate port approach route can be designed for LNG carriers. This route should be located as far as possible from the coast, providing a separate anchoring zone and/or pilot boarding area.

To attain a high level of safe navigation, it is recommended to assign a Vessel Traffic System (VTS), operated by a port control centre or similar organisation. This VTS can cover an area well beyond the port entry to allow sufficient time and space to organise the traffic flow. The implementation of such a service can only be validated if the port receives large numbers of ships, among which ships containing hazardous cargo. So not only LNG carriers benefit, but also the crude oil and product carriers and the chemical tankers.
Services that a VTS can provide are, among others, the following [13]:

- The exchange of information with ships on safety matters, traffic conditions and situations, etc.
- Provision of auxiliary services such as pilotage in order to assist ships in difficult navigational or meteorological circumstances, warn ships of obstacles and to provide alternative routes, and schedule ship moments (for example establishment of one way traffic).
- Prescription of ship speed and routes.
- Restrictions for entering the port depending on the weather and sea conditions (for instance excessive wind speeds or low visibility).
- In some ports, mostly Asian, entry permission is only given after signing a pledge letter in which all sorts of pledges are summed up which must be observed when the port is entered. A copy of such a pledge letter which must be signed in the port of Osaka is shown in Appendix C.

Additional regulations can be the following [13]:

- Restriction to daylight navigation of the LNG carriers.
- Priority status granted to the LNG carrier.
- Restriction or prohibition of other ship movements in the port or in a specific area around the LNG carrier when the ship is manoeuvring, or the establishment of single lane use.
- Installation of time frames for the entrance of the LNG carrier, depending on the tide and cross currents.
- Prohibition of overtaking manoeuvres involving an LNG carrier.
- Auxiliary services: high speed police escort boat, tugs and mooring boats.
- Prohibition of cross-lane traffic.

6.7. The transfer area.

The first safety measure in the transfer area is that of a zone around the jetty and the ship berthed alongside which might not be entered by other maritime traffic. The extent of this zone is determined by the local port authorities. The best solution is to make a dedicated LNG carrier port in which no other traffic is allowed.

To control the safety on the jetty, non-authorised personnel is refused admittance to the areas affected by the transfer operation. This is also valid for moving vehicles. These areas must be clearly identified and shall at least comprise of the manifold and unloading arms area. Supplying stores during transfer is prohibited, bunkering may be allowed, but only under stringent procedures.

When a spill occurs, it is prevented from coming in contact with the jetty structure by a collection channel under the transfer arms, pipelines and valves. Ignition sources in the form of electrical or non-electrical equipment are often controlled by operational procedures. This means that on detection of an LNG spill, this equipment is automatically shut down. A specific risk is the possibility of spark generation during (dis)connection of the manifold and unloading arm flanges due to the difference in electrical potential between the LNG carrier and the shore based unloading arms. To avoid this, an insulation flange between the ship and shore is installed [28].

When, in spite of these provisions, a fire does break out, fire fighting equipment must be available for direct use. The fire fighting equipment on the jetty is extensive, consisting of fixed and portable equipment.

Fixed equipment are both water and powder gun systems. These systems are installed at a level high enough to ascertain coverage of the upper part of the ship's deck in all occasions. The equipment must also be able to reach all parts of the transfer facility. Powder supply tanks should be located at a low level to protect them from heat radiation in case of a fire [28].

Portable equipment consists of hand carried dry powder extinguishers. These devices must be ready on all jetties to fight the outbreak of small fires. Their capacity must be above 9 kg of powder [28].

These fire fighting means should preferably be backed up by larger mobile units in case the fire increases [28].

When the unloading of LNG is achieved with high discharge rates, ESD must be incorporated in the transfer system. Normally, the ESD is triggered manually from one of the control centres and automatically when one of the following events are encountered [28]:

- Detection of a liquid spill.
- Detection of a fire.
- High high level in shore storage tanks.
- High pressure or vacuum in the ship or shore storage tank.
- Loss of electric or control power on the ship or shore.

The ESD procedure consists of stopping the terminal's gas compressors and the ship's LNG pumps, closing the ship's ESD valves on the manifold, closing the shore based ESD valves and assure prevention of surge pressures. After the emergency situation is tackled, the transfer operation must be able to continue quickly.

There is still one other reason when ESD is initiated, and that is when the unloading arm exceeds the movement limit defined by the second level extension alarm of the Position Monitoring System (PMS) of the transfer arms. PMS permanently monitors the position of the connection flange of the transfer arm, this is visualised in figure 6-1 [15].



Figure 6-1 The definition of the Position Monitoring System.

ESD then is part of a larger system of spill protection, namely the Emergency Release Procedure (ERP). The ERP most often consists of three stages:

- Sounding an alarm when the arm reaches the limit defined by the first level extension. This is a
 pre-alarm stage. No action is taken, only a signal is sent to the operator that corrective action
 must be taken to bring the LNG carrier under control (for example tensioning the mooring lines)
 [15].
- Stopping the LNG pumps of the ship and closure of the ESD valves when the arm reaches the limits of its working range (execution of ESD). This is the second stage alarm. The sequence is still reversible, transfer can be restarted immediately when the situation is under control.
- 3. Initiating the disconnection sequence when the arm reaches its limit of the maximum operating envelope (ERS).

ERS stands for Emergency Release System. This is a disconnection system which is initiated before or after completion of the ESD. If the emergency situation still exists the normal disconnection procedure can not be achieved. This might be the case when there is a possibility of transfer arm failure due to excessive movement of the ship. In this case a device called the PERC (Powered Emergency Release Coupling) provides the disconnection. The PERC includes two ball valves, joined together with an emergency release coupling. When the over-extension alarm is reached, the two ball valves will automatically be closed and when shut-off is completed, the coupling between the two balls automatically releases the outboard part [16].

6.8. Safety provisions for LNG storage tanks.

Various systems are developed to monitor and control the operation of LNG storage tanks on import terminals. These systems must, as a minimum, cover the following phenomena:

- Liquid level in the tanks.
- Pressure in the tanks.
- Temperature of the liquid and tank walls.
- Density of the LNG in the tanks.

Hereafter, the instrumentation to measure the preceding items will be described.

LIQUID LEVEL MEASURE INSTRUMENT.

The instruments that measure the liquid level must also be able to initiate protective actions. These devices must particularly allow [7]:

- Continuous measurement of the LNG level in the tank from at least two independent systems. Each system must include a high level alarm and a high high level alarm.
- Detection of the high high level by a system, independent of the ones mentioned above. High high level alarm must initiate the ESD function for filling pumps (on the ship) and ESD valves in the tank filling lines.

As a last resort, a tank overflow pipe can be installed. This pipe is lead through the side wall of the primary container. The overflow pipe must be located at a height at least equal to the high high liquid level [7].

PRESSURE MEASURE INSTRUMENT.

Pressure checking instruments in storage tanks have the following functions [7]:

- Continuous pressure measurement.
- Detection of excess pressures by instruments, independent of the continuous measurements.
- Detection of vacuum in the LNG storage tanks by instruments, independent of the continuous measurements.

Following detection of excess pressure, safety devices -being at least two overpressure valvesdirectly relief vapour to the atmosphere. When this is not possible because of an emergency situation, such as a fire, which would be worsened by direct venting, the valves will be linked to the flare/vent system [7].

When a vacuum situation is detected, the boil off compressors and tank unloading pumps are automatically stopped. These actions might be supported by a vacuum breaker system which consists of [7]:

- A gas or nitrogen injection system. This will act first.
- Vacuum relief valves that allow air entrainment in the tank. Because the introduction of air in the storage tank can form a flammable vapour in combination with LNG vapour, this must only be used as a last resort to prevent permanent damage to the storage tank.

TEMPERATURE MEASURE INSTRUMENT.

Five sets of temperature measurement systems must be installed [7]:

- On the outer skin of primary tank wall and bottom. This enables the monitoring of cool down and warm up of the tank. This is not applicable in membrane tanks.
- On the warm side of the insulation layer (wall and bottom) to detect LNG leakage from the primary tank.
- On the outer surface of the secondary containment tank to monitor the temperature gradient.
- The temperature of the LNG must be measured at several depths, measurement points must be within 2 metres vertically of each other.
- The vapour temperature above the liquid must also be measured.

DENSITY MEASURE INSTRUMENT.

The density of the liquid must be measured throughout the liquid depth.

Temperature and density measurements in the liquid are carried out in order to detect the possibility of a roll over (see section 3.2.2).

Other measures that can prevent the roll over phenomenon are the installation of a recirculation system that mixes the LNG in the tank and the monitoring of the boil off rate. Increased boil off can also indicate the roll over phenomenon.

6.9. Safety provisions for pipework.

Pipelines and their supports are generally protected against heat radiation through coatings. ESD valves are incorporated in long pipelines to limit the amount of spilled LNG in case of pipework failure. Impounding basins might be installed underneath these ESD valves and pipe flanges to collect any spilled LNG and preventing it from damaging unprotected carbon steel such as that from pipe racks.

Thermal relief valves for the protection overpressures in pipework resulting from ambient heat inleak are recommended to be installed. They should be installed at least at the section limits of the process installations and in storage and unloading areas [7].

There are several fire protection systems available for pipework protection. These systems comprise a water deluge system, water curtains, high expansion foam and dry chemical powder [7].

7. GENERAL TERMINAL LAYOUT.

7.1. Determination of a suitable location.

When there is a need for importation of LNG, a suitable location must be found. There are various restrictions governing the location. An important boundary condition is the location of the customer. When the customer is a power plant, the terminal would be preferably located in the vicinity of the installation. This is favourable as the cold LNG can pre-cool the air intake of the power plant and thus creating an increased efficiency and power output [2]. On the other hand the warm cooling water from the power plant can be used in LNG vaporisers at the terminal. Other facilities that can be of joined use are for example fire fighting facilities.

This might be possible if the site study allows an LNG terminal to be built. The site study is a very extensive investigation consisting of the following elements [7]:

- A soil survey.
- A study of ground water tables.
- A study of the marine environment.
- A study of the tidal conditions.
- A study of the marine access.
- A survey of the surrounding infrastructure
- A study of shock-waves and flooding.
- A climatic study.

The soil survey comprises a geotechnical survey enabling the determination of geomechanical characteristics of the subsoil, and a geological and tectonic investigation. This investigation must ensure a sound geological base over which the terminal installations foundations will be built.

A geotechnical parameter is for instance the foundation strength of the soil types. Geological information is concerned with the layering of soil types and the physical processes in the subsoil. From this information, the seismic activity around the site can be predicted. The seize of the region to be investigated depends on local circumstances. As a general guideline, a distance less then approximately 300 km around the site is investigated in the first analysis [7]. A region within 80 km surrounding the site is subject to a detailed investigation of seismic faults, indicating the possible risk of earthquakes [7].

If there is a possibility of earthquakes, a site specific earthquake analysis must be performed. This analysis involves research and evaluation of historically reported earthquakes in the region that would effect the proposed terminal location. With this earthquake analysis, together with the geological and tectonic survey, it is possible to establish [7]:

- The Safe Shutdown Earthquake (SSE).
- The Operating Basis Earthquake (OBE).

These conditions determine the working limits of the terminal in case of an earthquake and can be decisive for equipment choice.

A climatic study must be included, containing the following points as a minimum [7]:

- Wind strength and direction, storm potential.
- Temperatures.
- Precipitation.
- Atmospheric stability.
- Frequency of lightning.
- Relative humidity.
- Range and rate of change of atmospheric pressure.

The hydrological survey is made to investigate the possibilities for the LNG carrier reception. The survey includes tidal information, currents, bathymetry and wave heights. Knowledge of other marine traffic can be useful [2].

The proximity of populated areas in the immediate vicinity of the proposed LNG terminal has to be considered from a safety as well as a public relations point of view. The LNG terminal does not pose an immediate threat on the surroundings, it is preferable to locate them as remote as possible. This is not only more safe but can be more economic as well, for instance when LNG storage tanks must be built in-ground because of the visual pollution in populated areas. Proximity to industrial facilities can be convenient and economic, because auxiliary services can possibly be shared [9].

To determine the environmental effects generated by the construction and operation of the LNG terminal, an Environmental Impact Assessment is executed. The increased activity caused by construction and operation must be assessed and undesirable levels of activities must be eliminated or limited and restricted. The following items are the most important [7]:

- Permanent and temporary increase in population.
- Increase in traffic.
- Increase of noise and vibration levels.
- Increase of night work.
- Flaring of excess gas.
- Warming or cooling of water.

From the environmental point of view, an LNG terminal is a very clean industry, with very limited emissions of any type. The main environmental impact will be sustained during the building of the terminal facilities. The effect of the warming and cooling of the seawater is the main concern during operation [9].

7.2. Import terminal area requirements.

The space that a terminal needs is depending on its function. Receiving terminals can be of three types: a baseload terminal, a peak-shaving facility or a combination of both.

A baseload terminal provides a continuous send out of natural gas to a customer. There are no large fluctuations in the transferred amounts. Therefore the amount of tanks can be adapted to the schedule of arrival of LNG carriers. The tank capacity must be sufficient to cater for the send out for the time between the arrival of the subsequent LNG carriers.

A peak shaving facility is used as a back up for periods in which natural gas demand is high. In this case, the supply of LNG is not regular but intermittent. The storage tank(s) will most of the time be full and ready for use.

A combination of the foregoing alternatives will have storage tanks for baseload supply, joined by peak shaving tank(s). The latter is often found when the customer is a power plant. This facility will have periods of high energy demand for which the peak shaving facility may support the base load send out.

Land areas differ, as said, on the function of the terminal but also on the customers and the amount of transferred LNG. Examples of sizes of LNG terminals are given in table 7-1 [29].



Oman	Total area 184,000 m ² This includes 2 tanks, an LNG train and auxiliary facilities.
Guangdong (proposed)	Total area 200,000 m ² Including space for 4 tanks, flare, gasification, etc.
Rotterdam (proposed)	Various options up to 200,000 m ²
Ras Lafan	Total area 140,000 m ² Including 3 tanks and flare.
Qatar	Total area 43,000 m ² Including 2 tanks, no flare or gasification.
Incheon	Present used area 400,000 m ² Including all facilities, three storage tanks, handling 3 million tons of LNG per year [30].

Table 7-1 Examples of space requirements for LNG terminals.

From another source, the space requirement for an import terminal receiving five million tons of LNG per year and serving a 2,400 MW CCGT power plant will be approximately 600,000 m² [2].

7.3. LNG terminal components.

An LNG receiving terminal provides several essential functions, being the following [7]:

- Unloading LNG from LNG carriers.
- Storage of the LNG.
- Boil off gas recovery or pressurisation.
- · Vaporising LNG into natural gas.
- Gas quality adjustment (if required).

The equipment and installations used to accomplish these functions are the following:

- Transfer arms.
- Pipelines.
- Pumps.
- Safety valves.
- Control centres.
- Storage tanks.
- Compressors.
- Vaporisers.
- Metering equipment.
- Odorising equipment.
- Gas treatment equipment.
- Flare/vent system.

These items will be described in later sections.

The prevailing wind direction is a main parameter in LNG terminal design. The reason for this is that the wind moves a flammable vapour cloud resulting from an incident or venting system. It must be prevented that this flammable vapour cloud reaches areas where escalation of the incident is possible. Where practicable, buildings and ignition sources shall not be downwind of accidental and planned releases of flammable materials. These items must be located outside the vapour cloud envelope as far as possible, assuming a wind in any direction. The terminal must be laid out to provide safe access for construction, operation, maintenance and incident fighting. Separation distances shall take in to account in particular the following parameters [7]:

- LFL contours.
- Radiation flux levels.
- Pressure effects.

Threshold values of these parameters are determined in a hazard analysis, examples are given in section 5.6.

The LNG terminal main control room must be located outside the hazardous area determined by the mentioned parameters. It must additional be designed to sustain overpressure from vapour cloud deflagration and to keep flammable gases outside the building. The personnel in the main control room must be protected against the effects of accidents and provide a safe escape possibility.

7.4. Jetty design and construction.

When a suitable location for the LNG import terminal is found, a berthing arrangement for LNG carriers must be designed. The location of this berthing arrangement, being jetty-type, should enable ships to berth and unberth in a safe manner. A turning cycle before the berth is recommended. Unberthing must be able without tug assistance, in case of emergency situations. The berth must be adequately sheltered from the prevailing winds and currents and passing traffic. Depending on the local situation this can be achieved by breakwaters. The location must certainly be located outside navigation channels.

In figure 7-1 a typical jetty layout is showed. This is the jetty of the LNG import terminal in the port of Zeebrugge.

The jetty design is governed by the range of ship sizes to be expected; not only of the largest ship, but also the size of the smallest ship is important in connection with the mooring arrangements. Further points of attention are the nature of the subsoil and the applicable loads, imposed by the superstructure.

The jetty consists of a central operating platform, provided with breasting dolphins to support the ship hull when alongside. On both sides of the jetty head, multiple mooring dolphins are provided to keep the ship attached to the jetty [31]. The following equipment and provisions are present on the operating platform:

- Transfer arms.
- Pipework including a manifold.
- Safety equipment.
- The jetty control centre.
- Jetty crane.

A typical operating platform size is 20x30 m [6].

The operating platform is connected to the shore by an approach trestle. This must be wide enough for vehicles to drive on. The approach trestle also contains a pipe rack, leading the LNG from the transfer arms to the storage tanks. A top view of a typical jetty configuration is given in figure 7-2.

Figure 7-1 Typical jetty configuration.



Figure 7-2 Jetty configuration.

Figure 7.3 gives a close look on the transfer arm arrangement. Clear to see are the articulated arms. The arms are connected to the ship's manifold at the bends in the pipe. At the bends, the PERC is installed.



Figure 7-3 Transfer arms example.

The mooring system is often sophisticated, consisting of quick release mooring hooks installed on swivelling and rotating supports. The quick release system can only be initiated after authorisation of the LNG carrier master. A mooring tension monitoring and operation system can be provided [28].

7.5. Storage tanks.

Storage tanks are used to safely contain the LNG at cryogenic temperatures. The filling and emptying of the tank is done via the roof and provisions must be made to permit the boil off gas to be removed. Air and moisture must be kept out of the tank and to maintain the ambient temperature inside the tank, sufficient insulation must minimise the heat inleak from the surroundings [7].

The criteria for the foundation of the storage tanks are defined by the seismological and geotechnical surveys of the nature of the ground. When earthquakes can be expected, antivibration provisions can be installed to protect the storage tanks. The foundation must be able to reduce the uneven settling of the tank so it stays within the permissible limits set for the tank walls. Thermal characteristics of the subsoil and foundation must be determined to detect any frost heave. When this can not be excluded, a heating system must be provided [7].

All storage tank types except the full containment type must be provided with a bund wall, serving as the secondary containment. When more than one tank is present, the bunds of two tanks may be adjacent, using the same bund wall. A bund must be able to contain at least the maximum storage tank content of LNG. When the bund walls are placed more than 15 metres away from the storage tank wall, it is recommended to install impounding basins [7]. These impounding basins are capable of collecting small liquid spills, especially from LNG pipework, in a controlled manner.

Design criteria that apply to these impounding basins are [7]:

- The capacity of the impounding basin must be at least equal to the amount of liquid spilled by the rupture of the pipeline with the highest leak rate for the time required to detect an interrupt the flow.
- The impounding basin must be open to the atmosphere to avoid gas accumulation.

Spacing of the storage tanks is depending on the results of the risk analysis and on the decision of the decision makers. For full containment tanks, which are thought to bear low failure risks, the distance between tanks should be in the order of 0.5 to 1 times the diameter of the tanks.

7.6. LNG pumps.

LNG pumps have various applications throughout the terminal. These pumps are of centrifugal type and are mainly used for transfer and recirculation. The specific functions of the LNG pumps are the following [7]:

- LNG unloading from the LNG carrier.
- Transfer of LNG between different storage tanks.
- Transfer of LNG from the storage tank to the vaporiser, hereby bringing it up to the desired pressure, usually that of the transmission pipeline.
- Circulation of LNG within the storage tank, to avoid roll over.

7.7. Vaporisers.

A vaporiser has only one function and that is to warm up the LNG so that it vaporises and natural gas originates, with a temperature above 0° C.

There are various types of vaporisers on the market of which the two most often used types are already described in section 2.6. Design rules for these types, the Open Rack Vaporiser (ORV) and Submerged Combustion Vaporiser (SCV) are described hereafter.

OPEN RACK VAPORISER (ORV).

The ORV uses (sea)water as a heat source, it flows directly on the outside surface of the heat exchanger which is open to the atmosphere. The ORV must be protected from bad weather conditions such as wind, snow and rain. The water flow must be evenly distributed over the tubes and between different tubes which are mechanically connected in order to avoid distortions caused by temperature gradients. Excessive ice formation on the tubes and manifolds which are not in direct contact with water must be prevented, for example by a heat insulating chamber [7].

SUBMERGED COMBUSTION VAPORISER (SCV).

The SCV is based on the principle that water is used as an intermittent fluid between a heat source and the LNG. The water is contained in a water bath open to the atmosphere. Heating is provided by submerged combustion into the water bath, using natural gas as a fuel. The burner operation is governed by the water bath temperature which must be low enough for good efficiency but high enough to prevent freezing. The construction material of the water bath must be able to cope with the acidity of the water, resulting from the dissolving of fumes (CO_2 and No_x) in the water. The SCV must be equipped with a circulation pump enabling the burner to be cooled and preventing the water from freezing [7].

To obtain an idea about the size of vaporiser facilities, in figure 7-4 an effort is made to show this. On the right side of the picture a set of vaporisers is visible.





7.8. LNG terminal pipework.

Pipelines are abound at an LNG terminal. They are the artery of the installations, included in the following systems [7]:

- The main process systems.
- Auxiliary process systems.
- Utility systems.
- Fire protection systems.

In the main process systems, pipework facilitates the following processes [7]:

- Unloading from the LNG carrier to the storage tanks.
- Low and high pressure LNG systems.
- Boil off gas treatment, including discharge to the flare/vent system and vapour return to the LNG carrier.
- High pressure natural gas system to the natural gas transmission network.

Pipework in the auxiliary process systems is provided for [7]:

- Drain systems (collection of hydrocarbons originating in the main process system and draining drums).
- Systems for cooling large equipment.
- Cool down and cold retaining systems.

Utility systems that are provided depend on the type of plant. Pipework in utility systems can be the following [7]:

- Natural gas lines for use as a fuel gas for SCV, space heating, gas engines, vacuum breaker gas, etc.
- Pipelines containing water as a cooling provision.
- Nitrogen gas system for use as a service gas, inerting and drying equipment, rapid extinction of flares and vents, cooling and purging of insulation spaces in LNG storage tanks.
- · Air systems for instruments, service air and breathing air.
- Tanker supplies such as fuels and drinking water.

Fire protection systems are described in section 6.3. Pipework is incorporated in the water deluge systems, water curtains and foam generating equipment [7].

Pipework that is in permanent or occasional contact with LNG must be made of material having cryogenic properties to avoid brittleness due to the low temperatures.

Pipelines are arranged on a pipe rack. Allowances for the movement of pipes due to thermal contraction or expansion must be incorporated in order to reduce the internal stresses. These variations can be absorbed by expansion loops or hinged systems. It is recommended that pipework of the main and auxiliary process systems is routed in the open air to avoid combustible gas accumulation [7].

In figure 7-5 an example of pipework that is used on LNG terminals is given. Clearly visible are the insulated pipes in the lower left corner of the picture. Also visible are the pipe rack provisions and the variety of pipework. In the upper left corner the filling/emptying pipelines arrangement of LNG storage tanks is visible, leading to the top of the tank.



Figure 7-5 Pipework arrangements.

7.9. Boil off treatment.

During filling of storage tanks and due to heat inleak in the storage tanks, some of the LNG vaporises again, the resulting gas is called the boil off. The boil off must be safely disposed of. This can be achieved through [7]:

- Reliquefaction.
- Compression of the gas and sending it to the transmission gas network.
- Using it as a fuel gas.
- Sending the vapour to the flare/vent system.
- Return the vapour to the LNG carrier.

In receiving terminals, the boil off gas is usually compressed and cooled and then fed into a recondenser for reliquefaction. An example of the boil off compressor configuration is given in figure 7-6. Boil off collection is done via pipelines made of material with cryogenic properties as the boil off gas can have temperatures as low as -160° C.



Figure 7-6 Boil off compressor unit.

A vapour return system to the LNG carrier via the vapour return arm on the jetty is connected to the boil off collection system. The vapour transfer from the storage tanks to the LNG carrier provides a compensation of the shifted liquid volume during loading of the storage tanks. If necessary, a booster pump can be used to provide the pressure for transport [7].

7.10. Flare/vent system.

The flare and or vent system are designed to dispose of excess LNG vapour in a safe manner. There might be more then one system, especially in cases of high pressure gas releases; these are normally connected to a separate flare/vent. Systems and equipment or processes that usually are connected to the flare/vent system are:

- · Boil off disposal from unloading an LNG carrier.
- Boil off disposal from LNG storage tanks.
- Vapour relief valves and pipelines.
- Vaporisers.

The nominal flow rate of the flare/vent system is the sum of the maximum vapour discharge from the storage tanks and the boil off gas due to heat inleak of all LNG containing devices which are connected to the flare/vent system [7].

Accidental flow rates are defined as [7]:

- 1. The nominal flow rate increased with the flow of one vaporiser safety relief valve when this is connected to the same flare/vent system.
- 2. The nominal flow rate increased with the flow rate of the outlet of safety relief valves of one tank, if connected to the same flare/vent system.

If both the above systems are not connected to the flare/vent system, the accidental flow rate is equal to the nominal flow rate [7].

The location of the flare on the terminal must be chosen according to the prevailing wind direction, to be able to keep the flame away from possible flammable vapour clouds. It is also important that the threshold values for heat radiation, resulting from the flames, are respected. When in case of an accident a flammable vapour cloud manages to reach the flare, a snuffing and cooling device might be able to prevent ignition of the vapour cloud. A snuffing device quickly extinguishes the flame of the flare and the cooling device cools down the hot part of the flare tip to a temperature lower than the auto-ignition temperature of the vapour. The time available for these devices to do their work must be less than the time required for the flammable vapour cloud to reach the flare tip [7].

The location of the vent must also be chosen with respect to the prevailing wind direction. The aim here however is to prevent the flammable gas to reach an ignition source before dispersion [7].

7.11. Buildings.

The LNG terminal needs buildings for various purposes, such as [7]:

- Administration buildings like offices, etc.
- Control buildings, the main control centre and jetty control centre.
- Electrical stations, etc.

7.12. Send out of natural gas.

Before the natural gas is introduced to the transmission network, it must first be checked for the appropriate quality, metered and odorised.

Gas quality must be in accordance with the customers qualification. There must be on-line monitoring of the gas and a means to adjust the gas quality parameters. The correction can be carried out through adding propane or butane to the natural gas in order to boost up low calorific gas and air or nitrogen to gas with a too high calorific value.

The metering of the gas is necessary for fiscal, custody transfer, material balance and customer charging purposes [7]. A metering station is shown in figure 7-7.



Figure 7-7 Metering station layout.

Installations where odorisation of the natural gas is required by local regulation or at the customer's request are equipped with odorisation storage and injection equipment. An odourant is added to give the natural gas a distinctive smell. Odourants are typically a blend of volatile organic sulphur compounds, being flammable and have an extreme noxious smell [7].

7.13. Examples of LNG terminal layouts.

On the following pages examples are given of various terminal layouts.

In figure 7-8 a proposed layout for the LNG import terminal in Rotterdam is shown. Clearly visible is that the tanks are full containment storage tanks, because they are grouped only 0.5 times the diameter of a tank from each other. Separated from the other facilities, the flare stack is projected on the left of the figure, the dashed line indicates the heat radiation threshold zone. The buildings for control, administration maintenance and electricity facilities are separated from the areas where LNG is present.

Figure 7-9 is the same Rotterdam LNG terminal, but now the flow sheet is given in stead of the exact locations. All the handling installations are indicated in a systematic manner.

In figures 7-10 and 7-11 the same idea as for Rotterdam is valid, but now for the LNG import terminal at Incheon, Korea. The difference with the Rotterdam terminal is that the boil off gas is recondensed after compression and then fed to the vaporisers, while in Rotterdam the compressed boil off gas is transmitted to an industrial facility as a fuel gas.

Examples of existing LNG terminals are given in figure 7-12 and 7-13. Figure 7-12 is the Montoirde-Bretagne terminal of Gaz de France. This terminal owns two berths, alongside the estuary axis. Another feature that is visible are the bund walls around the storage tanks and the remote location of the flare stack, on the right side of the picture. Even further from the transfer and storage installations are the control and administration buildings located.

Figure 7-13 is of a different concept: the buildings are placed adjacent to the storage tanks and near the jetty, where the LNG carrier is berthed perpendicular to the coast.



7

GENERAL TERMINAL LAYOUT

7-15

Figure

7-9

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Figure 7-10 Schematic layout of the Incheon LNG import terminal.



Figure 7-11 Terminal components of the Incheon LNG terminal.

Figure 7-12 View on the Montoir-de-Bretagne LNG import terminal of Gaz de France.



Figure 7-13 Picture of an LNG terminal.

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8. CASE STUDY: ULSAN PORT.

8.1. General.

In south-east Asia, there is an increasing need for new infrastructural facilities, among which are port facilities. An example of this is the Ulsan region in Korea, where the existing Ulsan Port is thought to expand significantly [32]. A plot of the port surroundings is given in figure 8-1. In the port's vicinity there is a power plant, and plans provide for a second facility. The existing power plant is using oil as a fuel at present. In the future, plans indicate that the two power plants will be fuelled by natural gas. This product is not available in Korea, and therefore has to be imported. The trajectory for the implementation of such a project is as follows:

- 1. First, the send out to the customers (in this case the power plants) must be assessed.
- 2. When the send out is known, contracts must be concluded with one or more gas supplier(s).
- 3. In co-operation with the supplier the amount and frequency of gas deliveries by LNG carrier are determined.
- 4. When the amount and frequency of ship arrivals are known, the berthing facilities can be designed.
- 5. Dependent upon the type of facility to be served by the LNG terminal, the number of storage tanks and other handling facilities on the terminal can be assessed and designed.

For the Ulsan Port case study, the send out to the power plants is taken from the master plan. For the situation in 2011 a forecast of 2,650,000 metric tons was made and for the 2020 situation it is 4,750,000 metric tons. Conversion to m^3 gives values of approximately 6,000,000 m^3 and 10,000,000 m^3 for 2011 and 2020 respectively, with an average specific volume of 450 kg/m³ [32]. These values are fairly comparable to other natural gas driven power plants over the world. Examples show that 2,500,000 metric tons of LNG per year is no exception [2].

In this stadium, there is no information about the origin of the LNG and possible contractors. It is therefore assumed that the gas can be continuously supplied over the year. The number of ships to be put on the line is not important in this stage, only the total amount of ship movements in the port and approach routes.

The LNG is assumed to be shipped with LNG carriers with a capacity of 125,000 m³ each [32]. These ships are always fully loaded to prevent sloshing of the cargo and the danger of instability. Division of the total amount of LNG needed per year through the hold capacity of the ships gives the number of arrivals per year. For 2011 this will be equal to approximately 50 arrivals and for the year 2020 the number of arrivals will be equal to 80. These values must be doubled to obtain the number of ship movements (arrival and departure). Recalculations to inter-arrival times, in 2011 every 7.5 days an LNG carrier arrives at the port (and leaves it after unloading) and in 2020 this inter-arrival time is 4.5 days.

Assuming that the transfer pumps have a capacity of 11,000 m³/h (common practice for modern ship and terminal design), the ship is unloaded in 11.5 hours. Assuming 3.5 hours for berthing and unberthing leads to a total port time of 15 hours per LNG carrier.

In 2011, 50 ships must be unloaded, leading to a total port time of 50*15 = 750 hours. When the terminal is able to receive ships 24 hours/day and 350 days/year -being 8,400 hours-, the berth occupancy is equal to 0.09. Even with downtime due to weather, facility shutdown and occupied berth, this will be sufficient to restrict the berthing facility to one berth.

In 2020, 80 ships must be catered for, using 1,200 hours of port time, leading to a berth occupancy of 0.14. This will still be sufficient for one berth.

To cater for the fuel consumption of the power plant(s), at least two tanks of a capacity equal or larger than one ship load will be required. A common dimension for storage tanks is 140,000 m³ hold capacity, being a tank with an outer diameter of 80 metres. This can be well used in this case. When in times of high energy demand the power plants require more fuel, a peak-shaving tank might cater for the increased natural gas demand. Therefore three storage tanks will be provided. Another point of interest is that when natural gas is imported for the power plants, other customers might be interested to use the facilities of the import terminal to attain natural gas, for instance for heating purposes or as a feeder gas for fertiliser generation. In this case land area must be sufficient for additional storage tank construction.

8.2. Location of the LNG import terminal.

When deciding on the location of port facilities such as terminals, one is engaged in long term planning on a strategic level. The most important factor in strategic planning is economic feasibility, but environmental and safety factors are important considerations or restraints in this planning [25]. With regard to safety and terminal location on a strategic level, three policies can be indicated:

- 1. Not bothering about any location choice, just choose the most appropriate for terminal operation. This policy is used only in remote areas, where no other human activities are present.
- The location is determined with the help of effect distances; no other facility or population might be present within the zones defined by the effect distances. This policy can be used in areas with ample space, not restricted by dense populated areas.
- 3. The location is determined guided by a combination of effect and probability: risk. This policy is used in densely populated areas and in the vicinity of large industrial areas.

The third option is observed in the Netherlands. It is recommendable to apply the third policy in the Ulsan case study as well because the terminal must be incorporated within the extensive port and industrial facilities already present there.

In the Ulsan Port master plan, the LNG import terminal is assessed to be located near the power plants. Advantages of this solution are:

- Various provisions can be jointly used, such as fire protection facilities.
- Boil off gas can be used as fuel gas
- Warm cooling water from the power plants can be used to vaporise LNG
- Cold vaporiser water can be used for cooling purposes in the power plants.
- The cold from the LNG can be used for cooling purposes at the refrigerated cargo terminal adjacent to the LNG port.

The water depth at the proposed site is ample up to 500 metres out of the coast and the location is well protected from adverse atmospheric conditions generating high winds and waves because the location is in the shade of a cape. Other locations are possible but are far more exposed and most probably will range outside the harbour limits or are prohibited because of other purposes such as a guarantine area and anchorages.

The possibilities for gas supply to the power plant can be systematically analysed. The process of interest is then cut in three basic systems:

- 1. The LNG carrier arrival and berthing alongside (navigational system).
- 2. The transfer of LNG from the LNG carrier to the storage tanks (the transfer system).
- 3. The storage of LNG, conversion into natural gas and send out to the customer (the terminal system).

8.3. The navigational system.

8.3.1. General.

Before the LNG can be imported, the LNG carrier must be able to sail into the port area and berth alongside the jetty. This is more difficult than it seems, because an LNG carrier transports large amounts of dangerous goods. Because the LNG carrier is moving, and so are other ships in the vicinity, two hazards are posed: a collision hazard and a grounding hazard which both might lead to loss of containment. The measures that must be taken are all in service of avoiding these two conditions.

8.3.2. Measures to avoid grounding.

The advantage that Ulsan Port owns over other locations is that ample water depth is available up to distances of 500-1,000 metres off the coast. Therefore the risk of grounding is relatively small. Outside the fairways, sufficient space is available for planned or sudden manoeuvres. The only risk of grounding is present within the LNG port breakwaters, because there the water depth is reduced. The first measure is to dredge the basin to a sufficient depth. In the master plan for Ulsan Port this depth was set at 12.5 metres [32]. This will probably not be sufficient, because 125,000 m³ LNG carriers can have a draught up to 12.5 metres. A keel clearance of 2.5 metres is advised in view of the rock bottom, resulting in a minimum water depth of 15 metres in the LNG port. Behind the jetty, the water depth is not sufficient for LNG carriers to navigate, but this poses no problems because the ship does not enter this area. Even when the ship accidentally comes in this area, the probability of a grounding that causes severe damage such that the cargo tanks are punctured is very small because the speed of the ship within the port will be very small. Furthermore the LNG carrier will at this time be supported by multiple tugs which have much of the command over the ship's manoeuvres.

A stranding on the New Ulsan Port breakwaters in bad weather (wind, waves, low visibility) or due to mishaps on board the LNG carrier are both possible and must be avoided to the utmost, because in this case the damage can be such that a cargo tank is ruptured. Therefore regulations must be implemented about bad weather access of the LNG carrier. One could think of an alternative approach route to the LNG port in stead of using the Ulsan Main Fairway (running north-south in figure 8-1). This is possible because of the availability of deep water, but anchorages are located in this area. Another measure can be to refuse entry permittance in bad weather conditions. From weather statistics this would implement that 3% of the time the ship is denied entrance because of low visibility circumstances and approximately 0.2% because of a high wind condition (Beaufort 7 or more) [32]. This is bearable in terms of downtime. An appropriate anchorage for LNG carriers must be provided.

Because mishaps on board can lead to loss of navigational control of the LNG carrier, tugs must be standby when the ship approaches the LNG port and sails near the Ulsan New Port breakwaters.



8.3.3. Measures to avoid collisions.

Collisions between ships are never planned, but still occur fairly regular in port surroundings. Especially in low visibility and night conditions, collisions tend to occur frequently. This can be addressed to inattention of navigators and ship masters, bad communication, ignorance of the local fairway situation and the intensity of the traffic. Collisions can generate major consequences in case an LNG carrier is involved. This is the case if the colliding ship is able to penetrate a cargo tank of the LNG carrier. The LNG then is released from its containment and can form a large pool fire or flammable vapour cloud, see chapter 4.

Regarding the foregoing considerations, it is obvious that a collision involving an LNG carrier must to the utmost be prevented. The difficulty is how to achieve this. There are several measures possible, described in section 6.6, but implementation of these measures depends on the local situation.

In the case of Ulsan Port, the hazard of a collision is very well present. The first reason for this is the relative location of the LNG port with respect to the other port facilities, see figure 8.1. The LNG port, and its entrance, is located adjacent to the New Ulsan Port, having its own approach fairway south of the LNG port. In front of the LNG port entrance the Ulsan Main Fairway, running to the Ulsan Main Port north of the new port facilities, is located. The problem posed is that LNG carriers sailing to or from the LNG port will undoubtedly have to cross at least one fairway in the present fairway configuration.

In cross traffic the most dangerous collision conditions are imposed. The probability that a ship penetrates a cargo tank from the LNG carrier is the greatest when this ship rams the LNG carrier perpendicular. In section 3.7.2 collision speeds of ramming ships that are able to penetrate the cargo tank of the LNG carrier are determined. Ships of 10,000 DWT are able to penetrate a cargo tank when sailing at speeds of 8 knots or higher. These speeds are attained in the Ulsan Main Fairway because at the LNG terminal location, the Ulsan Main Port berths are still a long way to travel. In the New Ulsan Port fairway these speeds will not be attained, because within 2,500 metres the ships must be put to a stop.

Head on collisions between an LNG carrier and an other ship or collisions in which the LNG carrier is the ramming ship will only result in cargo tank penetration when the speed of the LNG carrier is more than 12 to 15 knots. In the port approach the speed of the LNG carrier will already be reduced to not more than approximately 5 knots to be able to receive tug assistance, so this possibility can be ruled out.

A second reason for the great collision hazard around Ulsan Port is the dense traffic in the fairways. In 2011, approximately 26,000 ship movements will be encountered in the New Ulsan and existing Onsan Port, using the New Ulsan Port fairway, and another 24,000 ship movements will be present in the Ulsan Main Fairway [32]. These are very large numbers, even more than Rotterdam nowadays. In 2020 these figures will further increase to 36,000 ships for the New Ulsan Port fairway while the traffic in the Ulsan Main Fairway remains constant at a vast 24,000 ship movements [32]. When these numbers are reproduced in numbers of ships per hour in the fairways, this becomes in 2020 three to four ships per hour as an average, peak values can be as high as 8 to 10 ships per hour.

When an LNG carrier arrives or departs (160 times a year in 2020), provisions must be taken to avoid collision situations. To do so, LNG carriers can be given a priority status in port approach. This means that when an LNG carrier arrives in the port approach channel, other traffic is informed and ordered to clear the water area where encounters would otherwise be possible, by increasing or decreasing their speed. In some cases ships must be stopped when their schedule can't be adapted. The traffic can be influenced by patrol boats blocking the fairway or installation of a virtual area around the LNG carrier in which no other traffic may be present [33]. This virtual area must be large enough to avoid collisions in case a ship on a ram course is forced to a crash stop. During cruising speeds of 16 knots this distance is rather large (averaging 10 times the ship length).

In port approaches the speed is normally reduced, but in the Ulsan Main Fairway still speeds of 8 knots may be encountered, requiring a crash stop length of 2.5 to 5 times the ship's length, depending on the type of ship [6]. The safe virtual area will thus be in the order of 1,500 metres (to avoid collisions with large ships). Installation of single lane traffic without overtaking manoeuvres is possible but not recommended because the LNG carrier does not follow the fairway but crosses it, which then still can lead to a dangerous situation.

Other protection against collision can be the denial of entry in bad weather such as fog and high winds and waves. Because this was also required in grounding avoidance, this poses no extra problems.

8.3.4. Approach fairway.

With the preceding discussions in mind, the approach fairway for LNG carriers must now be pointed out. Various options are open (reference is made to figure 8-1):

- A dedicated LNG carrier fairway west of the Ulsan Main Fairway.
- A dedicated LNG carrier fairway east of the Ulsan Main Fairway.
- The LNG carrier uses the Ulsan Main Fairway.
- The LNG carrier uses a separate fairway in between the Ulsan Main and New Ulsan Port fairways.

All of these options incorporate their own specific advantages and disadvantages.

DEDICATED FAIRWAY WEST OF ULSAN MAIN.

Advantages:

- Ships, that in spite of the regulations enter the virtual area surrounding the LNG carrier will not be able to penetrate the cargo tanks in case of a collision because their speed will be limited in the short port approach of New Ulsan Port.
- 2. Between the New Ulsan Port and LNG port entrances sufficient space is available for tugs to slow down the LNG carrier. When desirable, the LNG carrier can be turned an towed into the port astern.
- 3. In case of an emergency departure, the fairway is always available for use without immediate encounters with other ships.

Disadvantages:

- 1. LNG carriers must cross the New Ulsan Port fairway. The traffic to and from the New Ulsan Port must be slowed down or stopped, and this twice per ship: on arrival and departure.
- 2. When the LNG carrier leaves the port in emergency condition (for instance when a fire is present on the ship) the New Ulsan Port Fairway must be crossed. This is not a desirable option.
- 3. The manoeuvres before entering the port are made close to the New Ulsan Port's north breakwater. This will have an effect on the apparent perception of navigational space and might incorporate a higher risk level regarding grounding.
- 4. South of the New Ulsan Port and west of the Ulsan Main Fairway there are several anchorages in the present situation. These must be shifted with this alternative and must be located at a more exposed location.

DEDICATED FAIRWAY EAST OF ULSAN MAIN.

Advantages:

1. The traffic to and from the New Ulsan Port experiences no hindrance of the LNG carrier arrival or departure.

Disadvantages:

- 1. Ships sailing to and from Ulsan Main Port, with relatively high speeds, can cause angular collisions with severe damage. Therefore stringent regulations must be incorporated to restrict the traffic when an LNG carrier is ready to cross the Ulsan Main Fairway to avoid any probability of ship collisions. The time that traffic is prohibited is therefore likely to be longer than is the case for the dedicated west fairway discussed above.
- 2. Another point of concern is the tug assistance and turning manoeuvre. Tugs will have to make fast at the east side of the Ulsan Main Fairway. They must wait further offshore than is the case in the preceding option. This might not impose insuperable problems, but turning the vessel to bring it at the jetty stern first must also be done east of the Ulsan Main Fairway. This means that the ship will be sailing astern for at least 1,500 metres and what is worse, crossing the Ulsan Main Fairway this way, unable of avoiding a collision by giving way to a passing ship (although this ship will be trespassing regulations). In this case the best solution is that the LNG carrier sails into the port bow first, escorted by tugs that have made fast east of the Ulsan Main Fairway, and turned in the port basin. This is possible because a turning basin with diameter 600 metres is foreseen in the LNG port design [32].
- 3. There is little space east of the Ulsan Main Fairway because existing anchorages are present there. These can be shifted to a new position but lead to more exposed locations. This is not desirable.

USING THE ULSAN MAIN FAIRWAY.

Advantages:

- 1. This is a well surveyable solution. All ships use the same fairway and there is little chance a ship will be overlooked.
- 2. The anchorages adjacent to the Ulsan Main fairway (both on the east and west side) will not be disturbed.

Disadvantages:

1. For a longer period of time, encountering traffic is prohibited to avoid head on or steep angle collisions. This is necessary for at least 5 to 6 miles south of the LNG port. With speeds of the LNG carrier averaging 4 knots in this period this comprises 1.5 hours. This is not acceptable for a port where in peak hours 30 ships then have to wait. The only option for this problem would be to lead the LNG carrier to an anchorage to wait for quiet times before coming in. The same must be applied to departing ships which then must wait at the jetty. This is not desirable.

A SEPARATE LNG CARRIER FAIRWAY IN BETWEEN THE NEW ULSAN AND ULSAN MAIN FAIRWAY.

This option needs explanation because it is a more complicated solution. The only way in which the traffic to and from the New Ulsan Port and Ulsan Main Port will not have to be stopped is when the fairways to these ports are separated and the LNG carriers are directed to a fairway in between the preceding ones. To clarify this see figure 8-2.

Advantages:

- 1. No delay for ships sailing to or from Ulsan Port.
- 2. Sufficient fairway width to cater for the dense traffic expected in the future.

Disadvantages:

- 1. Existing anchorages east of the Ulsan Main Fairway must be shifted to other places, lying more exposed or remote.
- 2. The Ulsan Main Fairway contains a bend at the entrance of the port. This is nautical undesirable.
- 3. The LNG carriers are navigating in a separate channel, but traffic is present on both sides of the fairway. Strict observation of the rules dictated by the port management is required.

A decision between these four options is difficult. On all possibilities advantages and disadvantages are applicant. It must be stressed that a port management system must be installed for Ulsan Port. This is necessary to control the vast amount of ship movements in the Ulsan Port region and to control the safety in the port, because almost 70% of the ships in the Ulsan Port area are sailing with dangerous cargo [32]. Besides LNG carriers also crude carriers up to 325,000 DWT, product carriers and chemical tankers manoeuvre in and around the port. If no port management system is installed, it will not be attainable to maintain a safety level high enough to receive these ships and in particular LNG carriers in the LNG port.

This port management system, using among other facilities a Vessel Traffic System (VTS), can schedule the arrival of ships in co-operation with the terminal operators and planners. The VTS can be of help in granting entry permission for the LNG carriers. Therefore it must be known if it is possible to enter the LNG port. Entry denial can be given in bad weather conditions, if other ships can cause hazardous situations or if the berth is still occupied.

It is recommended that the ships are monitored by devices such as radar, and tagged. This means that when the ship that is visible on the screen is touched by a digital pencil, a tag can be given to the ship, inhibiting specific information such as the ship's name, cargo, destination, origin, etc. All ships can thus be followed and at every moment the situation can be kept under control. This is a costly system, but marginal with respect to the costs of the port construction and necessary to control the dense traffic that is foreseen. The system is used in the Port of Rotterdam successfully, with 40,000 ship movements per year.

It is proposed that the LNG carrier approach is a combined option of separate fairways and using the Ulsan Main Fairway. This will now be clarified. Because all options require the installation of a VTS, this criterion is not used in option selection. In every option, fairways must be crossed, on arrival as well as on departure. The most important factor remaining is the surveyability of the situation. It is clear that the most surveyable situation is created when all traffic in a sea lane sails in the same direction. A separate fairway adjacent to the Ulsan Main Fairway is therefore rejected because in such a case two times two directions of ship movements are created. A full combination with the Ulsan Main Fairway inhibits too many risk factors. Therefore on both sides of the Ulsan Main Fairway a strip of 100 metres wide is added that can be used by the LNG carriers. The LNG carriers are escorted by a patrol boat that warns other traffic by means of light signals that an LNG carrier is in the vicinity of the fairway. When a fairway is crossed, two patrol boats close the fairway for other traffic. This traffic is already warned via the VTS that a crossing manoeuvre of an LNG carrier is in progress. After crossing the Ulsan Main Fairway the arriving LNG carrier is stopped and turned in the dedicated LNG port in the 600 metres turning cycle. Departing LNG carriers use the west side of the Ulsan Main Fairway and cross the New Ulsan Port fairway.

The hindrance of the LNG carrier to the other traffic in the fairways is not considered to be inadmissible. There will be two peaks in traffic density in the fairways, that is in the morning (after the first shift change), and in the evening (after the second shift stops working). When an LNG carrier arrives at these times, it must go to the anchorage and wait for less busy hours in which the ship movements may be reduced to for instance 2 per hour. The fairways will then be closed for approximately half an hour to an hour, hindering 2 ships. This is admissible.

8.4. Port and berth configuration.

In the Ulsan Port master plan, the LNG terminal is provided with a separate port facility. The main reason for this is that when it was combined with other port facilities, the probability of an accident is increasing because of the large amounts of ship movements and the diversity of the ship dimensions, destinations within the port and cargoes. The location of the LNG port, adjacent to the power plant of KEPCO, has lead to the decision to provide two breakwaters, although nautical not required.



The north-east breakwater would probably not be necessary because this side is well protected from the elements by the cape east of the Ulsan Main Fairway. Currents would not be felt at the berth because it is located outside the through water area, see figure 8-1. The reason why this breakwater is still provided is to avoid ships sailing in the Ulsan Main Fairway and for some reason driven out of its course to collide with the LNG carrier lying alongside the jetty.

The jetty arrangement in the master plan was based on a two berth LNG port. Calculations using queuing theory showed that in 2020 two berths have to be provided. The berth arrangement is one of the finger jetty type. A more detailed example is given in figure 8-2. At the time of designing the berth arrangement it was thought that this was a cheaper solution. In 2011 calculations showed that only one berth was required. This ship could be berthed at the finger jetty. In 2020, when two berths were thought to be necessary, only unloading arms would have to be placed on the other side of the jetty head and the other ship could also be berthed.

When searching for examples of such berth layouts in LNG port practice, only one example of a finger jetty was found, being the Tokyo Gas Sodegura LNG terminal, the largest terminal in the world today. A picture of the finger jetty arrangement in Tokyo is given in figure 8-4. This proofs that in principle this layout is feasible, but not common practice. There are reasons thinkable why this is not a desirable solution:

- Efforts are made to prevent the navigation of ships in the vicinity of an LNG carrier. When
 approaching the finger jetty, one LNG carrier is navigating within 30 metres of another LNG
 carrier. This is contradicting with the first aim.
- When transferring LNG, the probability of a spill is present. Two LNG carriers are then in the vicinity of this spill which poses an additional hazard in terms of escalation of the incident.



Figure 8-3 Finger jetty layout.

During the set up of the master plan, it was not clear what the unloading rate of the LNG would be and it was set at an average of approximately 3,500 m³/hour [32], while in this report the unloading rate was set at 11,000 m³/hour (see section 8.1). Therefore the preceding discussion needs not to be applied to the Ulsan case, because one berth will be sufficient. It is advised that this berth is located adjacent to the north-east breakwater, to make the distance to other port facilities as large as possible and to split the LNG pipework from the crude oil and oil product pipelines already travelling over the south-west breakwater. LNG pipelines over the north-east breakwater top lead to onshore storage tanks.

When in a later stadium the terminal throughput is increased to such an extent that a second berth is required, a leaped jetty layout is advised to secure a safe departure of the different LNG carriers. Such a design is showed in figure 8-5.



Figure 8-4 Finger jetty for LNG carriers at Tokyo Gas' Sodegura terminal.



Figure 8-5 Leaped jetty layout.



8.5. Terminal facilities.

As stated in section 8.1, one berth will be sufficient to cater for the LNG import. This berth will be jetty type, with transfer arms being able to attain an unloading rate of 11,000 m³ LNG per hour. The arms arrangement must be compatible to the LNG carriers manifolds. From the jetty, pipelines facilitate the storage tanks.

The storage tanks are thought to be of the full containment type. These storage tanks incorporate the lowest risk levels in storage tank design. The risk level for storage tanks of the double containment type is assessed to be 10⁻⁶, for the full containment type this is 10⁻⁸ regarding to the IPO-A73 norm. This is generally considered as a negligible risk. The European standard EN 1473 poses even that catastrophic failure of a full containment tank can be ruled out. The reason for this is that the materials of which these tanks are made have crack arresting properties, so that a full bare rupture is not possible. Full containment storage tanks therefore need no bund area and the space between adjacent above ground storage tanks can be as low as 0.5 times the diameters of the tanks. The choice for full containment tanks is made because the terminal will be built in the vicinity of other industries working with dangerous goods, such as crude oil storage farms and an LPG facility. Furthermore the space available for the terminal is likely to be limited, because most of the land space is already occupied. It is not necessary to make inground storage tanks for reasons of visual pollution, because the vicinity is crowded with above ground crude oil, oil product and gas storage tanks. It can still be advantageous to opt for inground storage tanks because these tanks can be placed only 0.25*D apart and their h/D ratio is very high, meaning that with a small diameter a large holding capacity can be attained. All this is favourable when building on small spaces. The building of inground storage tanks is approximately 35% more expensive than constructing above storage tanks. The risk levels for the two tank types are the same.

When things go wrong after all, inground storage tanks are coping with the problems more efficient. Because the LNG can not escape through the sides, a relatively small exposed surface is available for LNG vaporisation in case the roof has failed. The liquid is contained in the hole in the ground. Above ground full containment storage tank failure could be caused by a large commercial aeroplane crashing into the tank. In this case the LNG from the tank will be spilled to the surroundings.

Because a bund wall is not required, failure of a full containment tank can lead to catastrophic accidents, with multiple tank fires, large vapour clouds, etc. Therefore, although the risk of failure of above ground full containment tanks is negligible, almost always bund walls are provided around these tanks. Another reason for this is that the relative costs of such a bund wall in comparison with the total costs of the terminal are marginal.

The LNG will be sent to a set of vaporisers. The choice for a specific type of vaporiser must be subject to an economic evaluation. When choosing between the common vaporiser types (ORV and SCV) some features of the two vaporisers are important.

Open Rack Vaporisers (ORV) are relatively expensive to install and provisions must be made for the high supply and discharge of water. These vaporisers are however rather cheap to operate.

Submerged Combustion Vaporisers (SCV) are cheaper to install than the ORV's. This type of vaporiser however is more expensive during operation, because it uses approximately 1.5% of the vaporised LNG as fuel gas [9].

For peak-shaving terminals, having low utilisation factors, the SCV is often the appropriate vaporiser type, while a baseload terminal providing a high continuous gas flow (relative to its design send out flow) will best be fitted with ORV's. Because power plants require a baseload for most of the time, the vaporisers used in the Ulsan Port LNG terminal will be ORV's. In this case, the aforementioned advantage of cold water resulting from the vaporisation process can be used as a power plant cooling fluid which is advantageous from an environmental point of view.

The boil off gas will be used as a fuel gas on the terminal, for example in heating installations, or is compressed via boil off compressors and put in the send out pipeline to the power plants.



With this study an attempt has been made to describe the hazards that accompany the handling of LNG on ships and terminals and measures to reduce and minimise the consequences when incidents occur.

In principle a wide variety of spill causes and consequences exist. It is important to estimate the probability of occurrence of these causes and consequences. With this information decision makers are able to judge to what extent terminal design must be adapted to these consequences. No consensus is yet reached over some of these probabilities. For instance the full containment storage tank is thought to be fail safe in the European Standard EN 1473, but in the IPO-A73 standard the fail frequency is set at 10⁻⁸ per year.

In this study catastrophic failure of a storage tank or LNG carrier at berth is excluded, the maximum credible accident is thought to be the rupture of the main transfer pipeline in combination with delayed ESD triggering.

It is recommended that when sufficient funds are available, the terminal is equipped with extensive safety equipment. As an example, a bund wall should be built around a full containment storage tank to contain the spill if a weapon destroys the two containment systems (although not reckoned with in the EN 1473).

A point of concern is the reliability of the detection equipment. In many cases the detectors are assigned in double or triple systems in order to prevent false alarms or for use as a back up facility. Improving the reliability can eventually reduce the costs of the detection system.

The European Standard, which is the State-of-the-art in LNG terminal design, is very well applicable on the proposed Ulsan Port LNG import terminal. The standard is very extensive and all possible options are described. Adaptation to the local situation poses no problems.

The most problematic issue in the Ulsan Port case is the approach fairway configuration. Conclusions and recommendations according to the LNG port location comprise:

- 1. LNG import at the chosen location can only be possible if a well equipped port management system, provided with a VTS, is set up for Ulsan Port. This because not only 60,000 commercial ship movements will be present in 2020, but every these ship movement generates 5 to 10 auxiliary ship movements, from tugs to patrol boats, bunker ships and custom boats.
- 2. When the first condition is satisfied, the fact that LNG carriers are crossing the New Ulsan Port fairway will not be a problem. Additional requirements then will be:
 - The LNG carrier must wait at the anchorage when arriving in peak hours until traffic is low.
 - In low visibility conditions the LNG carriers must be denied entry and crossing fairways.
 - Tug and pilot assistance must be provided in early port approach stages.
- 3. Crossing the Ulsan Main Fairway poses more problems because the available fairway width is limited here. Ships sailing in this fairway have higher speeds. When considering capacity problems, these are not foreseen if in 2020 LNG carriers force the traffic to be stopped for a period of time.
- 4. A more stringent point of concern will be the movement of LPG carriers moving to and from the three small LPG berths (see figure 8-2). From [32] it follows that in 1995 already 1,600 LPG carrier movements were present. These ships are relatively small, with an average cargo per call of 500 tons and need no tug assistance.

They therefore need less time to cross the Ulsan Main Fairway, but this fairway must be closed when an LPG carrier is crossing it for the following reasons:

- LPG is even more hazardous than LNG because it is able to detonate. During collisions, sparks that are generated are able to cause this explosion.
- These small ships will not be de-gassed when the LPG is unloaded. So when departing from the berths a collision can still lead to detonation of the remnant gas.
- The LPG carriers are rather small boats that are more sensitive to collisions than the larger LNG carriers.

It is strongly recommended that additional research is done to see if this affects the safety of the port.

5. When the port decides that stopping traffic is not allowed, the only solution is to separate the three fairways, resulting in three adjacent fairways, the middle for LNG carrier traffic. The traffic separation will be made by buoys and orders from the VTS.

The terminal layout has been difficult to determine because the information about the hinterland conditions are limited. Only some suggestions could be made. Further investigation is recommended.

As a general conclusion it has become clear that LNG terminals can be shared among the most safe industries and that LNG carriers are the most safe ships on the oceans. This is possible because ample safety measures can be implemented and are able to reduce and minimise the consequences of a spill.

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Appendix A. Storage tank and LNG carrier design.



Figure A-1 Examples of single containment storage tank design.



Figure A-2 Example of a spherical storage tank.



Figure A-3 Example of a membrane type storage tank.

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Figure A-5 Examples of double containment tanks.





Figure A-6 Examples of full containment tank types.

Suspended deck Reinforced (Aluminium deck) concrete roof Prestressed concrete secondary Loose fill container insulation . Primary container Carbon steel liner Concrete outer raft 9% Ni steel base **Base insulation** Bottom heating 1 ť Suspended deck Outer steel roof (Aluminium deck) Cryogenic Loose fill Cryogenic prestressed insulation prestressed concrete concrete primary container secondary container 9% Ni steel base Elevated Base concrete insulation raft

Figure A-7 Examples of cryogenic storage tanks.



METH	IAN	IE PRINCESS -
1964		
Capad	city	: 27.400 m ³
LOA	=	175.00 m
В	=	24.80 m
D	=	7.90 m
JULE	s v	'ERNE - 1965
Сара	city	: 25.500 m ³
LOA	=	188.00 m
В	==	24.70 m
D	=	7.30 m
-		

POLA	R	ALASKA - 1969
Сара	city	∕: 71.500 m³
LOA	=	230.00 m
В	=	34.00 m
D	=	10.00 m

PAUL	. K <i>i</i>	AYSER - 1975
Capa	city	r: 125.000 m³
LOA	=	266.00 m
В	==	41.60 m
D	=	11.00 m

New design with Kvaerner-Moss tanks - 1976 Capacity: 125.000 m³ LOA = 270.00 m B = 43.00 m D = 11.70 m

Figure A-8 Examples of LNG carriers that have been developed over the years.

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Figure 11: LNG Carrier Polar Eagle

Figure A-9 Picture of a medium size LNG carrier.

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Appendix B. Example of a ship/shore safety checklist.

PORT AUTONOME DE ANTES/ST-NAZAIRE

FICHE DE CONTROLE NAVIRE/TERRE SHIP/SHORE SAFETY CHECK LIST

Nom du Navire Ships Name	
Poste d'amarrage Berth	Port
Date de l'arrivée Date of arrival	Heure de l'arrivée Time of arrival

STRUCTIONS SUR LA MANIERE DE REMPLIR LA PRESENTE LISTE DE CONTROLE

Pour que les opérations puissent être exécutées en toute sécurité, il faut que les réponses à toutes les questions soient affirmatives **X**. Lorsqu'il n'est pas possible de donner une réponse affirmative, la raison doit être indiquée, et le personnel du navire et celui du terminal doivent convenir des précautions appropriées à prendre. Lorsqu'on estime qu'une question est sans objet, on l'indiquera par une note dans la colonne observations.

The safety of operations requires that all questions be answered affirmatively \mathbf{X} . If an affirmative answer is not possible, the reason should be given and agreement reached upon appropriate precautions to be taken between the ship and the terminal. Where a question is not considered to be applicable a note to that affect should be inserted in the remarks column.

- □ Lorsque ce symbole figure dans les colonnes "Navire" ou "Terminal", les vérifications doivent être effectuées par la partie concernée.
- The presence of this symbol in the columns "ship" or "terminal" indicates that checks shall be carried out by the party concerned.

rsque la lettre A ou la lettre P figure dans la colonne Code, cela indique ce qui suit :

À les procédures et accord mentionnés doivent être établis par écrit et être signés par les trois parties.

P - Lorsqu'une réponse est négative, l'opération ne doit pas être exécutée sans l'autorisation de l'autorité portuaire.

The presence of the letters A and P in the column "Code" indicates the following:

A - the mentioned procedures and agreements shall be in writing and signed by the third parties.

P - In case of a negative answer the operation shall not be carried out without the permission of the Port Authority.

		PARTIE A PART A Liquides en vrac-généralités Bulk Liquids-General	NAVIRE SHIP	TERMINAL	OFFICIER DE PORT HARBOUR AUTHORITY	CODE	OBSERVATIONS REMARKS
	A1	Le navire est-il bien amarré ? Is the ship securely moored?	٥				
(mark)	A2	Les câbles de remorquage d'urgence sont-ils correctement disposés? Are emergency towing wires correctly positioned?		•	a		
	A3	Existe-t-il un accès sûr entre le navire et la terre? Is thère safe access between ship and shore?	a				
	A4	Le navire est-il prêt à se déplacer par ses propres moyens?				P	

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	PARTIE A PART A Liquides en vrac-généralités Bulk Liquids-General	NAVIRE	TERMINAL	OFFICIER DE PORT HARBOUR AUTHORITY	CODE	OBSERVATIONS REMARKS
-	A5 Une veille efficace est-elle assurée sur le pont du navire et une surveillance adéquate au terminal et à bord du navire? Is there an effective deck watch in attendance on board and adequate supervision on the					
	A6 Le système de communication convenu navire/terre est-il en état de fonctionnement? Is the agreed ship/shore communication system operative?				A	
	A7 Les procédures de manutention de la cargaison, du combustible et du ballast ont-elles été convenues?				A	
	As Les procédures d'interruption en cas d'urgence ont-elles été convenues? Has the emergency shut down procedure been	a			A	
	 agreed? A9 Les manches à incendie et le matériel de lutte contre l'incendie à bord et à terre sont-ils en place, prêts à être utilisés immédiatement? Are fire hoses and fire fighting equipment on board and ashore positioned and ready for immediate use? 		٥			
	A10 Les flexibles ou bras de cargaison et de combustible sont-iis en bon état et correctement installés et les certificats ont-ils, le cas échéant, été vérifiés?		0			
	Are cargo and bunker hoses arms in good condition and properly rigged and, where appropriate, certificates checked? All Les dalots sont-ils efficacement obturés et les gattes en place, tant à bord qu'à terre? Are scuppers effectively plugged and drip trays					
	in position, both on board and ashore? A12 Les bouches de cargaison et de combustible inutilisées, y compris la conduite de déchargement arrière, s'il y en a une, sont-elles obturées? Are unused cargo and bunker connections including the stern discharge line if fitted			-		
	blanked? A13 Les vannes/soupapes de rejet à la mer et par- dessus bord sont-elles fermées et assujetties si elles ne sont pas utilisées? Are sea and overboard discharge valves, when not in use closed and lischer?	D				
	Al4 Tous les couvercles des citernes à cargaison et des soutes à combustible sont-ils fermés? Are all cargo and bunker tank lids closed?	L1				
	est-il en service? Is the agreed tank venting system being used? A16 Les lampes électriques à main sont-elles d'un					
	Are hand torches of an approved type? A17 Les émetteurs-récepteurs portatifs VHF/UHF sont-ils d'un type agréé?					
	Are portable VHF/UHF transceivers of an approved type? A18 Les antennes de l'émetteur radio principal du navire sont-elles mises à la masse et les radars					
	stoppés? Are the ship's main radio transmitter aerials earthed and radars switched of?		•			
	Aly Les cables d'alimentation du materiel electrique portatif ont-ils été mis hors circuit? Are electric cables to portable electrical equipment disconnected from power?					

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Exemplaire destiné à la Capitainerie

APPENDIX B. EXAMPLE OF A SHIP/SHORE SAFETY CHECKLIST.

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	PARTIE A PART A Liquides en vrac-généralités Bulk Liquids-General	NAVIRE	TERMINAL	OFFICIER DE PORT HARBOUR AUTHORITY	CODE	OBSERVATIONS REMARKS
A2	0 Toutes les portes et toutes les ouvertures extérieures des locaux d'habitation situés au milieu du navire sont-elles fermées? Are all external doors and ports in the admidships accommodation closed?	<u> </u>				
A2	1 Toutes les portes et toutes les ouvertures extérieures des emménagements arrière qui ouvrent ou donnent sur le pont des citernes sont- elles fermées? Are all external doors and ports in the after accommodation leading onto or overlooking the tank deck closed?	٥				
A2	2 Les prises d'air destinées à la climatisation par lesquelles les vapeurs de la cargaison pourraient s'introduire sont-elles fermées? Are air conditioning intakes which may permit the entry of cargo vapours closed?	٥				
A2	3 Les climatiseurs du type fenêtre ont-ils été débranchés ? Are window-type air conditioning units disconnected ?					
A2	4 Les prescriptions relatives à l'interdiction de fumer sont-elles respectées ? Are smoking requirements being observed ?		O			
A2	5 Les prescriptions relatives à l'utilisation des fourneaux et autres appareils de cuisson sont- elles observées? Are the requirements for the use of galley and					-
A2	other cooking appliances being observed? 5 Les prescriptions relatives aux feux nus sont- telles observées? Are naked light requirements being observed?					
A2	7 Une issue de secours est-elle prévue ? Is there provision for an emergency escape possibility ?	C		D		
A2	3 Y a-t-il à bord et à terre du personnel en nombre suffisant pour faire face à une situation d'urgence? Are sufficient personnel on board and ashore to deal with an emergency?	⊆	۵			
A2	9 Les précautions contre les effets des courants de circulation et l'électricité statique ont-elles été prises ? Are adequate insulating means in place in the shin/shore connection ?	С	۵	٥		
A3	0 Des mesures ont-elles été prises pour assurer une ventilation suffisante de la chambre des pompes? Have measures been taken to ensure sufficient pumproom ventilation?	C				
A	PARTIE C Vérifications supplémentaires - Gaz liquéfiés en vrac PART C dditional Checks - Bulk Liquified Gases	NAVIRE <i>SHIP</i>	TERMINAL	OFFICIER DE PORT HARBOUR AUTHORITY	CODE	OBSERVATIONS REMARKS
j	Dispose-t-on des renseignements nécessaires pour manutentionner en toute sécurité la cargaison, y compris, s'il y a lieu, un certificat d'inhibition fourni par le fabricant? Is information available giving necessary data for the safe handling of the cargo including, where applicable, a manufacturer's inhibition certificate?	0	Ċ			
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	PARTIE C Vérifications supplémentaires - Gaz liquéfiés en vrac PART C dditional Checks - Bulk Liquefied Gases	NAVIRE SHIP	TERMINAL	OFFICIER DE PORT HARBOUR AUTHORITY	CODE	OBSERVATIONS REMARKS
ß	Dispose-t-on d'un équipement de protection suffisant et satisfaisant (y compris des appareils respiratoires autonomes) et de vêtements de protection prêts à être utilisés immédiatement ? Is sufficient and suitable protective equipment (including self contained breathing apparatus) and protective clothing ready for immediate use ?					
C4	Les espaces vides ont-ils été mis correctement en atmosphère inerte lorsque cela est nécessaire ? Are void spaces properly inerted where required ?	٥				
CS	Les vannes télécommandées sont-elles toutes en état de fonctionner? Are all remote control valves in working order?	۵	٥			
C6	Les soupapes de sûreté des citernes à cargaison sont-elles branchées sur le circuit de dégagement du gaz du navire et les dérivations sont-elles fermées? Are cargo tank safety relief valves lined up to the ship's venting system and are bypasses closed?					
C7	Les pompes et compresseurs à cargaison requis sont-ils en bon état de fonctionnement et les pressions de service maximales ont-elles été convenues entre le navire et la terre? Are the required cargo pumps and compressors in good order, and have the maximum working pressures been agreed between ship and shore?			-		
C8	Le dispositif de contrôle de la reliquéfaction ou de l'évaporation fonctionnet-il correctement? ls reliquefication or boil off control equipment in good order?					
යා	Le dispositif de détection des gaz réglé pour la cargaison est-il étalonné et fonctionne-t-il correctement? Is gas detection equipment set for the cargo, calibrated and in good order?					
C10	Les jauges et alarmes du circuit de la cargaison sont-elles réglées correctement et en bon état de fonctionnement? Are cargo system gauges and alarms correctly set and in good order?					
C11	Les dispositifs de fermeture d'urgence fonctionnent-ils correctement? Are emergency shut down systems working properly?					
C12	Le personnel à terre connaît-il les conditions de fermeture des vannes automatiques du navire? Le personnel de bord disposet-il des mêmes renseignements concernant le circuit à terre? Does shore know the closing rate of ship's automatic valves; does ship have similar details of shore system?		٥		A	
C13	Des renseignements ont-ils été échangés entre le navire et la terre sur les températures de service minimales des circuits de la cargaison? Was information been exchanged between ship	۵	□		A	

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	NAVIRE SHIP	TERRE SHORE
Est-il prévu de nettoyer les citernes pendant le séjour du navire le long de l'installation à terre? Are tank cleaning operations planned during the ship's stay alongside the shore installation?	Oui/Non* Yes/No*	
Si oui, l'autorité portuaire et le terminal ont-ils été informés? If so, have the port authority and terminal been informed?	Oui/Non* Yes/No*	Oui/Non* Yes/No*

* Rayer la mention inutile

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*Delete Yes or No as appropriate

DECLARATION DECLARATION

Nous avons effectué, ensemble lorsqu'il y avait lieu de le faire, les vérifications prévues sur la fiche de contrôle, et nous certifions que les réponses que nous avons données sont, pour autant que nous sachions, exactes et que des dispositions ont été prises pour que de nouvelles vérifications soient faites selon que de besoin.

We have checked, where appropriate jointly, the items on this check list, and have satisfied ourselves that the entries we have made are correct to the best of our knowledge, and arrangements have been made to carry out repetitive checks as necessary.

POUR LE NAVIRE FOR SHIP	POUR LE TERMINAL FOR TERMINAL
Noт Name	Nom Name .
Grade Rank	Fonction Position
Signature	Signature
Signature	Signature
L'OFFICIER DE PORT HARBOUR AUTHORITY	
Nom Name	Heure Time
Grade Rank	Date
Signature	
Signature	-

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Appendix C. Pledge letter used in the port of Osaka.

COFY of The SAFTY PLEDGE LETTER to The MARINE SAFTY AGENCY

Safe	ty measures for port entry and departure and
	ty measures for port entry and departure, and
	ng port stay
(a)	We will employ 2 pilots (1 for departure) for
	the vessel.
(Ь)	We will enter or leave port in daytime from
	sunrise till sunset.
(c)	For port entry and departure, we will arrange
	for a boat equipped with 'Category 4' fire-
	fighting installations and a guardboat, as
	specified in the Maritime Traffic Safety Law.
(d)	We will so arrange, at all times, that the
	vessel may be escorted by a guardboat capable of
	discharging 2 tons or more of dry chemicals
	within a short time.
(e)	As well as controlling fire on board the vessel,
	we will keep a strict watch on the surrounding
	area of the vessel and keep off other
	approaching vessels on which fire is probably
	insufficiently controlled, by drawing their
	attention.
(f)	We will not release boil-off gas while the
	vessel is sailing or staying in port.
(g)	We will put into practice safety measures
	required to be taken by vessels carrying other
	flammable and dangerous goods, such as the
	preparation at fore and aft of fire wires for
•	immediate use.
(h)	We will display a sign "LNG on board" on both
	ship's sides while sailing or staying in port.

SAFETY ASPECTS REGARDING LNG IMPORT TERMINALS.

(i) We will keep a sufficient under-keel clearance (10% or more of the draft) while sailing or staying in port.

Safety measures for berthing and unberthing

- (a) We will employ pilots for the vessel.
- (b) We will use 4 or more tugboats (of about 3,000
- HP) for berthing and 3 or more for unberthing.

Safety measures while alongside berth and cargo handling operations

- (a) We will not use the auto spinning mechanism during cargo transfer operations.
- (b) When it is necessary to use the auto spinning mechanism while in berth except during cargo transfer operations, the vessel should notify the berth master to that effect, and the master will so arrange that sufficient communication may be kept between the navigating bridge and the engine room in order to avoid unforeseen accidents.
- (c) As well as providing against a possible outbreak of fire by checking fire preventive and fighting installations, we will establish an arrangement to fight fire.
- (d) We will make a safety check in accordance with a checklist before carrying out cargo handling operations.
- (e) We will not load ship's stores, etc. during cargo handling operations.
- (f) We will establish an arrangement to communicate with the shore and provide on board a list of parties to contact in emergencies.

APPENDIX C. PLEDGE LETTER USED IN THE PORT OF OSAKA.

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(g)	For bunkering, we will use the exclusive piping
	system and deploy oil booms at necessary
	locations in addition to keeping vigilance by
	stationing crew members as lookouts.
(h)	We will, as a rule, take on bunkers only in
	daytime and we will not start loading bunkers at
	night.
(i)	Criteria by which to suspend cargo transfer
	operations:
	(1) When lightning is expected;
	When a tsunami warning is issued;
	(3) When an earthquake vigilant state is
	issued; and
	(4) When abnormal conditions are observed with
	the cargo handling facilities and
	instruments.
(5)	When cargo transfer operations are suspended, we
	will promptly report to the Captain of the Port
-	as well as closing valves and disconnecting
	manifold pipes, depending on the situation.
(k)	When a lightning squall advisory is issued, we
	will intensify our arrangement of vigilance.
(1)	When a typhoon or depression is approaching, we
	will take action in ample time following
-	instructions or recommendations by the Captain
	of the Port and the local Typhoon Disaster
	Prevention Consultative Council without losing
	timing for taking shelter. We will also comply
	with other instructions from the Captain of the
	Port.
(m)	We will comply with the safety measures prepared
	by the berth administrator and approved by the
L	Maritime Safety Agency.

Safety measures while alongside berth and during cargo transfer operations

- (a) When the wind speed is forecast to reach 15 m/sec and has actually reached 10 m/sec or the wave height has exceeded 1.5 m, we will suspend cargo handling operations.
- (b) We will resume cargo handling operations when the wind speed has dwindled to 10 m/sec or less and the weather condition is forecast to improve.
- (c) When the wind speed is forecast to exceed 20 m/sec, we will unberth in ample time and take shelter at a safe place.

3. Osaka (Senboku Quarter)

Safety measures for port entry and departure, and during port stay

We will arrange for a boat equipped with firefighting installations as a guardboat while in port.

Safety measures for berthing and unberthing

(a) We will refrain from berthing when the wind speed has exceeded 12 m/sec (average 8 m/sec; maximum 12 m/sec) or the wave height has exceeded 1.2 m (1.0 m), or the visibility has reduced to 1 mile or less. Note: The figures in the parentheses are applicable to No. 2 berth.
(b) We will maintain the berthing speed at a maximum of 8 cm/sec.

Safety measures while alongside berth and during				
Cargo transfer operations				
(a)	We will suspend cargo handling operations when			
	the wind speed has exceeded 15 m/sec or the wave			
	height has exceeded 1.5 m.			
(b)	We will resume cargo handling operations when			
	the wind speed has dwindled to 15 m/sec or less			
	and the weather condition is forecast to			
	improve.			
(c)	When the wind speed is forecast to exceed 20			
	m/sec, we will unberth in ample time and take			
	shelter at a-safe place.			
(d)	We will not take on bunkers from a vessel			
	alongside our LNG carrier.			
	4. Himeji (Higashi Quarter)			
Safety measures for port entry and departure, and				
during port stay				
	We will arrange for a boat equipped with fire			
fighting installations as a guardboat while in port.				
Safety measures for berthing and unberthing				
(a)	We will refrain from berthing when the wind			
	speed has exceeded 8 m/sec, or the wave height			
	has exceeded 1.2 m, or when the visibility has			
	reduced to 1 mile or less.			
(Ъ)	We will maintain the berthing speed at a maximum			
	of 10 cm/sec.			
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Project	: The Ulsan Port development plan
File	: 002
Length of report	: 125 pages
Author	: Michiel de Jong
Contributions	: G.C. de Jong
Project Manager	: M.H. Schreuder
Project Director	: A. B. van der Boon
Date	: 12 November 1997
Authorization	:

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G-2



THE ULSAN PORT DEVELOPMENT PLAN

Figure G-3



THE ULSAN PORT DEVELOPMENT PLAN







G-5



Conceptual layout of the proposed LNG import terminal in Rotterdam. Figure 7-8



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1	TANKER
2	JETTY
3	LHG TANKS
4	UNLOADING LNG RETENTION POND
5	SENDOUT LNG RETENTION PONG
8	0-R-Y
7	HEAT EXCHANCER
8	FUEL GAS HEAT EXCHANCERS
٩	BOG COMPRESSOR SUCTION DRUM
10	BOIL OFF COMPRESSORS
11	NITROGEN INJECTION
12	FLARE K-O DRAIN DRUM
13	FLARE STACK
14	HETERING FROM UGS
15	HETERING TO UGS
16	HETERING HHY SEND OUT
17	HETERING LHY SEND OUT
18	WATER PUPPS
19	Celeted
28	TRANSFORMERS
21	HAIN POWER STATION
22	ELECTRIC SUB STATIONS HT
23	ELECTRIC SUB STATIONS Nº2
24	EHERCENCY GENERATOR
25	FIRE WATER PUMPING STATION
26	FRE HOLSTRIAL WATER AND DALLSIFIER STOWCE & PLAPTIC

7-13



Figure 8-1 The Ulsan Port extension with a separate LNG port.

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