PORT EXPANSION SHANGHAI

Evaluation of Shanghai's needs for new port areas
Conceptual design of a new port area at Changxing Island
Entrance Channel Dredging Simulation Model

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PREFACE

The port of Shanghai is China's principal port and ranking third in the world's largest ports. Shanghai faces one major problem: the poor accessibility from sea for vessels greater than 10000 dead weight tonnes. This reports incorporates a study to the deepening of the entrance channel to Shanghai. Another problem of Shanghai's harbour is its spatial diversity. Terminals are scattered along the Huang Pu and Yangtze rivers. This reports also presents a vision of how further port expansion of Shanghai could be coherently facilitated.

I would like to thank the following persons:

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Special thanks to my parents, brother and lovely wife Petra for their support during the entire study of civil engineering and writing of this report.

Joris van de Looij
READING SUGGESTIONS

This report consists of five parts which more or less succeeds each other. Each part can be read separately, accordingly to the reader's interest.

Part 0 General Introduction
The scope of this study is outlined in the part. Shanghai's principle problems analyzed and research targets specified.

Part I China, the Yangtze river and delta
This part gives the reader a introduction into the economic profile of China. This total macro-economic overview of China is presented to later better understand the problems facing the port of Shanghai.

Part II Harbour Development
This part investigates the demand for new harbour areas within the greater Shanghai area. Three alternatives locations for future port expansion are presented and evaluated.

Part III Harbour development at Changxing Island
This part will give a basic design of a new harbour in the mouth of the Yangtze River. Due to limited information available, especially about soil conditions, only a spatial layout of the new harbour is made. The port design gives a impression of how a coherent future port could look like.

Part IV Entrance Channel Dredging Simulation Model
The most acute problem, facing Shanghai's harbour is the limited depth of the entrance channel. This part provides a computer driven simulation model to calculate different dredging scenario's. Thereby taking in account the limiting boundary conditions such as waves, gales and tides.
SUMMARY

China's economy is growing rapidly. For 1997 an economic growth of 10.5 per cent is expected (source: Economic pages of de Volkskrant, December 1996). With the economic growth the demand for new industrial zones and harbour areas arises. To facilitate these demands the port authority of Shanghai faces two major problems: the shortage of free land and the shallow depth of the entrance channel to Shanghai.

To counter the first problem, the lack of free land, the Chinese authorities appointed special port planning zones. These areas are strictly reserved for future port development. Unfortunately, the special port planning zone of Shanghai, called Jinshanwei, is located some 100 kilometres away from the city centre and the existing harbours. This is a very unworkable situation. Therefore new alternative plans have been developed. The first plan involves the reclamation of new land along the south bank of the Yangtze River. On this new land terminals can be built. The new terminals will be separated from the Yangtze river by a dam. Thereby an artificial canal to the sea is recreated. This plan is called the coastal canal option. The second plan involves the conversion of two islands, close to Shanghai, into new port areas. This plan anticipates at the expected great economic burst of the cities upstream along the Yangtze river. The most important function of the new terminals at these island will be providing a cargo transit-hub to the ports upstream. The islands in the mouth of the Yangtze delta are Changxing and Hengsha. In the future the terminals at these island can be linked with an eight kilometre long bridge to the industrial centre of Shanghai; the Pudong area.

The second, and most acute, problem of Shanghai's port is the shallow depth of its entrance channel. Currently the depth of the channel is some seven metres below Chart Datum. At spring tide a maximum water depth of eleven metres is available. These depths are far to small for today's modern vessels. Therefore the Chinese, together with Dutch counterparts, conducted intensive research to the deepening of the entrance channel. The research showed that a combination of river training dams and dredging works will provide the opportunity to deepen the channel from CD-7.00 metre to CD-12.50 metre. With aid of a newly developed entrance channel dredging simulation model the dredging of the entrance channel has been simulated. Five large 15000 m³ trailing suction hopper dredgers can bring the channel to its desired depth in some 3.5 years. Thereby taking in account limiting conditions such as waves, gales and typhoons.

Currently new dredging techniques are under development and made commercially available. One of these dredging methods is called water injection dredging (WID). As combination of conventional trailing suction hopper dredgers and water injection dredgers could be the ideal solution for the dredging operations within Shanghai. Soil and seabed conditions are very favourable for WID. This requires further research. The entrance channel dredging simulation model can be expanded with a module, representing the process of a water injection dredger. New simulation runs and evaluations should provide the answer whether a combination of these dredgers lives up to its high expectations. Perhaps this is the solution to Shanghai's entrance channel problems.

1
PART 0 GENERAL INTRODUCTION

1 INTRODUCTION

The harbour of Shanghai is China’s largest port and ranking third in the world’s largest ports after Rotterdam and Singapore. During the last five years the greater Shanghai area experienced strong economic growth. The development of the harbour of Shanghai is constrained, due to two major problems. Firstly the shallow draught of the Yangtze delta limits the maximum size of a vessel, which can enter the harbour of Shanghai, to 20000 dwt using the high water tidal benefit. The old harbour of Shanghai is situated along the Huang Pu River. The city has fully enclosed the old harbour. This is the second major problem of Shanghai’s harbour: the shortage of space for harbour expansion. The principle goal of this thesis is finding a solution for these two problems; the shallow draught of the Yangtze delta and the lack of space within the harbour. It is important to look for a solution which deals with these two problems at the same time. To find an integrated solution is a great challenge because possible land reclamation projects and navigation channel improvements are strongly related to each other.

1.1 Previous Studies

During 1985-1995 the Port and Delta Consortium (PDC) conducted three studies for the Chinese government. These studies involve means of regulating the water and sediment flows within the Yangtze Delta. The latest study of July 1995 explored the feasibility of deepening the existing channels or constructing a coastal canal with a lock complex.

1.2 New Study to the Yangtze Estuary

The Dutch Ministry of Economic Affairs has started an investment program to improve the position of Dutch companies on the international market. A part of this program is the Land Water Impuls (LWI). This is a co-operation between various competitors to develop a knowledge infrastructure on the field of designing, constructing and managing infrastructure works. Joining forces of the various competitors will strengthen the market parties overall and increases the position of Dutch companies at the international market. The development and use of information technology is a central part of the LWI program. Typical is the integrated approach of combining civil engineering aspects, economic judgements, environmental values, risk analysis and spacial allocation problems. A foreign pilot study is part of the LWI program. On May 21st, 1996 the Port and Delta Consortium (PDC) proposed a pilot project for developing a Decision Support System (DSS) for the Yangtze estuary. This is a computer based instrument for the management and development of estuaries, delta’s and coastal zones. The computer driven system combines the latest techniques of measurements, data processing, designing and modelling.
Figure 1  The Yangtze river and the important ports along the river.
1.3 About this Master Thesis

The consulting engineering company DHV of Amersfoort is involved with the Yangtze pilot study of developing a Decision Support System (DSS) for the Yangtze delta. The DSS can be used for establishing new visions for future development of Shanghai’s harbour. The development of the DSS will take at least another year. This thesis is a precursor at possible results from the DSS. A plan will be made to overcome congestion problems of Shanghai’s harbour.

2 PROBLEM ANALYSIS

The port of Shanghai is the China’s largest harbour. The greater area of Shanghai, situated at the Yangtze delta is experiencing strong economic growth. The region could develop to one of the most important industrial centres of China. Shanghai has the potential to be a mainport of China, but there are a number of problems to overcome:

- The old harbour installations of Shanghai are situated along the Huang Pu River. This river is an arbitrary to the Yangtze River. Mainport development is not possible due to the limited depth of the Huang Pu river and lack of free land areas. The harbour areas are surrounded by the city.
- Shoals and bars in the Yangtze delta are restricting the accessibility of Shanghai harbour. Substantial depth increases of the navigation channel are very difficult to establish. Annually 10 million m³ is dredged to keep the navigation channel at a width of 250 metres and a depth of 7.00 metres below chart datum over a length of 25 kilometres.

These problems will be further analyzed in greater detail. The final report will describe concept plan for the future development of Shanghai harbour.

3 TARGETS

The development of a mainport plan for the port of Shanghai strongly relates to improvements to the existing navigation channel. Earlier, the Port and Delta Consortium (PDC), investigated two alternatives:

1. Deepening of the existing navigation channel, combined with training dams guiding currents to prevent siltation.
2. Construction of a new canal from the sea to Shanghai to avoid the shoals and the bars in the river mouth. This coastal canal option will need a new navigation channel at sea (see figure 2, next page).

The next figure gives the two alternatives which have been developed by the PDC. The deepening of the existing navigation channel (South Channel) and the construction of a coastal canal. The principle target of this thesis project is developing a concept expansion plan for the port of Shanghai. These issues will be investigated in greater detail.
1. Developing global harbour spatial allocation plans
The spatial allocation of harbour activities must be investigated in relation to
the two alternatives developed by the PDC. Recent shipping forecasts will be
used to calculate the required land areas for harbour activities.

From the alternative locations for future port expansion, one will be selected
to be investigated in greater detail. A plan view of a new port design will be
presented:

2. New harbour development
With aid of throughput estimates the required new land areas for the new
terminals will be calculated. The total number of berths and the total quay
length are calculated for the year 2000 and 2010. Nautical and meteorological
requirements determine the port’s layout of the terminals and the water areas.

The new harbour must be easily accessible from sea. This is one of the major
problems of the present harbour of Shanghai. The old harbours and the future
terminals must have good access from sea. DELFT HYDRAULICS and the Port
and Delta Consortium (PDC) have conducted a feasibility study to the
deepening of the Yangtze river, accompanied by river training works. The
annual maintenance dredging quantities have been calculated with aid of
hydraulic models. The sediment has to be removed by means of dredgers.
The way of how this dredging operation can be executed is the subject of the
final detailed study of this thesis:

3. Entrance channel dredging simulation model
The expected quantities of dredged material are known. Not known is how
this material should be removed from the seabed. The dredging simulation
model assumes the use of self propelled suction trailer hopper dredgers. The
vessels are available in various sizes, ranging from 500 dwt to 20000 dwt
.loaded with sand). The model will optimize the usage of available vessels,
the dredging regime, travelling distances and loading times.

Figure 2. The location of the navigation channels within the Southern Channel (North
Passage and South Passage) and the location of the possible coastal canal.
The figure below represents the contents of this thesis. Part I China, The Yangtze river and delta describes the economic profile of China to provide the reader with some background information. Part II Harbour Development focuses on port development within the Shanghai area. Cargo throughput estimates are derived from historical figures, taking different growth scenarios in account. New port development is based on these throughput estimates. The alternative locations of new harbour development will be presented. Eventually, one location will be selected and evaluated in further detail. Part III Harbour Development at Changxing Island further describes the most favourable location for future port expansion. A conceptual port layout is presented and motivated. The last section of this thesis, Part IV Entrance channel dredging simulation model, investigates how the entrance channel to the Shanghai harbours could be dredged. A computer driven simulation model will optimize the dredging process.

Part I China, The Yangtze River and Delta

Part II Harbour Development

Part III Harbour Development at Changxing Island

Part IV Entrance Channel dredging simulation model

The figure above is a graphical representation of the four parts of this thesis. The Parts I an II have a descriptive nature, whereas the parts III and IV have a engineering, designing nature.
PART I CHINA, THE YANGTZE RIVER AND DELTA

This part is written to give the reader an update to the latest economic developments within China. China is still a very poor country, but has double digit economic growth figures. Growth figures for 1997 are expected to reach 10.5 percent. In contrast, the Dutch economy will have an expected growth between 2 and 3%. China’s growing economy will put a heavy burden on the already clogged transportation network. Coastal and inland shipping will provide the much needed extra transportation capacity. This, in turn, has great impact on future port developments.

1 ECONOMIC PROFILE OF CHINA

In 1994 some 1.2 billion people are living in China. Annually the population number increases with 1.5%. The economic growth exceeds the population growth. During 1994 the Gross Domestic Product grew with 11.8%. Despite this immense growth China still remains one of the poorer countries of the world. The World Bank estimates the Gross Domestic Product per capita at US$470 [20].

Since 1978 the Chinese economy is rapidly changing. The emphasis is put at flexibility. A change in ideology was most important. De-centralized government control and private enterprises were put in operation. Between 1978 and 1992 the Chinese economy grew 10% annually. The central Chinese government tried to distribute the economic growth over the entire country. These efforts failed. Especially the coastal provinces experienced strong economic growth. In 1992 the export of goods from the provinces Guangdong (opposite Hong Kong) and Fujian (opposite Taiwan) grew with 20%.

Strong economic growth encourages inflation. To counter excessive inflation the Chinese government imposed tight financial restrictions. Increased borrowing costs might restrain economic growth and increase production costs. This reduces economic growth. At the same time the public spending power is reduced. By introducing fees over importing and exporting goods the international trade is the first sector suffering from tight government financial restrictions.

The table below summarizes some economic characteristics of both the economies of China, the United States of America and the twelve (1993) European member states. Remarkable, the Chinese economy experiences the greatest economic growth, but is still substantially smaller then the economies of the USA en Europe. During 1995 and 2000 the Chinese economy is expected to growth with 8 to 9 % annually.
Table 1  China and the World's economies [20] (GDP = Gross Domestic Product).

<table>
<thead>
<tr>
<th></th>
<th>GDP 1993 (billion US$)</th>
<th>% of EU-12 GDP</th>
<th>% growth over 1984-93</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU-12</td>
<td>6327.9</td>
<td>100.0</td>
<td>2.9</td>
</tr>
<tr>
<td>USA</td>
<td>5765.1</td>
<td>91.0</td>
<td>2.8</td>
</tr>
<tr>
<td>China</td>
<td>541.3</td>
<td>8.5</td>
<td>8.9</td>
</tr>
</tbody>
</table>

China has three main economic regions: Bohai Coastal Region, The Yangtze Gateway and the Guangdong Region. Within northern China the Bohai Coastal Region serves the capital Beijing and the hinterland. The Yangtze Gateway is situated at the mouth of the Yangtze River. This river symbolises the economic backbone of China. China's largest port, Shanghai, has been located along the Yangtze river. Within southwestern China lies the province of Guangdong. The Guangdong region is the most prosperous province of China. The important harbour of Hong Kong is also situated within this province. By July 1st, 1997, Hong Kong will be handed over from the British to the Chinese government. The province of Guangdong already has a Gross Domestic Product which equals that of Malaysia (1992). Goods, which are shipped out of Hong Kong, are often produced in Guangdong province. Of all containers transferred in Hong Kong some 50% originates from, or is bound for, China. The Guangdong province exceeded the Shanghai region as main export base of China. Of the total Chinese exports 41% comes from Guangdong province.

Table 2  China's principal economic regions [30].

<table>
<thead>
<tr>
<th>Inhabitants (millions)</th>
<th>GDP 1993 (billion Yuan)</th>
<th>GDP growth 1992-93</th>
<th>Export share 1993</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bohai Region</td>
<td>200 (17%)</td>
<td>747 (24%)</td>
<td>15.5%</td>
</tr>
<tr>
<td>Yangtze Gateway</td>
<td>185 (16%)</td>
<td>694 (22%)</td>
<td>20.8%</td>
</tr>
<tr>
<td>Guangdong</td>
<td>66 (6%)</td>
<td>323 (10%)</td>
<td>22.3%</td>
</tr>
<tr>
<td>China</td>
<td>1185 (100%)</td>
<td>3134 (100%)</td>
<td>13.2%</td>
</tr>
</tbody>
</table>

The three regions: Bohai Coastal Region, Yangtze Gateway and the Guangdong Region are the principal centres of economic activities within China. Of the total Gross Domestic Product (GDP) 56% is generated in these three areas. Also 75% of the total export of China runs through these regions.
Figure 3  China's principal economic regions.
FOREIGN TRADE

The main trading partners of China are the United States of America, Japan and the European Community. With these trading partners China has built a substantial trade surplus. Low value consumer goods such as shoes, clothing, textiles and garments contribute to this success. In 1992 these items accounted for 52% of the total export value of China. With the increasing economic development of China higher value consumer good will be produced in the near future. For instance, with Philips a joint venture has been established to produce television sets. The low costs of labour in China will attract foreign investors. In 1994 some 120 billion US$ was exported and some 115 billion US$ imported. The trade surplus became 5 billion US$. In 1993 the trade deficit was still some 12.2 billion US dollar. This turnover is a good example of the potential of the Chinese economy. The major export products of China are: textiles, light industrial products such as toys, metals, chemicals and crude oil. Imported are chemicals such as fertilizer and plastics, steel, industrial half-products, industrial plants and various machinery.
Figure 4  China’s international trade 1993 [20].
YANGTZE RIVER AND DELTA

The Yangtze river is China's largest river. With a length of some 6300 kilometres the Yangtze river is ranking third of the World's largest rivers after the Nile and the Amazon. An area of 1.8 million square kilometres feeds its water to the Yangtze river. This equals 18.8% of the total land area of China. Annually one trillion (1 \(10^{12}\)) m\(^3\) water flows from the Yangtze river into the sea. This amount of water equals the size of the Netherlands covered with a water disk with a thickness of 24.3 metres.

For many centuries the Yangtze river is used for (inland)shipping. The river is the main transportation axis between eastern and western China. The three important regions of southwestern China, central China and east China are linked by this river. Important cities such as Chongqing, Wuhan, Nanjing and Shanghai are situated along this river. Within the river basin live some 385 million people, some 35% of China's population. Some 25% of the total farmland is located within the Yangtze river area. Along the river important iron- and chemical plants are located and minerals are found. The provinces and cities along the Yangtze river are the backbone of China's economic expansion [8].

INLAND WATER TRANSPORT

The Yangtze river is the most important river of China's inland water transport network. Large parts of the upper reach of the Yangtze river is situated in the province of Sichuan. Within this province the Yangtze river is called Chuanjiang (Chang Chiang). In 1986 some 275 million tonnes of cargo was shipped over the Yangtze river system. For comparison: in 1986 the harbour of Rotterdam had a throughput of 258 million tonnes (source: Havenplan 2010). Upstream, at the locks of the hydro-power station of Gezhouba, some 6 million tonnes of goods and 8790 passenger vessels passed the locks. The three south-western provinces Yunnan, Guizhou and Sichuan have large mineral reserves. Some 20% of the national coal reserve and 41% of the total phosphate reserve is situated within these provinces. Also important reserves of vanadium, titanium, lead, zinc, cobalt, strontium and mercury are present.

The economic growth within China runs from east to west. Especially bulk cargoes such as coal, phosphate, copper, iron, wood, fertilizer and cement will be increasingly shipped over the Yangtze river. By the year 2000 it is expected that some 49 to 55 million tonnes of cargo and 2.5 million passengers will be shipped over the Yangtze river [11].
SEAPORTS ALONG THE YANGTZE RIVER

The five principal ports of the Yangtze river are Shanghai, Nanjing, Nantong, Zhangjiagang and Zhenjiang. Ships up to 10000 dwt can sail to Nanjing, ships up to 5000 dwt can reach Wuhan.

1. Shanghai

This is the largest and principal port of China. Ships up to 10000 dwt can enter at any time though a dredged canal. The tides are semi-diurnal with a mean tidal range between 2 and 4 metres. The average flood current varies between 2.5 and 4 knots. The maximum draught of ship within the harbour is 10.5 metres. The harbour is divided into twelve districts. There are 88 berth alongside a quay and 86 berth at mooring buoys.
Figure 5  Principle ports along the Yangtze river.
### Table 3 Harbour districts of Shanghai [38].

<table>
<thead>
<tr>
<th>District</th>
<th>Quay length (m)</th>
<th>Number of berths</th>
<th>Draught (m)</th>
<th>Cargo type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Dongchang</td>
<td>733</td>
<td>7</td>
<td>8-10</td>
<td>General cargo</td>
</tr>
<tr>
<td>2. Mingsheng</td>
<td>963</td>
<td>5</td>
<td>8-10</td>
<td>Grain, ore</td>
</tr>
<tr>
<td>3. Huishan</td>
<td>1121</td>
<td>8</td>
<td>8-10</td>
<td>General cargo</td>
</tr>
<tr>
<td>4. Mucai</td>
<td>752</td>
<td>5</td>
<td>8-10</td>
<td>Timber</td>
</tr>
<tr>
<td>5. Gaoyang</td>
<td>1112</td>
<td>7</td>
<td>8-10</td>
<td>General cargo</td>
</tr>
<tr>
<td>6. Kaiping</td>
<td>387</td>
<td>2</td>
<td>8-10</td>
<td>General cargo</td>
</tr>
<tr>
<td>7. Meitang</td>
<td>1223</td>
<td>8</td>
<td>8-10</td>
<td>Coal</td>
</tr>
<tr>
<td>8. Xinhua</td>
<td>1758</td>
<td>10</td>
<td>8-10</td>
<td>Ore, fertilizer</td>
</tr>
<tr>
<td>9. Zhanghuabang</td>
<td>1324</td>
<td>7</td>
<td>8-10</td>
<td>Containers</td>
</tr>
<tr>
<td>10. Jungong</td>
<td>1600</td>
<td>9</td>
<td>8-10</td>
<td>Dry cargo</td>
</tr>
<tr>
<td>11. Gongqing</td>
<td>993</td>
<td>10</td>
<td>8-10</td>
<td>Dry cargo</td>
</tr>
<tr>
<td>12. Fuxing</td>
<td>886</td>
<td>10</td>
<td>8-10</td>
<td>Dry cargo</td>
</tr>
<tr>
<td>13. Boashan</td>
<td>1420</td>
<td>8</td>
<td>8-10</td>
<td>Ore, cont.</td>
</tr>
<tr>
<td>14. Waigaoqiao</td>
<td>900</td>
<td>4</td>
<td>8-10</td>
<td>General cargo</td>
</tr>
</tbody>
</table>

The transport of passengers over water play an important role within China. The modern Shiliupu Passengers Terminal can cater 20000 passengers daily. A network of passenger services connects many Chinese ports, Hong Kong and numerous foreign harbours.

2. Nantong

This is the first major port upstream from Shanghai. Grain, coal, oil, ores, fertilizers and containers can be handled. The total quay length is some 1540 metres. Ships with a 16 metre draught can berth at Langshan Wharf No 3. However, ships with this draught cannot enter the Yangtze river from the sea, due to the shallow draught at the river mouth. Depth at the mouth of the Yangtze delta is kept at CD-7.00 metres.

3. Zhangjiagang

This is a natural harbour, almost fully enclosed by land. The entrance channel has a width of 1200 metres and a depth of 10 metres. Seventeen sea-going vessels can be handled at the same time. The harbour plays an important role for alleviating congestion at the harbour of Shanghai. There are plans to extent the harbour with five more berth for vessels up to 25000 tons.

4. Zhenjiang

This harbour is situated at the intersection of the Yangtze river and the Grand Beijing - Huangzhou Canal. In Zhenjiang Old Harbour ships of 1000 to 2000 dwt and a draught of 3 to 5 metres can be handled. At close by Dagang ships up to 25000 dwt and 11 metre draught can berth. The major imports are timber, ores, coal and oil products. Exported are cotton, grain and general cargo.
5. Nanjing

The entrance channel has a width between 480 and 1200 metres and a minimum depth of 10 metre during the whole year. There are 40 berths with a total length of some 2600 metres. The harbour is an important node by the transfer of cargo from sea-going vessels to inland water transport vessels. Ships up to 10000 dwt can be handled. Currently harbour extension programs are being executed. After completion ship up to 20000 dwt can be served.

Figure 6 Harbour areas along the Huang Pu river, Shanghai.
DEVELOPMENTS AT SHANGHAI HARBOUR

The old harbour of Shanghai is situated at the western bank of the Huang Pu river. The Huang Pu is an arbitrary to the Yangtze river. At the eastern bank of the Huang Pu new harbour and industrial areas are constructed. These areas must alleviate congestion at the old harbour installations. This new industrial area is called Pudong New Area, some 320 square kilometres in size and about 1.38 million people live here. The central Chinese government appointed Pudong New Area as a central focus of the new economic reform policy. Pudong must restore Shanghai's function as a national economic centre and set a firm foundation for Shanghai to become one of the economic, financial and trade centres in the Far East.

Currently some 2000 companies have settled in Pudong New Area and provide work for 400000 employees. The major industries are the petrochemical industry, shipbuilding, iron and steel plants and the machinery manufacturing industry. Important companies are: the Shanghai Gaoqiao Petrochemical Corporation, the Hudong ship yard, the Shanghai No. 3 Iron and Steel Factory and the Shanghai Yaohua Glass Plant. Pudong also provides Shanghai with agricultural products. In 1990 the agricultural output of Pudong accounted for some 8% of the total of Shanghai's region.

Along the east bank of the Huang Pu river are currently 186 berths. Of these 35 are suitable for vessels of 10000 dwt. In 1990 a throughput of 60 million tonnes was achieved. This is some 49% of the total throughput of Shanghai's harbour.

Pudong New Area has been divided into five relatively independent new zones:

A. Lujiazui - Huamu : financial and trade zone
B. Gaoqiao - Waigaoqiao : free trade zone
C. Qingningsi - Jinqiao : export processing zone
D. Zhouchi - Liuli : hi-tech park
E. Beicai - Zhangjiang : industry (hi-tech) zone

These industrial zones are scattered over Pudong New Area. Between these industrial areas residential living quarters and recreational areas have been situated. The Chinese government has ambitious plans for the future:

1. Establishment of first-class infrastructure of roads, bridges, a metro system, electricity plants, natural gas installations, waste water treatment plants and telecommunication networks.
2. Establishment of the nation’s biggest business centre. By the year 2000, about 150 skyscrapers such as financial buildings, trade centres, shopping centres, exhibition halls and conference centres will be built. The Lujianzui finance and trade zone is some 28 square kilometres in size.
3. Establishment of the most advanced hi-tech industry and export processing zone. The development will emphasize on modern electronic industries, bio-technology, off shore natural gas exploration, consumer electronics production, shipbuilding and machinery production.
4. Establishment of a free trade zone with the most flexible policy in China. Within the Waigaoqiao area new warehouses, entrepot trade houses and export processing zones are erected. This must become China's largest international trade centre.
5. Establishment of advanced rural industry. The aim is to integrate rural and municipal developments to create garden like areas.

6. Build up of high quality residential areas. Each house must have an internal floor space of at least 100 square metres. Also schools, hospitals, sports centres and culture centres will be constructed.

The development of the energy and transport industries is preferred, followed by the construction of harbours, storage areas and wharfs. Least preferred are agricultural developments, ranking 35. The Pudong New Area must become a strong industrial function.

### THROUGHPUT FIGURES OF SHANGHAI

Shanghai is China's largest harbour. In 1993 the throughput of goods grew to 176 million tonnes. The next year the throughput fell to 165 million tonnes due to drop in coal throughput. The transport of coal by ship faces strong competition from the railways. The throughput of containers is growing strongly. In 1990 some 456000 TEU were handled. This number increased to 1.53 million in 1995. An increase of 336% in just five years. The principal container ports of Shanghai are: Zhangguabang, Jungong and Baoshan. These three harbours are situated close to each other at the intersection between the Huang Pu river and the Yangtze river. The container terminals are operated by the Shanghai Container Terminal (SCT) company. This is a joint venture between Shanghai Port Container Comprehensive Development Co. and Hutchison Whampoa Limited of Hong Kong. The latter is one of the largest terminal operators at Hong Kong harbour. SCT started projects to extend the harbour. Existing general cargo berths are converted to container terminals. By completion in 1996 it is expected to have 2281 metres of container berth available with a depth of 12.5 metres. In 1996 a throughput of 1.7 million TEU is estimated.

The majority of goods, shipped to Shanghai harbour, are dry bulk products (about 70%). Coal takes half of this amount. Since January 1994 the central Chinese government lifted regulations on coal pricing. Coal mines were free to ship their cargo with the cheapest provider. This gives the railway system a clear advantage for the time being.

#### Table 4

**Total throughput at Shanghai harbour 1990-94 (source: Port of Rotterdam).**

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Million tons</td>
<td>Million tons</td>
<td>Million tons</td>
<td>Million tons</td>
<td>Million tons</td>
</tr>
<tr>
<td>Coal</td>
<td>57.73 (41%)</td>
<td>54.64 (37%)</td>
<td>61.55 (37%)</td>
<td>60.00 (34%)</td>
<td>56.22 (34%)</td>
</tr>
<tr>
<td>Ore</td>
<td>18.28 (13%)</td>
<td>23.38 (16%)</td>
<td>26.52 (16%)</td>
<td>28.24 (16%)</td>
<td>29.96 (18%)</td>
</tr>
<tr>
<td>Steel</td>
<td>8.23 (6%)</td>
<td>7.54 (5%)</td>
<td>10.17 (6%)</td>
<td>12.11 (7%)</td>
<td>13.30 (11%)</td>
</tr>
<tr>
<td>Constr. material</td>
<td>10.66 (8%)</td>
<td>11.63 (8%)</td>
<td>14.35 (9%)</td>
<td>18.40 (11%)</td>
<td>18.80 (11%)</td>
</tr>
<tr>
<td>Agriproducts</td>
<td>9.35 (7%)</td>
<td>10.05 (7%)</td>
<td>11.08 (7%)</td>
<td>5.36 (3%)</td>
<td>11.61 (7%)</td>
</tr>
<tr>
<td>Other dry bulk</td>
<td>9.35 (7%)</td>
<td>10.05 (7%)</td>
<td>11.08 (7%)</td>
<td>5.36 (3%)</td>
<td>11.61 (7%)</td>
</tr>
<tr>
<td>Oil, gas, etc</td>
<td>13.64 (10%)</td>
<td>14.67 (10%)</td>
<td>15.97 (10%)</td>
<td>21.82 (12%)</td>
<td>17.92 (11%)</td>
</tr>
<tr>
<td>Others</td>
<td>17.24 (12%)</td>
<td>18.79 (13%)</td>
<td>19.42 (12%)</td>
<td>30.35 (17%)</td>
<td>8.60 (5%)</td>
</tr>
<tr>
<td>Containers</td>
<td>4.46 (3%)</td>
<td>6.11 (4%)</td>
<td>7.50 (5%)</td>
<td>8.47 (5%)</td>
<td>10.58 (6%)</td>
</tr>
<tr>
<td>Totals</td>
<td>139.59</td>
<td>146.81</td>
<td>166.56</td>
<td>176.40</td>
<td>165.30</td>
</tr>
</tbody>
</table>
Figure 7  Throughput at Shanghai harbour.
SHIPPING FORECASTS

During the last ten years the throughput at Shanghai grew substantially. In 1984 some 100 million tonnes was shipped, some 147 million tonnes in 1991, 167 million tonnes in 1992, 176 million tonnes in 1993 and 166 million tonnes in 1994. For comparison: in 1992 the port of Rotterdam had a throughput of 293 million tonnes (source: Havenplan 2010). At present some 75% of the total cargo flow is imported and 25% exported. The Chinese economy has been growing rapidly and trade regulations are being lifted. The ratio of imports versus export may change to increased exporting of goods. China might produce more goods for the foreign market.

By 2000 it is expected to establish a throughput of 210 million tonnes. Some 55% of this total volume will be shipped by vessels of 25000 dwt and over. These vessels need a navigation channel with a draught of at least CD-7.00 metres. About 4780 will use this channel annually. This equals some 15 vessels a day. With the present entrance channel depth these vessels can only enter the Yangtze delta partly loaded. Of these ships 30% are container ships, 30% coal carries, 15% ore carries, 25% general cargo ships and various other vessels. These estimates have been derived from data provided by the Chinese government (SIDI) and estimates by the Port and Delta Consortium (PDC).

Table 5 Shipping forecasts for Shanghai harbour at 2000 (source: SIDI/PDC).

<table>
<thead>
<tr>
<th></th>
<th>Throughput million tonnes/year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>Containers</td>
<td>20</td>
</tr>
<tr>
<td>Ore</td>
<td>40</td>
</tr>
<tr>
<td>General cargo</td>
<td>26</td>
</tr>
<tr>
<td>Various</td>
<td>5</td>
</tr>
<tr>
<td>Coal</td>
<td>90</td>
</tr>
<tr>
<td>Oil and various</td>
<td>29</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>210</strong></td>
</tr>
</tbody>
</table>

The table above shows that the navigation channel is mainly used by container vessels and bulk carriers. Modern, fourth generation container vessels, have a draught of some 13 metres and a capacity of 4500 TEU. At Shanghai the throughput of containers and foreign trade grew strongly during recent years. Since 1980 the number of containers handled at Shanghai grew 25 to 30 % annually.

The largest bulk carries which can enter the Yangtze delta are the 130000 dwt vessels for the Baoshan Steel Works at Wusong. With the present depth of the navigation channel, these vessels can only enter with high water and only carry a 40% load. To sail to Wusong fully laden these vessels need an additional water depth of seven to eight meters. At present the depth of the navigation channel is kept at CD-7.00 metre by means of large dredging operations. Ships up to 20000 dwt (second generation container vessels) can enter the estuary fully laden at high water.
HINTERLAND TRANSPORT

The railway network takes an important role within the national haulage of goods through China. China has a very outstretched railway network. Only the railway networks of the United States of America and India outrank the Chinese network. Currently the network has a length of 60000 kilometres and some 600000 railcars are in use. About 50% of China’s total cargo volume is transported by rail. If coastal shipping is excluded, some 75% of total volume of cargo and passengers is hauled by the railways. The railway network is a cheap and efficient way of transporting large volumes of cargo. Especially within northwestern China, where hardly any natural waterways exist, the railways have a prominent position. The Great Rivers of China are mainly running from West to East. The railways provide the important North - South link.

Some 40% of the total cargo volume is transported by ship. Coasters take 75% of this volume. For inland shipping some 109000 kilometre of waterway is available. Shanghai is the principle port for passenger transportation over water. In 1988 some 14 million passengers were transported. Of these passengers 1/3 went by sea, the remainder by the inland water transportation network.

Transportation over the road is increasing. Many roads, constructed between 1950-1960, are of very poor quality. Today, continuous road repairs are executed. The many rivers within China impose obstacles for further development of the road network. Bridges are costly so many rivers are crossed by ferries. This takes a lot of time and causes congestion. Only 20% of China’s roads qualifies to international standards.

Intermodal transport within China is still in its infancy. Especially creating an air link to and from China causes much problems. A large Taiwanese carrier, Evergreen, came up with the following solution: from Shanghai cargo is shipped to Pusan or Inchon in Korea, then flown to the United States of America. Due to various logistic problems, direct airlifts from Hongqiao airport, Shanghai, to the USA are not possible. Other carriers such as Nedlloyd, Sea-Land and APL have established their own freight stations in China to keep some control over their cargo. Especially shipping container to and from the port causes problems. Not so long ago containers were stuffed and stripped on the quay. This process must be taken away from the waterfront and out of the harbour.

Inland transport by rail is also a time consuming. In 1995 hauling a container from Shanghai to Beijing (1460 km) took a least 21 days. China consists of various regional economies. This creates distribution problems because economic reforms, dictated by the central government, are not always followed by the regional governments. The many local regulations, free, taxes and duties constrain the growth of the inland transportation network. A remarkable example: a production company within northern China ships its products to Hong Kong, then importing them again for the South-Chinese market. Another example, an estimated 25 to 30% of fresh food products spoils before it can reach consumer markets or food processing industries. China must import food because transportation is inadequate to move domestic food to areas of concentrated demand [14].

23
PART II HARBOUR DEVELOPMENT

This part focuses at economic developments within the greater Shanghai area. In particularly the expected cargo volume throughputs of Shanghai’s port. These future throughput figure determine the number of terminals and berths that have to be constructed. The throughput figures of 1994 are conservatively extrapolated to the years 2000 and 2010. From these figures future space demands for new harbour areas are compiled. With this information available, new locations for future port development will be selected. After an evaluation and selection process, the most favourable location will be investigated in further detail.

1 INTRODUCTION

The old harbour of Shanghai is situated along the Huang Pu river. The Huang Pu river is a arbitrary to the Yangtze river. See figure 6, part I. Most harbour sites are completely surrounded by the expanding city of Shanghai. Further inland extension of those harbour sites is no longer possible. The various wharfs are scattered along the Huang Pu river. Due to the congested road network, inter-port traffic is faced with long transportation times. To stimulate new development in the Shanghai area the local government has appointed the Pudong area as the new centre for economic development. Pudong New Area is located to the east of the Huang Pu river and southwest to the Yangtze river mouth. Within the Pudong New Area five free trade zones have been appointed. See figure 6, part I. These areas are frontrunners of the economic reform policy in China. Domestic and overseas enterprises can get exemption of custom duties and industrial and commercial tax. Each of the five special free trade zones in Pudong New Area have been selected to a special purpose such as financial business, trade, processing and hi-tech industry. A coherent vision about inter-relationship between the various free trade areas is not particularly clear.
2 ECONOMIC DEVELOPMENTS

To get an impression of China's needs of new harbour developments this chapter outlines China's economy. China is the world's biggest emerging market and has one of the fastest growing economies today. In the period 1984-93 the Gross Domestic Product (GDP) showed an average annual growth of 8.9%. For 1996 a GDP increase of 9% is expected. The trade volume is rising and so is the maritime industry. According to Drewry Shipping Consultants report, published in 1995: 'providing it is able to maintain its impressive rate of economic growth, the remainder of the 1990s should see China become an increasingly important driver of world dry bulk trade, particularly in the iron ore, coal and grain trades.' In 1993 China's share in bulk commodities accounted for 9.3% of world iron-ore shipments, 2.7% of grain trade, 5.4% of coal trade and 2.5% of the global container movements [20]. The largest chinese national shipping company, China Ocean Shipping Company (COSCO), is the world's third largest shipping company. COSCO controls over 11 million dwt. A subsidiary of COSCO, Florens, owns a fleet of 270000 boxes making it one of the world's largest container leasing company [17].

2.1 Coal throughput

China is forced to rely on coal for about three-quarters of its energy consumption. In 1994 China produced a monumental 1.186 billion tons of raw coal. Most of this coal, some 307 million ton, is produced in the Shanxi province in northern China. There is a spatial mismatch between coal supply and demand. The raw coal is found in northern China, but wanted in southern parts of China. The gap is most glaring in East China (centred on Shanghai). In 1985 this province needed 54 million ton over and above its own production. This shortfall is expected to grow to 190 million tons by the year 2000.

Chinese coal exports have grown strongly over the past decade. Between 1985 and 1994 export volumes increased by over 280%. In 1994 some 24.4 million tons of coal have been exported. This equals 6 to 7% of the world seaborne coal trade. As the numbers above show, only 2.1% of the total Chinese raw coal production is exported. High domestic coal demands do not allow to divert more coal for export. By 2000 it is expected to export some 30 million tons of coal. Still a very tiny fraction of the total coal production.

At Shanghai, during the period 1990-94, coal throughput varied between the 55 and 62 million tons. In January 1994 the central government lifted price controls on coal. Mines were free to distribute coal according to market demand rather than by state allocation. Since then it is more expensive and slower to send coal by sea than by rail. This resulted in a slight drop in coal throughput to 56.22 million tons in 1994 from 60 million tons the year before. On the down side the rail network is running at its maximum capacity and can only cater more train services with great difficulties.
Table 6  Expected coal throughput at Shanghai in 2000 and 2010.¹

<table>
<thead>
<tr>
<th>Year</th>
<th>Millions tons/year</th>
<th>Annual growth rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>56.22</td>
<td>(-6)%</td>
</tr>
<tr>
<td>2000</td>
<td>90 - 95</td>
<td>8% - 9%</td>
</tr>
<tr>
<td>2010</td>
<td>105 - 123</td>
<td>4% - 5%</td>
</tr>
</tbody>
</table>

¹ Expected throughputs are the author’s interpretations of available literature.

For predicting coal throughput for the year 2000, the annual growth rate of coal throughput is equalled with the annual growth rate of the Gross Domestic Product of China. This is a conservative estimate. The growth rate of the GDP of China is averaged over the whole of China. In reality great inequalities exists between the provinces of China. The coastal provinces, like Shanghai, have a much higher annual growth rate. Between 1992-93 the Yangtze area, including Shanghai, had a Gross Domestic Product growth of 21%. High economic growth will demand more coal to provide the energy source. Further economic growth towards the year 2010 will see change in the usage of coal. More oil, gas and nuclear fuel will be used to provide the energy. Therefore the annual growth rate drops to 4 to 5%.

Other ports along the Yangtze River, like Zhangjiagang, are constructing their own coal terminals. The recently completed coal terminal has a capacity of 3 million tons a year [43], [54]. This development will reduce Shanghai as a major transshipment hub for coal transport in the area. As rail transport is improving this will have its effect on coal throughput by ship. On the other hand, as new harbour areas are being constructed in Shanghai and the accessibility of the Yangtze delta is improved, this will strengthen Shanghai’s position within the national coal trade.

2.2 Iron ore and steel throughput

China is the world’s largest producer of iron ore. However, much of this output is of low grade with an iron (Fe) content of only 30-35%. Therefore China needs to import substantial volumes of iron ore to satisfy the steel-making industry. During the period 1989-94 Chinese iron ore imports almost trebled from 12.5 million tons to 37.3 million tons per annum. Chinese iron ore imports are likely to increase to 50 million tons by 2000.

At Shanghai, the Baoshan steelworks along the Yangtze River are by far the largest in the area. In 1993 a massive 22 million ton of steel was produced [48]. By comparison, the Hoogovens complex at Urmuiden in The Netherlands, produced 5.2 million ton of steel in 1992 [36]. The steel making industry at Shanghai has grown strongly the last few years. From 1990-94 the import iron ore grew from 18.3 million tons to 30.0 million tons. A 164% increase in just five years.
Table 7  Expected iron ore and steel throughput at Shanghai in 2000 and 2010.

<table>
<thead>
<tr>
<th>Year</th>
<th>Iron ore Millions tons/year</th>
<th>Steel Millions tons/year</th>
<th>Annual growth rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>29.96</td>
<td>12.11</td>
<td>6%</td>
</tr>
<tr>
<td>2000</td>
<td>40 to 43</td>
<td>16 to 17</td>
<td>5% - 6%</td>
</tr>
<tr>
<td>2010</td>
<td>65 to 76</td>
<td>26 to 31</td>
<td>5% - 6%</td>
</tr>
</tbody>
</table>

Great consumers of steel are the six shipbuilding yards of Shanghai. Most yards are fully booked until the end of 1997. The oldest shipyard of China, the Jiangnan Shipyards of Shanghai, has begun construction of a new facility at Waigaoqiao. Here it will be able to construct ships up to 200000 dwt.

2.3 Oil and petroleum products throughput

Chinese oil trade has changed in recent years. Traditionally China exported oil products to the markets in the USA, South Korea and Singapore. But from 1993 on China became a net importer of oil and oil products. Chinese refineries failed to satisfy growth in domestic oil demand. With the economic liberalization policy the demand for oil products will rise. This will further increase the Chinese oil trade deficit. The key to resolving the oil trade deficit is new infrastructure. A new pipeline network from its oil resource base in north-western China to the coast is desperately needed. Currently the domestic distribution of crude and oil products depends on the already overstretched rail network and small coastal tankers. For predicting future development it is estimated that annual growth of oil imports will exceed the annual Gross Domestic Product growth. Especially when it takes a number of years to improve the oil distribution system within China.

Table 8  Expected oil throughput at Shanghai in 2000 and 2010.

<table>
<thead>
<tr>
<th>Year</th>
<th>Millions tons/year</th>
<th>Annual growth rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>17.92</td>
<td>6%</td>
</tr>
<tr>
<td>2000</td>
<td>32 to 35</td>
<td>10% - 12%</td>
</tr>
<tr>
<td>2010</td>
<td>71 to 92</td>
<td>9% - 10%</td>
</tr>
</tbody>
</table>

2.4 Agricultural products throughput

China has traditionally been the world’s largest market for wheat. Due to poor storage facilities and inadequate transport China had to import large quantities of wheat. During 1994-95 China imported some 11 million tons of wheat. For 2000 imports are estimated at 20 million tonnes.

China exports maize to Japan, Taiwan, South Korea, Indonesia and Malaysia. However the growing use of meat in the Chinese diet will increase the demand for maize as a domestic livestock feed. As a result China may have to import maize to feed the domestic livestock. During 1994-95 a marginal 1 million tonnes where exported. China will probably a net importer of maize by 1997-98.
At Shanghai 11.6 million tonnes of agriproducts were handled during 1994. A 124% increase compared with 1990. Probably the demand for agriproducts will follow the economic growth. Increased spending power of the population will stimulate the consumption of luxury food items such as meat.

<table>
<thead>
<tr>
<th>Year</th>
<th>Millions tons/year</th>
<th>Annual growth rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>11.61</td>
<td>5%</td>
</tr>
<tr>
<td>2000</td>
<td>18 to 20</td>
<td>8% - 9%</td>
</tr>
<tr>
<td>2010</td>
<td>40 to 46</td>
<td>8% - 9%</td>
</tr>
</tbody>
</table>

2.5 General cargo throughput

China has a trading surplus with the world's three leading trading groups: the USA, Japan and the EU-15. This success has been based on the export of low value consumer goods such as textiles, footwear and clothing. As technology improves China will also become more involved in the export of higher value consumer goods.

At Shanghai large quantities of construction material are imported. Due to the economic growth construction activities rocketed. Another construction project, The Three Gorges Dam in the Yangtze River, will also require large quantities of construction material. Especially the port of Wuhan, 1125 kilometre up-river from Shanghai, hopes to profit from the dam construction activities. With the increase of container throughput it is expected that the flow of general cargo will reduce.

<table>
<thead>
<tr>
<th>Year</th>
<th>Millions tons/year</th>
<th>Annual growth rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>27.4</td>
<td>2%</td>
</tr>
<tr>
<td>2000</td>
<td>32 to 35</td>
<td>3% - 4%</td>
</tr>
<tr>
<td>2010</td>
<td>38 to 44</td>
<td>2% - 3%</td>
</tr>
</tbody>
</table>

2.6 Container throughput

In 1995 container throughput at Shanghai grew to some 1.53 million TEU. Over the past three years, container traffic in the port has more than doubled. In 1992 just 717000 TEU where handled. Approximately 85% (1.3m TEU) of the port 1995 throughput is handled at the three established facilities of Zhanghuaabang, Jungonglu and Baoshan. These terminals are operated by the Shanghai Container Terminals (SCT), which is a joint venture between the Shanghai Port Authority and the Hutchison Whampoa Limited of Hong Kong. The container terminals at Zhanghuaabang and Jungonglu are completely land-locked by the protruding city of Shanghai. Further in-land expansion is not feasible. SCT is upgrading its computer equipment and plans to implement a new terminal management system. But, irrespective of whatever improvements are carried out, the geography of the area dictates that Shanghai will never be able to handle large 5000/6000 TEU ships. These ships require 14
ments are carried out, the geography of the area dictates that Shanghai will never be able to handle large 5000/6000 TEU ships. These ships require 14 metres and more of water to berth. At present, with the Yangtze channel maximum depth of 10.5 metre, including tidal benefit, the maximum size of a fully-laden containership is limited to around 1500 TEU. The decision has been made to deepen the mouth of the Yangtze river from 7.00 metre to 12.5 metre below chart datum. This will enable Shanghai to accommodate ships along the Yangtze River of at least 3000/3500 TEU without tidal restrictions. At present (September 1996) it is not completely sure whether this immense dredging operation will be executed. In 1996 the Shanghai Port Authority expects a throughput of 1.7 million TEU. The port authority is confident of handling 2.5 to 3 million TEU by the year 2000 and 6 to 7 million TEU in 2010.

Table 11  Expected container throughput at Shanghai in 2000 and 2010.

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of TEU [millions]</th>
<th>Annual growth rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>1.7</td>
<td>28 %</td>
</tr>
<tr>
<td>2000</td>
<td>2.5 to 3</td>
<td>13 % - 18 %</td>
</tr>
<tr>
<td>2010</td>
<td>6 to 7</td>
<td>10 % - 11 %</td>
</tr>
</tbody>
</table>

2.7 Conclusion

China has the potential to be a major economic power in the next century. The population of 1.2 billion is a large consumer and production base. The country has rich supplies of coal, oil and iron ore. Shanghai has the largest port of China. In 1994 the throughput was 165.81 million tons. By comparison the throughput of Rotterdam, the largest harbour in the world, was 293.9 million tons in 1994. Looking at annual throughput Shanghai is ranking third after Rotterdam and Singapore. Based on the growth of the annual Gross Domestic Product of 8 to 9% predictions of the throughput have been made for 2000 and 2010. The table on the next page summarises the various results. The first three columns give the annual throughput for 1994, 2000 and 2010. The fourth column represents the maximum capacity of the existing port installations in 1996. These figures are provisional estimates and include undergoing harbour extension plans up to 1996. The last two columns of the table are estimates of the capacity that is needed by 2000 and 2010. All figures are in million tons/year, except those of container throughput which are in million TEU’s (Twenty feet Equivalent Unit).
Table 12  Summary of present and expected throughput at Shanghai harbour.

<table>
<thead>
<tr>
<th></th>
<th>Throughput at Shanghai [million tons/year]</th>
<th>Maximum capacity existing port installations</th>
<th>Required capacity [million tons/year]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>56.22</td>
<td>90 to 95</td>
<td>105 to 123</td>
</tr>
<tr>
<td>Iron ore</td>
<td>29.96</td>
<td>40 to 43</td>
<td>65 to 76</td>
</tr>
<tr>
<td>Oil</td>
<td>17.92</td>
<td>32 to 35</td>
<td>71 to 92</td>
</tr>
<tr>
<td>Agriproducts</td>
<td>11.61</td>
<td>18 to 20</td>
<td>40 to 46</td>
</tr>
<tr>
<td>General cargo</td>
<td>27.40</td>
<td>32 to 35</td>
<td>38 to 44</td>
</tr>
<tr>
<td>Container [million TEU]</td>
<td>1.20</td>
<td>2.5 to 3</td>
<td>6 to 7</td>
</tr>
</tbody>
</table>

1 Provisional estimates by the author, all numbers are million tons/year.
TRANSPORT FLOWS WITHIN CHINA

This chapter gives a general impression of the transport networks in China. For many years the railway network is the backbone of the Chinese transport system. The railways are operating at their maximum capacity. Therefore the Chinese government decided the invest in inland water transport and the road network. Old canals are being upgraded and new roads are being build. If new harbour installations are built good inland connections are essential. This chapter outlines the key transport modes within China.

3.1 Inland water transport

Inland water transport vessels can sail upstream the Yangtze river up to Chongqing, some 2400 kilometres from Shanghai. For smaller vessels Chongqing is hard to reach. From Shanghai to Wuhan the Yangtze river is very wide. The width at Shanghai is some 10 kilometres, 1125 kilometre upstream at Wuhan still some 1.5 kilometre. Further upstream from Wuhan water currents rapidly increases. Some 300 kilometres upstream from Wuhan are the famous Three Gorges. Yangtze river flows through narrow mountainous terrain. For some 200 kilometres vessels have hardly any possibilities to stop. The follow table gives an impression of the navigability of the Yangtze river.

<table>
<thead>
<tr>
<th>Section</th>
<th>Maximum deadweight [dwt]</th>
<th>Draught [meters]</th>
<th>Sea going vessels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shanghai - Nanjing</td>
<td>5000 - 30000</td>
<td>7.0</td>
<td>Yes</td>
</tr>
<tr>
<td>Nanjing - Wuhan</td>
<td>3000 - 5000</td>
<td>5.0</td>
<td>Yes</td>
</tr>
<tr>
<td>Wuhan - Yichang</td>
<td>1500 - 3000</td>
<td>3.2</td>
<td>No</td>
</tr>
<tr>
<td>Yichang - Chongqing</td>
<td>500 - 1500</td>
<td>2.7</td>
<td>No</td>
</tr>
<tr>
<td>Chongqing - Yibin</td>
<td>- 500</td>
<td>2.4</td>
<td>No</td>
</tr>
</tbody>
</table>

Upstream from Yichang to Chongqing are hardly any harbours present. Some ships discharge at floating pontoons. Cargo handling is done by means of manual labour. Between Chongqing and Yichang seasonal waterlevel changes of 40 meters are possible, which exclude the construction of fixed harbour installations. To improve the navigability of the Yangtze river dams are being built. The existing dam at Gezhouba has locks for inland shipping. Ships pass 16 metres of waterlevel change. At Yichang the Three Gorges Dam is being constructed. This dam will be the greatest electricity supplier of China. The construction of this dam will have a great environmental impact. Large land area’s will be flooded and some one million people have to move to higher area’s. For these reasons the World Bank decided no longer to fund this immense project.

In 409 BC the Chinese started building the Beijing - Hangzhou canal. In 609 AD the canal was completed and connects the Yangtze and the Yellow River. The length of the canal is some 1750 kilometres. During the last century the condition of the canal deteriorated. A program is started to revitalize the canal. The canal section between the Yellow River and Xuzhou is open for
ships up to 2000 ton. The 350 kilometre section between Hangzhou and the Yangtze River has been improved and allows the use of push barges. The remainder of the canal can only cater ships between the 30 and 100 ton. These ships are very small. The smallest commercially operated vessel on European rivers is the Spits. The Spits is some 39 metres long and can carry a load of some 300 tons. By 2000 the canal renovation will be completed and ships up to 2000 tons will be able to use the canal.

The Chinese have some 75000 inland water transport vessel available. About 87% of this total is owned by the Chinese government. The remaining 13% is operated by private enterprises. In 1993 the average size of a state owned ship was some 136 tons, a privately owned ship some 67 tons. A Chinese inland water transport vessel has some characteristic features. The vessels have a relatively large beam to a relatively small length. A typical 30 tons vessel has a beam of 6 metres and a length of 25 metres. A 100 tons vessel has some 7 metres beam and a length of 40 meters. Both ship types have shallow draught and a high superstructure including the wheelhouse. The last 15 years the number of push barges is increasing. The most frequently used push barge can carry 1500 tons with a draught of 3.2 metres. On the lower reaches of the Yangtze river larger push barges are used. The barges have capacities from 2000 to 4000 tons [61].

The Chinese inland water transport system faces a number of problems:
• Small and old vessels result in long transportation times. The Chinese fleet mainly consists of 30 and 100 tons vessels. For carrying a load of 1500 tons of coal between 15 and 45 vessels are needed. In Europe this load is carried in a single barge. The use of so many small vessels also increases the likelihood of failure of each vessel. Especially when the vessels are relatively old.
• Lack of intermodal transfer points. The inland water transport network is a good alternative for alleviating congestion on the rail and road networks. Shipping goods from one transportation system to another system is rather difficult. Sometimes new facilities are constructed, such as at Xinzhou (70 kilometres from Wuhan), but due to the lack of good transport connections, these new facilities are not fully operational.
• Uncertainty about the navigability of the rivers. Many of the Chinese rivers have great water level fluctuations during the winter and summer season. During the last decennium dams are constructed to improve the navigability of the rivers. On the Yangtze river the Three Gorges Dam is being constructed under great international protest, due to its great environmental impact. On the river inland water transport has to compete with growing demand for hydro-electric power.

3.2 Rail transport

The rail network is the backbone of the Chinese transport system. Without coastal shipping, some 2/3 of the total volume of cargo and passengers is transported by rail. The rail network has a length of some 60000 kilometres. About 75% of the rail tracks, built after 1949, is situated easterly of the imaginary line Beijing - Guangzhou (Hong Kong). Transport by rail is cheap. The central Chinese government keeps the prices artificially low. Although cheap, the railway system is also very slow and unreliable. Due to various taxes, fees and local duties transporting cargo by rail has become very
complex. The rail network is overstretched and different cargo commodities have to compete for the limited capacity. Priority is given to the transportation of raw materials, such as coal and iron ore. To haul other cargo a reservation have to be made one month in advance. Despite these obstacles the railways move immense quantities of cargo. During 1994 some 1247.7 billion ton-kilometres were travelled and some 1.63 billion tons moved. Also some 1.1 billion passengers were transported [61].

During the next Five Year Plan 1996-2000 the Chinese government will invest US$ 3.4 billion each year to improve the railway system. Eighteen major railway projects have been planned, including the construction of new railways, the doubling of existing railways and electrification of the railway network. At present 42% of all locomotives are steam engines, 50% is diesel engine powered and only 8% is powered by electricity (Chian, 1995).

3.3 Road transport

The average loading capacity of a Chinese truck is some 4.2 tons. This is a very small load, compared with an European truck with carries an average load of 25 tons. The Chinese road transport cannot serve large (bulk) loads. During 1995 the Chinese lorries hauled some 895 million tons. This load was carried by some 5.5 million trucks. The total road traffic achievement is made of many short trips.

Since the founding of the People’s Republic of China in 1949 the emphasis was set on the investment of rail infrastructure to support the heavy industries. In 1994 the total length of the road network was some 1118000 kilometres. About 89% of the roads is paved, but only 30% is built to international standards, which allows vehicle speeds of 80 km/h and over. The construction of roads is the responsibility of provincial governments. The quality of the road varies with the spending power of each province. The central Chinese government recognized the lack of good road connections as a serious threat to the future economic growth. The decision was made to build a new highway system: the National Highway Truck System (NHTS). During a 30 year period some 12 highways will be constructed with a total length of some 35000 kilometres. At these roads slow traffic, such as pedestrians, cyclist and other forms of slow transport will be banned.

3.4 Air freight

In 1980 the cargo volume transported by air was some 0.05% of the total Chinese cargo throughput. Despite strong growth of passenger transport during the last decade, the total volume of air cargo grew marginally compared with the total Chinese cargo throughput. By 1993 some 0.1% of the total cargo volume was transported by air [61]. The Chinese air transport industry is rapidly growing. Especially the number of domestic flights increases. With the economic growth of China there is a greater demand for long distance travelling. Because the rail and road networks are congested, air transportation is growing. China is an important market for the aircraft industry. In 1993 China accounted for 14% (46 airplanes) of the total turnover of the American aircraft builder Boeing [61].

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3.5 Modal split

The railway and water transport networks are the key elements of the Chinese transport infrastructure. Many of the great rivers of China run from West to East, while many of the important railways run in a North-South direction. Yet, these two systems are running independently. The transfer of cargo from one system to another system is still underdeveloped. During 1995 the railway and water transport networks accounted for almost 85% of the total transported cargo tonnage (tonkilometres). See the following table. Looking at cargo volume in million tons, some 24% of the total cargo volume is transported by road. By comparison, in the Netherlands almost 62% of the total cargo volume (without foreign shipping) is transported by road and only 2% by rail [source: Jaarbericht Rijkswaterstaat, mei 1996].

<table>
<thead>
<tr>
<th>Transport achievement [billion tonkilometres]</th>
<th>Share</th>
<th>Cargo volume [million tons]</th>
<th>Average travelling distance [kilometres]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail</td>
<td>1245.75</td>
<td>37.45%</td>
<td>1630.9</td>
</tr>
<tr>
<td>Road</td>
<td>448.63</td>
<td>13.49%</td>
<td>894.9</td>
</tr>
<tr>
<td>Ship¹</td>
<td>1568.66</td>
<td>47.16%</td>
<td>1070.9</td>
</tr>
<tr>
<td>Airplane</td>
<td>1.86</td>
<td>0.06%</td>
<td>0.8</td>
</tr>
<tr>
<td>Pipeline</td>
<td>61.20</td>
<td>1.84%</td>
<td>150.9</td>
</tr>
</tbody>
</table>

¹ Including domestic coastal shipping.

The large volumes of coal being shifted through China put a heavy burden on the transport infrastructure. More than 40% of the freight tonnage hauled by the railway system involves coal transport. Coal accounts for over half the total freight moved on the Beijing-Guangzhou and Beijing-Shanghai lines. The Chinese government invested heavily in improving the rail network in northern China. These railways are important links between the Shanxi coal field and the ports along the northern coast of China. Improving one part one the rail network created bottlenecks elsewhere. This increased the costs of rail transport substantially and ruled out rail transport as a reliable way of transport between north and south China. The government placed its faith in the intermodal system of railway and coastal shipping. From the main coal ports in northern China coal is shipped to southern ports such as Shanghai and Guangzhou. Transporting coal by ship introduces new problems. Most Chinese ports have limited water depths of about 8 meters. This reduces the maximum fully-laden ships size to 20000 dwt. Economies of scale give a 25 to 30% savings in freight costs when larger ships could be used.
The travelling times within China are still immense. To transfer a train load from Shanghai to Beijing (1460 km) will take some 21 days. The following table gives a rough indication of the transport times by various transport modes.

<table>
<thead>
<tr>
<th>Mode</th>
<th>East-China</th>
<th>Central-China</th>
<th>Southern-China</th>
<th>Northern-China</th>
<th>North-East China</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>1 - 7</td>
<td>4 - 10</td>
<td>10 - 15</td>
<td>4 - 10</td>
<td>15 - 30</td>
</tr>
<tr>
<td>Rail</td>
<td>15 - 30</td>
<td>15 - 25</td>
<td>30 - 60</td>
<td>15 - 45</td>
<td>30 - 60</td>
</tr>
<tr>
<td>Inland Water</td>
<td>30 - 60</td>
<td>30 - 90</td>
<td>30 - 90</td>
<td></td>
<td>30 - 90</td>
</tr>
</tbody>
</table>

4 PRESENT HARBOUR EXTENSION PLANS

When planning new locations for large scale harbour development it is useful to know where harbour extensions currently taking place. Perhaps these sites can be extended further. This chapter describes the locations where currently new berths are being built and if these sites can be included within future harbour extension plans. Next to the development of Pudong New Area, new harbour sites are being built at Waigaoqiao. Waigaoqiao is situated along the south bank of the Yangtze river in the Pudong area. By 1997 four general cargo berths will be completed. A further extension to eight berths has been approved by the central Chinese government. This new harbour site will have its own container facility. Inland extension at this site is a major problem. The berths are constructed in the Yangtze river. Therefore this site is not a favourable location for future large scale harbour developments.

In an anti-pollution effort, the existing coal terminal on the Huang Pu river will be removed. At Luojing a new coal and ore terminal will be constructed. Luojing is situated along the Yangtze river some fifteen kilometres upstream from the junction between the Huang Pu river and the Yangtze. The new terminal at Luojing opens in 1996 and will have a 10m ton capacity. After the project is completed, the Luojing coal and ore terminal will be the largest bulk handling centre in Shanghai. There will be two discharge berths for ships up to 35000 dwt and four loading berth for ships up to 2000 dwt. The 35000 dwt bulk carriers are special Chinese designed shallow draught carriers.

One of the major problems of the Shanghai harbour is the shallow mouth of the Yangtze river. In 1994 the central government approved an immense dredging project to increase the current depth from CD-7.00 meter to CD-12.50 meter. It is estimated that this will take ten years of labour and will cost about 1 billion US$. This makes the dredging project second in size next to the Three Gorges Dam Project [40].

Many of the major ports upstream the Yangtze river are being upgraded. Additional ports are being built in Nantong, Nanjing, Zhangjiagang, Zhejiang. Even Wuhan, some 1125 km inland from Shanghai and the keystone of regional intermodal travel has been upgraded. Wuhan lies at the crossroads of the Yangtze River running east-west and a north-south axis between Beijing
and Guangzhou. In 1991-92 Wuhan opened to foreign trade. In 1994 it handled 30m tons of cargo, most of it construction material for the Three Gorges Dam project. The two container wharfs handled 40000 TEU in 1995. A roll-on roll-off facility is due open in 1996 and will handle 150000 vehicles annually and 300000 in its second stage. Wuhan currently handles between 40000 and 50000 tonnes a day. Its daily capacity is about 70000 tonnes. The harbour faces though competition from the railways. The Chinese government encourages transport by water for distances under 500 km and by rail for anything over. Shorter rail trips have their freight rates increased by the government. Currently rail transport trough China is very inefficient.

**Table 16**  *Major ports on the Yangtze River, up-river from Shanghai.*

<table>
<thead>
<tr>
<th>Harbour</th>
<th>Existing situation</th>
<th>Harbour developments</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Nantong</td>
<td>Eleven berths varying from 90 to 325 meters, including two container berths at Langshan district. Total quay length 1640 meters.</td>
<td>At the Langshan district new berths are being built for vessels of the 10000 dwt class: * one new container berth * two bulk cargo berths * one multi purpose berth * one general cargo berth Also expanding inland water transport and passenger berths.</td>
<td>First major up-river port on the Yangtze River.</td>
</tr>
<tr>
<td>2. Nanjing</td>
<td>Forty berths of various sizes. Total quay length of 2614 meters. Throughout at wharves and in stream. Xinhengwei, new port area: * two berths for bulk cargo (up to 10000 dwt) * two berths for containers (up to 20000 dwt)</td>
<td>Five more 10000 dwt and seven 20000 dwt class berths are planned.</td>
<td>The port is a transshipment hub of river/sea transportation and plays an important role in alleviating cargo congestion at Shanghai.</td>
</tr>
</tbody>
</table>

Export: General cargo and cotton.
<table>
<thead>
<tr>
<th>Harbour</th>
<th>Existing situation</th>
<th>Harbour developments</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Zhangjiagang</td>
<td>A total of 17 ships can be accommodated. Wharf frontage of 2180 meters. Two quay berths can take vessels of 10000 dwt class, two pontoon berths can take 5000 dwt vessels. Three 10000 dwt berths have recently been completed. There are also ten buoy moorings, seven for 10000 dwt vessels, three for 5000 dwt vessels.</td>
<td>There are plans to construct five new berths. One coal terminal for 20000 dwt vessel, one for containers and one for timber, both for 25000 dwt vessels. Two berths for 10000 dwt bulk vessel will also be built. When completed the handling capacity of the port will be increased to 10m ton/yr.</td>
<td>This port also plays an important role in alleviating cargo congestion at Shanghai</td>
</tr>
<tr>
<td>4. Zhenjiang</td>
<td>At Zhenjiang Old Harbour a total of eight berths are available, all for vessels in the 1000 to 2000 dwt class. At Dagang are thirteen berths and two mooring buoys. Vessels up to 25000 dwt can be accommodated.</td>
<td>There are plans to construct four more berths at Dagang to take vessels of the 10000 dwt class, including a container berth and further berths for river vessels.</td>
<td>This port is situated at the junction of the Yangtze River and the Grand Beijing-Huangzhou Canal.</td>
</tr>
<tr>
<td>5. Wuhan</td>
<td>Six general cargo berth, equipped with 5 to 30 ton cranes. Depths ranging from 6 to 10 metres.</td>
<td>Extension of container handling facilities. Construction of roll on roll off terminal capable of handling 30000 vehicles/year.</td>
<td>Wuhan is situated between the major east-west and north-south cargo flows. Wuhan has a great potential to become an important intermodal transfer point.</td>
</tr>
</tbody>
</table>

At present (1996) only ships of 10000 dwt and under can enter Shanghai harbour at all times. The shallow depth of the entrance canal limits the maximum ship size. The canal is dredged to CD-7.00 meters. Using the tidal benefit a 20000 dwt ship can berth at Shanghai. The largest ship calling at Shanghai is the 150000 dwt bulk carrier for the Baoshan steel works loaded with ore or coal. This ship can only enter the Yangtze delta partially loaded. The largest Chinese shipping company (COSCO) has ordered six 5250 TEU container vessels from Japan for delivery the last to months of 1996. At present these ships will only be able to carry a 1500 TEU load into Shanghai. Luckily the Shanghai area is the largest producer of new containers in the world. In 1995 about 275000 TEU were produced. These empty boxes could leave Shanghai with the new 5250 TEU vessels.
The depth of the berths varies from 8 to 10.5 metres. Depth alongside at Shanghai container facilities is generally quoted as 10-10.5 metres [43], [54].

<table>
<thead>
<tr>
<th>Ship type</th>
<th>Length [m]</th>
<th>Beam [m]</th>
<th>Draught [m]</th>
<th>DWT [ton]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short Sea Trader</td>
<td>66</td>
<td>10.7</td>
<td>4.13</td>
<td>1400</td>
</tr>
<tr>
<td>Parcel tanker (1977)</td>
<td>111</td>
<td>16.6</td>
<td>6.92</td>
<td>6433</td>
</tr>
<tr>
<td>General cargo (1971)</td>
<td>169</td>
<td>23.3</td>
<td>8.24</td>
<td>9022</td>
</tr>
<tr>
<td>Reefer (1976)</td>
<td>156</td>
<td>21.5</td>
<td>9.15</td>
<td>11092</td>
</tr>
<tr>
<td>Multi purpose (1977)</td>
<td>174</td>
<td>25.6</td>
<td>9.50</td>
<td>14260</td>
</tr>
<tr>
<td>Roll On Roll Off (1983)</td>
<td>249</td>
<td>32.2</td>
<td>10.80</td>
<td>40000</td>
</tr>
<tr>
<td>Cont. ship Panamax (4258 TEU)</td>
<td>289</td>
<td>32.2</td>
<td>11.65</td>
<td>57800</td>
</tr>
<tr>
<td>Dry bulk carrier (1976)</td>
<td>245</td>
<td>38.7</td>
<td>16.00</td>
<td>117000</td>
</tr>
</tbody>
</table>

5 SPACE DEMANDS OF NEW HARBOUR AREAS

By searching for new harbour locations, the following four items are of great importance:

- Satisfactory approach channels and safe deep water at berthing points.
- Sufficient land area.
- A labour force.
- Good access to road, rail and waterway routes.

At the harbour of Shanghai most items above give reason for concern. Only a labour force is widely available. Future harbour extension plans should give great attention to the availability of the labour force, because the economic and social costs of re-settling workers is considerable.

At the basis of future space demands are the throughput estimates. The table on page 31 gives the expected throughput for 2000 and 2010. From the literature some rules of thumb are used to calculate the desired land areas from annual throughput. These figures give some impression of the required land areas. The table below gives the throughput capacities per ton/m²/year.


Table 18  Throughput capacities per [t/m²/year].

<table>
<thead>
<tr>
<th>Source [A]</th>
<th>Source [B + C]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Coal</td>
<td>15</td>
</tr>
<tr>
<td>Iron ore</td>
<td>30</td>
</tr>
<tr>
<td>Oil</td>
<td>40</td>
</tr>
<tr>
<td>General cargo</td>
<td>4</td>
</tr>
<tr>
<td>Containers</td>
<td>6</td>
</tr>
</tbody>
</table>

The figures in the table above may vary for each port. Specialized ports with well equipped infrastructure will have higher throughputs per m² per year. To get a first impression of the order of magnitude of space demands within the new port, the table may be useful. This first global impression of space demands will be refined at a later stage. For instance: the back-up area for a container terminal will be greater than that for a break bulk berth. Safety considerations also play an important role. Dangerous cargoes will need special zones and special locations. This will require additional space.

The following tables give the required capacity of the harbour installations for 2000 and 2010. Required capacities (in million tons) are converted into required land area's (in m² or ha). The expected growth of the Chinese Gross Domestic Product will be between the 8 and 9% per year. All the various commodities, such as coal, iron ore, general cargo and containers will have different annual growth rates. Especially the oil and container imports are expected to grow strongly the coming years. The chapter 'Economic Developments' handles about this issue in greater detail.
The future space demands are based on two economic growth scenarios: a low economic growth and a high economic growth. The efficiency which cargo is handled may vary for each port. Inexperienced, low motivated crews will have low cargo throughput capacities. The two future economic growth scenarios and the two different rates which cargo is handled by the harbour authorities give four possibilities for future space demands.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Low</td>
<td>Low economic growth and low cargo throughput</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
<td>Low economic growth and high cargo throughput</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
<td>High economic growth and low cargo throughput</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
<td>High economic growth and high cargo throughput</td>
</tr>
</tbody>
</table>

**Table 19** Space demands new harbour areas.

<table>
<thead>
<tr>
<th></th>
<th>Required capacity [million ton/year]</th>
<th>Throughput capacities [v/m³/year]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>By 2000 Low</td>
<td>By 2010 Low</td>
</tr>
<tr>
<td>Coal</td>
<td>30</td>
<td>45</td>
</tr>
<tr>
<td>Iron ore</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Steel</td>
<td>16</td>
<td>17</td>
</tr>
<tr>
<td>Oil</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>Agriproducts</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>General</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Cargo</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Containers²</td>
<td>30 10⁶ ton/year</td>
<td>15 10⁶ m²/year</td>
</tr>
</tbody>
</table>

With the required new capacities and the throughput capacities the required land areas can be calculated. See the following example.

1. Required new capacity for coal terminals by 2000 with low economic growth, table above:
   Coal (by 2000, low): 30 million ton/year

2. Annual throughput for a coal terminal with low productivity, table above:
   Coal (low): 15 ton/m²/year

3. The required land area for 2000 becomes.

\[
\frac{30 \times 10^6 \text{ ton/year}}{15 \text{ ton/m}^2/\text{year}} = 2 \times 10^6 \text{ m}^2 = 200 \text{ ha}
\]

1. The m² refers to the total terminal area, including internal roads, offices, workshops, etc.

2. Container load 10 to 15 ton/TEU, source [34], part 7, page 11.
Table 20 Required new land areas [ha].

<table>
<thead>
<tr>
<th>Economic growth</th>
<th>By 2000</th>
<th>By 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput capacity</td>
<td>Low Low</td>
<td>High High</td>
</tr>
<tr>
<td>Coal</td>
<td>200</td>
<td>120</td>
</tr>
<tr>
<td>Iron ore</td>
<td>17</td>
<td>13</td>
</tr>
<tr>
<td>Oil</td>
<td>30</td>
<td>24</td>
</tr>
<tr>
<td>Agriproducts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General cargo</td>
<td>50</td>
<td>33</td>
</tr>
<tr>
<td>Containers</td>
<td>83</td>
<td>50</td>
</tr>
<tr>
<td><strong>TOTALS [ha]</strong></td>
<td><strong>380</strong></td>
<td><strong>240</strong></td>
</tr>
</tbody>
</table>

The table above summarizes the various space requirements. By 2000 a minimum of 240 ha and a maximum of 590 ha is needed to provide port expansion. For 2010 these figures are 878 and 1903 ha. These numbers are global indicators of future space requirements. By comparison, the future extension of the harbour of Rotterdam will incorporate some 2000 hectare for harbour developments and some 750 hectare for nature and recreational areas. This project, called Maasvlakte II, is a seaward extension of the harbour of Rotterdam. The size of Maasvlakte II is based on space predictions that 1000 ha is needed by 2010. The Maasvlakte II will serve Rotterdam’s needs until 2025/35 [50].

Shanghai future space demand will be as follows:

<table>
<thead>
<tr>
<th></th>
<th>By 2000</th>
<th>By 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum (ha)</td>
<td>240</td>
<td>878</td>
</tr>
<tr>
<td>Maximum (ha)</td>
<td>590</td>
<td>1903</td>
</tr>
</tbody>
</table>
With respect to the required area for the new container terminal the following remarks are made:

* In 2010 the expected container throughput will be some 5 million TEU. According to the calculations between 400 and 800 hectares of land are required. This is a very rough estimate. The actual size of an container terminal needs to be studied in greater detail. The claim to available space very much depends how the terminal is operated. For instance, automatic guided vehicles (AGV) and automatic stacking cranes (ASC) or multi trailer systems (MTS) and straddle carries (SC) have different space claims. The size of the stacking areas depends on the average dwell time of a container and the stacking height.

* In January 1996 a study has been completed to the development of a container terminal at Gadok, Korea. By 2011 an annual throughput of some 8.03 million TEU is expected. Some 486 hectares of land are reclaimed to construct this terminal. The total quay length will be some 7500 metres. The terminal depth is 650 metres. At this terminal automatic guided vehicles (AGV) and automatic stacking cranes (ASC) will be used. If these throughput - area ratios are related to the future terminal at the harbour of Shanghai then this terminal will be some 300 hectares. Much smaller then the earlier mentioned size of 400 to 800 hectares.

6 FUTURE SITES FOR LARGE SCALE HARBOUR DEVELOPMENT

The old harbours of Shanghai are completely locked by the protruding city. Further inland expansion is not possible. To accommodate the growing throughput volumes new harbours sites were constructed on the shores of Pudong, opposite the city of Shanghai. Within the Pudong area various trade, industrial and manufacturing activities have been established. At Waigaoqiao, in the Pudong area along the Yangtze river, new berths are constructed. The major problem with Chinese harbour developments is the total lack of a coherent vision of the harbour location and its customers. Often harbours are planned at free sites along the coast without any rail and road connections. For example, the Pudong New Area and the Waigaoqiao berths have no connection to the national railway system. This is a peculiar situation because the railway network is the backbone on the Chinese transportation network. Over 2/3 of the total Chinese cargo volume is transported by rail.

To follow the growing throughput volumes the harbour of Shanghai needs to expand. In this report three different spatial alternatives are investigated (see figure next page):
• **Alternative 1: Harbour development at Changxing Island**
  Changxing Island is a 8400 hectare island in the mouth of the South Branch of the Yangtze delta. This island is situated opposite the mouth of the Huang Pu River, the entrance to the old harbour of Shanghai. To connect Changxing Island with the mainland an eight kilometre long bridge or tunnel is needed.

• **Alternative 2: Harbour development along a Coastal Canal**
  The existing harbour of Shanghai faces two major problems: the lack of space and the shallow draught of the river mouth. A Coastal Canal along the South bank of the Yangtze delta would bypass the bar in the river mouth. Along the bank of the coastal canal new land can be reclaimed. On this reclaimed land new harbour sites can be made. The canal of some 55 kilometre length starts at Nanhui and runs to the Pudong area. At sea an entrance channel from deep water to Nanhui has to be dredged and maintained.

• **Alternative 3: Harbour development at Jinshanwei**
  Jinshanwei is situated some 100 kilometres from Shanghai on the coast of Hangzhou Bay. Already three kilometres from the coast 15 metre deep water is available. This makes Jinshanwei an ideal location for large scale harbour developments. Unfortunately fifteen kilometres from the shore the seabed is rising to a minimum depth of seven metres below Chart Datum. This means an access channel to Jinshanwei must be dredged.

In the following chapters three alternative locations for future expansion of Shanghai harbour are investigated in greater detail. For design purposes it is assumed that the existing harbour installations are running at almost their maximum capacity. The new harbour installations will absorb the growth in cargo throughfput volumes. The three locations are considered as single units. For instance, there is no partial harbour development at all three alternative locations. Each location represents a different vision at future harbour developments.
Figure 8  Three alternative locations for large scale harbour expansion.
7 ALTERNATIVE 1: HARBOUR DEVELOPMENT AT CHANGXING ISLAND

7.1 Introduction

The Chinese Ministry of Water Resources is conducting intensive research to improve the navigability of the Yangtze estuary. By executing large dredging operations the depth of the North Passage is kept at CD - 7.00 metre. The research focuses at complementary measures such as the construction of regulatory works, training dams and groynes. The report of the Port and Delta Consortium (PDC), published in July 1995, deals with these matters in greater detail. One feasible solution is the construction of a training dam along the north bank of the North Passage. This dam starts at Heng Sha island and runs over the Heng Sha shoal. See figure below. The aim is to concentrate the flood current along the southern side of the dam and thereby reducing sedimentation in the navigation channel.

![Map of harbour development at Changxing island.](image)

Figure 9 Harbour development at Changxing island.

The construction of training dams could be incorporated with large scale harbour development on the island of Changxing. This relatively uninhabited island in the centre of the Yangtze estuary is located at the end of the navigation channel (North Passage). To transfer goods from Changxing Island to the shore a land connection is needed. This land connection must pass the South Channel, which has a width of some 8 kilometres. A tunnel or a bridge are the main alternatives to cross the South Channel.
7.2 Accessability of Changxing Island for road and rail traffic

Many large scale harbour developments have taken place on islands. For instance the new container terminals of Hong Kong and the Port of Kobe in Japan are being built on artificial islands. In Kobe two man made islands have been made: Port Island (133.2 ha) and Rokko Island (84.1 ha). The two islands are connected with bridges to the mainland. At Shanghai the spatial difference between the Changxing island and mainland is some 8 kilometres. If a bridge is constructed there must be sufficient clearance for large sea-going vessels. The largest vessel calling at Shanghai harbour is a 150000 dwt ore carries for the Boashan steelworks. The height of the bridge deck above water level will be some 60 metres. A vertical rise of 3% results in a slope of some 2000 metres. A good example is the East Bridge design over the Great Belt in Denmark. The whole bridge will be 6.8 kilometres long from coast to coast, emerging at 13 metre on one shore, climbing 2% to allow a 65 metre vertical clearance across the navigation channel and sloping down 2% to 25 meters at the other shore. Three different cable-stayed bridges and four different suspension bridges have been investigated. From simulations by the Danish Maritime Institute is was decided to choose a bridge with a span of 1624 metres.
Figure 10 Three cable-stayed bridges and four suspension bridges used in the design of the Great Belt crossing in Denmark.

Another way to link the island to the mainland is by means of a tunnel. See the enclosure: Dangerous cargoes in tunnels. A tunnel linking a harbour with the mainland should be built to Category I standards. Through a Category I tunnel all classes 2 to 9 goods may be transported. Class 1 goods are mainly munition and explosives for military use. Governmental regulation could ban such goods from a harbour situated on a island.
7.3 Layout of land areas

By 2010 some 2000 hectares of new harbour areas are needed. Changxing island is some 7000 hectares in size. This implies that the main part of the island is converted to large scale harbour development. This will have a severe impact on the local residents. Inhabitants have to be compensated, either financially or new land areas should be given to them. This may be a serious problem because free land is a scarce commodity within the Shanghai area.

7.4 Layout of water areas

The water basins could be dredged into Changxing island. Various port layouts are possible. To minimize the dredging quantities, long narrow piers could be built inside the harbour area. This is an old configuration when ships where small and cargo handling rates are low. Modern pier layouts are straight. Further allocation of land areas must be worked out in the detailed engineering phase. The port will be divided into various zones for handling different types of cargo. For instance the throughput of agricultural products, such as grain, can not be situated next to the throughput zone for fertilizers. Basin layout should be aimed at minimizing wave action. Waves passing a moored ship in a longitudinal direction generally causes the least problems with regard to the cargo handling operations. Basin length and widths should prevent the occurrence of standing waves or seiches. Siltation is a serious problem when harbour basins are constructed at Changxing. Within the basins hardly any currents exists. This will result in rapid sedimentation.

7.5 Final remarks

The construction of large scale harbour installations on an island is basically a feasible solution. Many of the world's largest harbours realized their expansion on islands. In 1966 the Port of Kobe started building the first port island. At the same time another island, Rokko island was built. Port Island has a size of 133.2 hectare and Rokko Island 84.1 hectare. At the centres of these islands residential living areas are built. At Rokko Island some 30000 peoples live in housing estates. Harbour activities are situated along the edges of the islands. Port Island is connected to the mainland by the Kobe Bridge. Over this bridge runs the 'Portliner'. This is an unmanned rubber tyred metro car, which carries people and workers from and to Port Island. The costs of constructing Port Island amounted some 6 billion US$.
In case of Shanghai, harbour development at Changxing island is a possibility. Changxing is situated at the end of the navigational channel. This gives easy access to the new harbour areas. Regulatory works under construction such as training dams and breakwaters must give better hydro-dynamic conditions and limit the quantities of material that settles within the navigation channel. If these measures fail to work then still large quantities of sediment have to be dredged to keep the harbour accessible to ships from sea. The land connection between Changxing and the Shanghai (Pudong) is a very expensive item. Some 8 kilometres of water have to be crossed. There are examples of bridges of the same size all over the world, e.g. the crossing of the Great Belt in Denmark. A tunnel is another solution for linking the two parts of land together. Not all kinds of cargo may be transported through a tunnel. Modern tunnels have insulated walls to protect them from internal fires. Constructing an eight kilometre long tunnel in a morphologic active area will be a very expensive undertaking. Changxing is situated at the interface between fresh river water and saline sea water. This results in flocculation of suspended particles and increased sedimentation. These are complicating factors when a tunnel is built or the design depth below the seabed has to be determined.
8 ALTERNATIVE 2: HARBOUR DEVELOPMENT AT NANHUI ZUI AND ALONG A COASTAL CANAL

8.1 Introduction

In July 1995 the Port and Delta Consortium (PDC) completed a ten year long study. The main objective of this study was investigating of possible methods to improve the accessibility of the Yangtze estuary for large sea-going vessels. One of the most promising solutions is the construction of a coastal canal. This canal runs from Nanhui to halfway the South Channel. See the figure below.

![Diagram of the coastal canal]

*Figure 11 Layout of the coastal canal.*

This coastal canal will completely bypass the shoals in the Yangtze estuary. In particular where fresh river water meets the saline seawater strong siltation occurs. Each year a massive 10 million m$^3$ is dredged to keep the existing navigation channel open. The construction of a coastal canal will reduce the overall maintenance substantially. However, the access from deep water to Nanhui will require dredging of a new access channel. By the Port and Delta Consortium (PDC) research has been done to the best alignment of the access channel. They concluded a southern orientated alignment of the access channel would give the lowest maintenance dredging costs. To maintain the depth of the access channel at CD-12.50 metre, annually some 10 million m$^3$ of bed material have to be dredged. By comparison, if the existing navigation channel is kept at CD-12.50 metre, then annually 50 million m$^3$ have to be removed from the seabed. The southern access channel would have a length of some 30 kilometres.

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8.2 Layout of the coastal canal

The creation of sheltered deep water conditions is one of the major benefits of the coastal canal. Along the inner bank of the canal new harbour area’s can be planned. This method of harbour extension shows great similarity with the construction of the Caland canal in the port of Rotterdam. Along the south bank of the Caland canal large scale petro-chemical complexes have been established.

To create an isolated condition from the Yangtze river a lock is needed. This lock is planned at the north end of the canal, opposite Changxing inland. A lock is always a obstacle to navigation, but the larger vessels will not have to use the lock. The deep water harbour locations are planned seaward the lock. At the seaward entrance of the canal breakwaters are needed. Also a shipping channel at sea from Nanhui to deep water has to be dredged. The Port and Delta Consortium (PDC) has done detailed studies to the morphologic and hydraulic aspects of dredging a channel from Nanzui to the sea. A southern oriented approach channel was chosen because it has the shortest connection to deep water and also has the lowest annual dredging costs.

8.3 Layout land areas

Shanghai desperately needs a second international airport. The government selected the south bank of the Yangtze river as the new site for this new airport. Therefore the new airport will interfere with future harbour extension plans. An airport puts a substantial claim to the limited available space. Some harbour operations, such as the storage of oil products are better not situated to close to airport operations.

By 2010 some 2000 hectares are needed for future port operations. This equals a square of 2 kilometres width and 15 kilometres length.

8.4 Layout water areas

The length of the coastal canal will be some 55 kilometres. Along the south bank of the canal harbours can be constructed. Modern harbours have straight piers. The water area between two piers should have a minimum width of 4 to 6 times the width of the design vessel. Between to piers enough space must be available to manoeuvre with tugs. This will require another 100 metres extra basin width. For a ship with B=45 metre a basin width of 5*B + 100 = 325 metre is desirable. This width allows two sided use of the basin.

8.5 Relation coastal canal and existing harbour areas

All the old harbour locations are situated behind the locks. This results in a substantial flow of ships. The largest vessel is a 150000 dwt ore carrier for the Boashan steel works north of Shanghai. At present this ship can only enter the Yangtze estuary with a 40% load. The average water depth between the future lock and Boashan is some 13 metres below Chart Datum. Including a tidal benefit of three metre, the maximum draught of the ore carrier could be 16 metres. This equals a 80% load of a 150000 dwt ore carrier.
At Waigaoqiao, along the Yangtze river at the north bank of Pudong, eight new berths are constructed. This new harbour site will have its own container facility. A container terminal behind a lock is a disadvantage, but this situation occurs at other ports such as Antwerp, Belgium and Incheon, Korea. Again, at present container vessels can only enter Shanghai with a 1500 TEU load due to the large shoals in the mouth of the river. Sailing to a harbour with a 40% load is even more unfavourable than sailing fully laden, but having to pass a lock. Eventually container terminals should be reallocated to the new harbour areas along the bank of the coastal canal. This process of reallocating of harbour installations will take ten years or more. The old container terminals could be converted for usage by coastal feeder vessels and inland water transport vessels. The larger sea-trade vessels will be handled at the new terminals along the banks of the coastal canal. It is a part of natural dynamics of port operations and harbour management. Similar operations are currently taken place in the port of Rotterdam. Old harbour basins, close to the city centre, are being filled with sand and land is being reclaimed. At the same time new berths are being constructed closer to the sea.

8.6 Final remarks

The construction of a coastal canal deals with two problems at the same time. Firstly the shallow bars at the mouth of the Yangtze River are passed. Secondly protected new harbour sites are created along the banks of the canal. This alternative requires a great capital investment. A 55 kilometre canal needs to be dredged, a lock complex built, breakwaters constructed and an access channel at sea has to be dredged. Still this solution might be the best way to overcome the two main problems of the port of Shanghai: the shallow draught of the river mouth and the lack of space in the old harbour.

![Diagram of harbour and coastal canal alignment](image)

*Figure 12 Impression of alignment of the coastal canal and new harbour areas.*
The figure gives a rough impression of how the various infrastructure elements could be situated. The location of the second international airport has been assigned by government. The final allocation of the harbour installations needs to be investigated in greater detail. With the high expected throughput the port may be divided into various zones. For instance: a specialized area for container handling, dry bulk, general cargo, etc. Each dedicated port area or zone will have:
- Its own design water depth.
- Different land area requirements.
- Different safety considerations.
- Its own connections to inland transport by road, rail and/or inland water transport.
- Its own impact to neighbouring zones, e.g. due to strong winds.
9 ALTERNATIVE 3: HARBOUR DEVELOPMENT AT JINSHANWEI

9.1 Introduction

Jinshanwei is situated some 100 kilometres from Shanghai on the coast of Hangzhou Bay. Already three kilometres from the coast fifteen metre deep water is available. This makes Jinshanwei an ideal location for large scale harbour developments. Unfortunately fifteen kilometre from the shore the seabed is rising to a minimum depth of seven metres below Chart Datum. This means an access channel to Jinshanwei must be dredged. This channel will be some 50 kilometres long.

![Diagram of Jinshanwei Harbour Development](image)

*Figure 13 Future harbour development at Jinshanwei.*

9.2 Existing harbour of Jinshanwei

At Jinshanwei a petro-chemical plant is situated. In 1990 plans where made to build a container terminal. Jinshanwei has a tanker terminal. Three to four tankers use the terminal each month. One pier can unload 25000 dwt oil tankers. Three other berths can handle 5000 dwt vessels loaded with chemical products. Two berths are 126 metres long with depths alongside of 8.6 and 9 metres. The other pier is 76 metres long with a depth of 5.2 metres. There are plans to build a number of 10000 dwt general cargo berths to ease congestion at Shanghai. Some ten years ago the Jinshanwei location was appointed by the Central Chinese Government as a special planning zone for future harbour extension.
9.3 Mud flows along the coast

Annually the Yangtze River discharges some 500 million tons of sediment in the East China Sea. Some 20% of this sediment load is deposited in Hangzhou Bay. It is not known how these mud flows will behave in the future. Especially with the large scale river-hydrological projects currently executed. At Yichang, some 2000 kilometres upstream from Shanghai the Three Gorges Dam is being built. This dam will have great impact on the river and sediment flow regime. The Chinese Ministry of Waterworks is conducting research to deepen the mouth of the Yangtze river. Including the construction of trailing dams, it is expected these measures will improve the navigability of the Yangtze river.

9.4 Final remarks

At first impression Jinshanwei appears to be a good location for the extension of Shanghai’s harbour. Deep water is close by and Jinshanwei is connected to the national railway network. But, from a mariners point of view, a better location for harbour extension is the port of Ningbo, some 70 kilometres sailing from Jinshanwei. The port of Ningbo truly offers deep water facilities. At Jinshanwei still a 30 mile long channel have to be dredged and maintained. Currently deep draught coal and ore vessels are lightened at Ningbo and then continue their voyage to Shanghai. The land journey from Ningbo to the industrial centres of Shanghai is some 350 kilometres. Jinshanwei is only 100 kilometres from Shanghai. To turn Jinshanwei into a large, major international port an immense dredging operation have to be executed. This same dredging effort could also improve the existing navigational channels to Shanghai. Therefore large scale harbour development at Jinshanwei will not immediately benefit the harbour and the industrial centra of Shanghai.
10 SELECTION ALTERNATIVES

In this chapter the three alternatives are evaluated on their merits. There are four main categories on which the alternatives will be judged.
1. Nautical and hydraulic criteria
2. Economic criteria
3. Environmental criteria
4. Social criteria

These criteria can be divided into sub criteria. The three alternatives for future harbour development will be discussed related to these criteria. The various criteria for each alternative are looked at relatively to each other. So, no absolute costs are given, but qualitative, relative, cost indications for each alternative.

10.1 Nautical and hydraulic criteria

These criteria affects the operation of ships within the harbour. This also includes the entrance channel(s) to the new harbour. Safety aspects are most important. Nautical criteria relate to the behaviour of ships in navigation channels and port entrances. Related to the ship are:
• Approach channel alignment and size
• Stopping length of ships and available space in a port
• Manoeuvring space in a port
• Depth of the navigation channel and port areas

Hydraulic criteria often dictates the design of a port. The prevailing waves, currents and wind forces determine the design of a safe port entry by vessels. Hydraulic criteria are:
• Waves at open sea
• Wave penetration into the port
• Cross currents at the approach channel
• Cross currents in front of the port
• Channel alignment versus prevailing winds
• Salt intrusion
• Siltation problems
• Littoral sediment flows
• High water protection

General criteria which improve the safety of ports are:
• Tug boat assistance
• Pilotage
• Vessel Traffic Control Systems (VTS)
10.2 Economic criteria

Constructing and operating a new harbour must be economically feasible. The future revenues from operating a port must exceed the construction costs. This is not always the case. Often other aspects play an important role such as prestige, political wishes and national development plans. Especially at Shanghai elements of national and international prestige play an important role. For many years the area of Shanghai was the industrial and economic base of China. Recently the southern province of Guangdong took this position from Shanghai. Now the economic output of Guangdong area exceeds that of the Shanghai region (41% versus 18% of the total national export). The local government of Shanghai will go to great lengths to regain the status of China’s industrial and economic centre. In this case a economic evaluation becomes somewhat awkward.

Economic criteria are:

• Costs of capital investments such as:
  - land reclamation
  - water defense
  - access channels
  - drainage and sewage systems
  - road and rail links
• Maintenance costs of channels and waterworks
• Future revenues from harbour activities
• Construction time, interest costs
• Relation between new harbour sites and existing or future industries:
  - transport distance
  - transport mode
  - hinterland connections
• Flexibility
  - possibility of phased growth
  - possibility of further inland expansion
  - possibility of further quay extension
  - land use changes
• Additional operating costs such as:
  - energy supply
  - water supply
  - environmental measures
10.3 Environmental criteria

For many years the environment in and around Shanghai has been neglected. Now clearing up operations are ongoing. The Huang Pu river which flows through Shanghai centre has no living fish. Water pollution is caused by the many industries which drain their waste water to the rivers. In China some 35 billion m$^3$ of waste water is produced annually. About 70% flows to rivers and lakes without any kind of purification treatment (source: China’s stinkende rivieren, Intermediar, 14 juni 1996). In relation to harbour developments the following environmental criteria are to be considered [29]:

- Water related impacts
  - Impacts causes by dredging
  - Impacts of dredged material disposal
  - Construction of piers, breakwaters and other waterside structures
  - Alteration of harbour/port ship traffic patterns
  - Ships discharges: oil, bilge water, sewage
  - Spills: detection and clean up of spills
  - Waterfront: industrial discharges

- Land related impacts
  - Excavation for fill
  - Wetland damage and filling
  - Loss of farmable land to harbour industries
  - Noise
  - Dust and other airborne emissions
  - Impacts by traffic
  - Handling and disposal of wastes
  - Waterfront drainage and runoff
  - Liquid wastes penetrating into the soil

- Air related impacts: emissions by gasses, smoke, fumes, particles and dust
- Safety aspects: hazardous cargoes, port layout and port zoning

10.4 Social criteria

Transferring land to port areas has large social, political and cultural impact. Often people have to leave their homes and the land where they lived for many generations. This causes friction and social unrest. Farmers and land owners have to be compensated. Not always the same quality and quantity of land is available. Port construction on reclaimed land from the sea will bring some relief.

The development of new harbours also creates new jobs, but due to the large scale of automatic machinery, job redundancy is a major problem in almost every port. Working shifts of 24 hours also have a great impact at traditional family structures. Relevant social criteria in relation to harbour development are:

- Impact at local tribal, cultural, ethnic, historical and religious traditions
- Location of population area versus harbour areas
  - Loss of (farm) land
  - Travelling times
- Changes in work type, loss of jobs, creation of new jobs
10.5 Evaluation of alternatives

The criteria mentioned in the previous chapter determine which location is most suitable for future harbour developments. The table below gives a rough indication of the various impacts of each alternative. The aspects are weighted relative to each other. For example: no absolute costs are given for each alternative, but relative indications such as high capital dredging costs, moderate capital dredging costs and low capital dredging costs. The three alternatives are:

- Alternative 1: Harbour development at Changxing Island
- Alternative 2: Harbour development at Nanhuizui and along a coastal canal
- Alternative 3: Harbour development at Jinshanwei

<table>
<thead>
<tr>
<th>Table 21 Evaluation of alternatives.</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>1. Nautical and hydraulic aspects</td>
</tr>
<tr>
<td>- Ship handling</td>
</tr>
<tr>
<td>- Terminal operation</td>
</tr>
<tr>
<td>2. Economic criteria</td>
</tr>
<tr>
<td>- Capital costs of:</td>
</tr>
<tr>
<td>land reclamation</td>
</tr>
<tr>
<td>water defenses</td>
</tr>
<tr>
<td>access channels</td>
</tr>
<tr>
<td>breakwaters</td>
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<tr>
<td>hinterland connections</td>
</tr>
<tr>
<td>- Maintenance costs:</td>
</tr>
<tr>
<td>dredging</td>
</tr>
<tr>
<td>breakwaters or river works</td>
</tr>
<tr>
<td>- Construction time</td>
</tr>
<tr>
<td>- Possible port expansion</td>
</tr>
<tr>
<td>- Distance from industrial centres</td>
</tr>
<tr>
<td>3. Environmental criteria</td>
</tr>
<tr>
<td>- Impacts by dredging</td>
</tr>
<tr>
<td>- Impacts by constructions</td>
</tr>
<tr>
<td>- Impacts by ship spillage</td>
</tr>
<tr>
<td>- Wetland damage and filling</td>
</tr>
<tr>
<td>- Impacts of emissions to urban areas</td>
</tr>
<tr>
<td>4. Social aspects</td>
</tr>
<tr>
<td>- Impact at local inhabitants</td>
</tr>
<tr>
<td>- Loss of (farm)land</td>
</tr>
<tr>
<td>- Travelling times</td>
</tr>
</tbody>
</table>

Legend: + Positive  o Average  - Negative

Note: The items on the table above are compared horizontally. This gives a quantitative impression of how the alternatives relate to each other on a single item. A vertical summation has no direct useful meaning, because the relative importance of each item may vary.
DISCUSSION AND CONCLUSION

With aid of Evaluation of Alternatives table at the previous page the various alternatives will be discussed for each of the four main criteria: Nautical and Hydraulic, Economic, Environmental, Social. The alternatives are evaluated relative to each other. This is done to be able to deal with an evaluation process, even when limited information is available. At a later stage, the selected alternative will be worked out in greater detail.

As a reminder, the three alternatives are:
- Alternative 1: Harbour development at Changxing Island
- Alternative 2: Harbour development at Nanhuí Zui and along a coastal canal
- Alternative 3: Harbour development at Jinshanwei

Discussion of Nautical and Hydraulic criteria
All the alternatives will meet the international standards for safe port entry and safe navigation within port areas as set by international bodies such as the International Maritime Organisation (IMO) and the Permanent International Association of Navigational Congresses (PIANC). Alternative 1 is situated more or less at the end of the navigation channel, but the enter the new port areas, ships have to make a 90° turn to starboard. Prevailing currents could make this manoeuvre difficult.

Alternative 2, see page 51, has a major benefit: the sheltered ports along the artificial canal. Ship navigation and terminal operations are less exposed to waves entering from sea. From a navigational and operational point of view alternative 2 is preferred.

Discussion of Economic criteria
The capital investment costs for each alternative vary strongly. Alternative 1 and 3 use existing land for future harbour development. Some land reclamation is needed, whereas alternative 2 is totally made on reclaimed land. The construction of an coastal canal, including a 55 kilometre long embankment, is a very costly operation. For connecting the coastal canal to the Yangtze river a lock complex is needed. Lock complexes require huge capital investments. It is assumed the capital investments for constructing a coastal canal will exceed the capital investments for purchasing land at Jingshanwei or Changxing Island.

Annual maintenance cost are very important to consider. Annually some 10 million m³ have to dredged to keep the existing navigation channel open at CD-7.00 m. When harbour developments take place at Jingshanwei (Alt.3) an additional navigation channel have to be dredged. This means two navigation channels have to be maintained. This will put an almost unbearable financial burden on the Shanghai Port Authority or the Shanghai local government.

With the construction of the coastal canal (Alt.2) annual dredging costs might reduce. A new navigation channel from sea to Nanhuí has to be dredged, while the old navigation channel does not have to be maintained. All ships bound for Shanghai can use the coastal canal.

Changxing Island (Alt.1) is situated at the end of the existing navigation channel. The Chinese intent to deepen this entrance channel from CD-7.00 metre to CD-12.50 metre. This means hardly any additional dredging operations are required to allow ships to sail to the new harbour area’s, because
the channel is already made. This results into substantial cost savings in the construction cost of alternative 1. New harbour installations at Changxing Island as well the existing old harbours of Shanghai will both immediately benefit from deepening the navigation channel. Therefore considering construction costs alternative 1 is preferred, because it benefits mostly from the deepened entrance channel. The channel dredging costs are not part of the harbour construction costs of alternative 1.

The Port and Delta Consortium (PDC) has made an extensive financial evaluation for various design depths. With a design depth of CD-12.50 metre, deepening of the existing channel, combined with the construction of a semi-submerged dam, is the most favourable solution. The time it takes to realise new port installations also has financial implementations due to interest costs and delay of revenues. The construction of the coastal canal will take the longest time. Land have to be reclaimed, a lock complex built, a canal dredged and an embankment built. At alternative locations 1 and 3 quay wall construction can start almost immediately, so revenues will be generated sooner. Especially at Jinshanwei were a small harbour is already present.

When selecting a location for new harbour developments the distance to the industrial centres is also important. Changxing Island has been situated opposite the Huang Pu river, the entrance to the old harbour areas of Shanghai. An eight kilometre long bridge or tunnel must connect Changxing Island to the mainland of Pudong. Jinshanwei has been located some 100 kilometres from Shanghai. Considering travelling distance between the port and the industrial centres the Jinshanwei is least preferred.

Discussion of Environmental criteria
Turning bare land into large scale harbour areas with industrial activities always put a considerable strain on the environment. Finding ways to minimize or compensate the environmental damage is an important issue. The largest environmental damage to the waterfront is done when the coastal canal is constructed. Shallow mud flats with its specific aquatic live will disappear. The design of the coastal canal incorporates the construction of new embankments, similar to the vanished one's. The old foreshore will be shifted towards the river. Along the newly constructed embankment new live forms could develop, but the environmental damage during construction will be substantial. The coastal canal also has environmental benefits. Spillages from ships can be controlled better.
Alternatives 1 and 3 have less impact to the waterfront, but more impact to the land areas. Farm land will be lost and people will have to move. Changxing island is relatively uninhabited so this location is preferred. With harbour and industrial activities there is a danger of emissions to urban areas. Especially dust emissions of coal, grain, animal food, fertilizer and cement cause great inconvenience to local residents. Dangerous cargoes must always be handled away from residential areas. Changxing Island is closest to the greater Shanghai area. An eight kilometre wide stretch of water should provide a sufficient buffer between the harbour and residential areas.

Discussion of Social criteria
Because Changxing Island (Alt.1) is relatively uninhabited harbour developments here have a marginal impact at the population of the greater Shanghai area. When the coastal canal (Alt.2) option is implemented new land will be reclaimed. Framers along the South bank of the Yangtze river will see new harbour installations emerge between their land and the river. New roads and rail links have to be built which result in some lose of farmland. Still the loss of farmland is minimized with the coastal canal option, so this option is most preferred. Looking at commuter traffic and the strain this inflicts on family life alternative 1 (Changxing Island) is most preferable.
CONCLUSION

Between the three alternatives one will be selected to be investigated in greater detail. The selection is qualitative by nature. This is one way to deal with the great many uncertainties. The next table summarizes the strongest positive and negative aspects of each alternative. Eventually an alternative will be selected.

<table>
<thead>
<tr>
<th>Table 22 Alternatives: PRO's vs CONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alternative 1:</strong> Harbour development at Changxing Island</td>
</tr>
<tr>
<td>+ Low costs of land purchase.</td>
</tr>
<tr>
<td>+ Dredging works both benefit the old and new harbours.</td>
</tr>
<tr>
<td>+ Close to Shanghai (±10 km).</td>
</tr>
<tr>
<td>- Expensive bridge or tunnel needed.</td>
</tr>
<tr>
<td>- Uncertainty of deepening of navigation channel from CD-7.00 to CD-12.50 metre will succeed.</td>
</tr>
</tbody>
</table>

| **Alternative 2:** Harbour development at Nanzui and along a coastal canal |
| + Reduced wave action at waterfront. |
| + Improved terminal operation. |
| + Dredging costs might be reduced. |
| + No loss of farmland. |
| + Ships spillages can be controlled better. |
| + Good operational flexibility. |
| - High capital costs of: |
| - Land reclamation |
| - Dredging |
| - Lock construction |
| - Embankment construction |
| - Increased maintenance costs of embankment and lock complex. |
| - Long construction time. |
| - Loss of original wetland. |

| **Alternative 3:** Harbour development at Jinshanwei |
| + Deep water close to the shore. |
| + Existing port can be expanded. |
| + Short construction time, low interest costs. |
| - New access channel has to be dredged. Two channels have to be maintained. |
| - Far away from Shanghai industrial centre (±100 km) |
Alternative 3 is the least favourable option. Jinshanwei is situated too far from Shanghai industrial centre. A new access channel has to be dredged and maintained. By now the existing navigation channel can hardly maintained, so maintaining two channels is almost impossible.

Alternative 2 is a very good solution to overcome the accessability problems of Shanghai harbour. The bars and shoals in the river mouth will be passed by means of a new navigation canal. The high initial costs will put a heavy burden on the Port of Shanghai.

Alternative 1 is relatively cheap solution, assuming that channel construction and maintenance costs are paid by others. Because Changxing Island is situated at the end of the existing navigation channel, capital dredging costs are limited. The navigation channel has to be deepened to allow larger vessels. Currently the Chinese Ministry of Water resources is undertaking various test if deepening of the navigation channel is possible.

Final Selection

<table>
<thead>
<tr>
<th>Is deepening of the existing navigation channel technically feasible?</th>
<th>ALTERNATIVE 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>yes</td>
<td>Harbour development at Changxing Island</td>
</tr>
<tr>
<td>no</td>
<td>ALTERNATIVE 2</td>
</tr>
</tbody>
</table>

Harbour development at Nanzui and along a coastal canal

The assumption is made that the Chinese dredging trails shows the deepening of the navigational channel from CD-7.00 m to CD-12.50 m is technically possible. The means Alternative 1 Harbour Development at Changxing Island will be investigated in further detail.
PART III

HARBOUR DEVELOPMENT AT CHANGXING ISLAND

China's economy is growing rapidly. During the period 1984-93 China established an annual Gross Domestic Product (GDP) growth of 9% thereby out-ranking the United States of America and the European member states which saw a 3% annual increase of GDP. Economic growth introduces international trade and visa versa. Harbours are extremely important to facilitate these cargo flows. The port of Shanghai is China's principle harbour. The previous parts describe the problems Shanghai is facing in relation to port extension. This part, Harbour development at Changxing Island, will give a basic design of a new harbour in the mouth of the Yangtze River. Due to limited information available, especially about soil conditions, only a spatial layout of the new harbour is made. Quay wall construction aspects and land reclamation are outside the scope of this project, but certainly needs further attention when constructing a new harbour.

1 INTRODUCTION

In Part II Harbour Development, three alternatives for future harbour extension were investigated. A qualitative analysis between the alternatives resulted into Alternative 1: Harbour Development at Changxing Island as most favourable.

When a new port is developed numerous questions arise. Mister Y. Akatsuke of the Asian Development Bank suggests the following important questions be asked about the port project [2]. These questions will be answered for the specific case of harbour development at Changxing Island.

Does the project fit in with national development priorities and with the long term development plan for the port?

Under China's new five year economic plan, the ninth so far which will last to the year 2000, maritime ports have been given a priority development status. Shanghai is the third largest harbour in the world and the largest harbour of China. Expansion of the port is essential if Shanghai wants to become the major coastal hub for central China's manufactures.

Is the proposed scope of the project consistent with anticipated increases in traffic and expected trends in shipping?

At present the port of Shanghai already faces congestion. New berths will bring some relief. If the Shanghai becomes the coastal hub for the production industries along the Yangtze river, new harbour areas will be desperately needed. The Chinese often describe the industries along the Yangtze river as China's economic Drake with the city of Wuhan as its heart and the city of Shanghai as its head. That the future economic output of this region will grow is beyond any doubt. This economic growth will increase traffic and shipping.
Can the port be made more efficient in a non-capital intensive way?

*Improvements in management qualities might increase cargo handling speeds and reduce dwelling times. Foreign shipping companies already established their own cargo handling stations outside the port. These container freight stations prevented stripping and stuffing of containers inside the container terminal itself. The old berths of Shanghai harbour are situated along the Huang Pu river. At this river the draught is limited to 10 metres. So these terminals will never benefit from the 'economics of scale' if larger vessels cannot berth.*

How competent and prepared is the port management to preform its task?

*The Shanghai Harbour Bureau (SHB) is responsible for port management operations. It is difficult to say if the are up to the task of efficiently running a harbour. Problems occur at a higher level of governmental organisation. All the ports and shipping activities of China are the responsibility of the Ministry of Communications. China's waterways are the supervised by the Ministry of Waterways and Energy Resources. Often these Ministries have different interests related to river management and waterway improvement. This results into delays were a swift approach is desirable.*

Have the necessary studies been undertaken to ensure that the project is technically sound?

*In July 1995 a ten year long study was completed to the deepening of the existing navigational channel. With aid of DELFT HYDRAULICS a computer model of the Yangtze delta was constructed to calculate the effects of training dams in the river mouth. The study concluded a training dam along the north bank of the northern navigation channel would increase the tidal currents and thereby reduce the annual siltation. Limited information is available of the geology of Shanghai in relation to large scale land reclamation. The first sand layer starts at some 40 metres below the surface. The aspect of land reclamation requires further detailed studying.*

Will policies promote cost recovery in an equitable and efficient manner?

*The deepening of the navigational channel and the reclamation of land are very costly operations. It is not known if these cost will be recovered by harbour duties, fees and taxes. Last year the Shanghai Container Terminals (SCT) had a 50% merger with Hutchison Whampoa Group of Hong Kong. As a result the quality of container handling at Shanghai improved and so did the prices. Tariffs were raised by approximately 50%, clearly indicating a growing awareness of product and service quality and economic cost recovery.*
Will the port economically viable?

With its large hinterland situated along the Yangtze river, the port of Shanghai has proven economically viable for many years. However, two main problems threaten the economic future of Shanghai. The first problem is the limited depth of the navigational channel to Shanghai. In some cases, only 7 metres of water is available. This is recognised as a serious problem, and a major dredging plan has been developed to deepen the mouth of the Yangtze river to CD-12.50 metre. The second problem of Shanghai harbour is the lack of space and container capacity to meet forecast demands.
DESIGN PHILOSOPHY

This chapter describes the starting points on with the design of the harbour on Changxing Island is based. Not all types of cargo are suitable for handling on an island. General cargo, for instance, can better be handled close to the end user. The harbour at Changxing Island will have a cargo transit function. Cargo from large sea-going vessels will be transferred to smaller feeder vessels and barges which will sail up-river to customers along the Yangtze. The type of harbours which will be constructed depends on future cargo and shipping forecasts. This, in turn, is strongly related to the expected economic growth. China’s economy is outlined in Part II Harbour Development, chapter 2 Economic Developments, page 26. This chapter summarizes the key figures on which the future space demands for new harbour areas are based.

2.1 Port of Shanghai compared with the Port of Rotterdam

The six main cargo commodities handled at Shanghai are: coal, iron ore, containers, general cargo, oil and agriproducts. The ports of Rotterdam and Shanghai show great similarity. Both port annually transfer large volumes of bulk cargoes. Rotterdam’s port is considered the largest port of the world, whereas the port of Shanghai in ranking third. Some 45% of Rotterdam’s annual throughput involves liquid bulk goods, mainly crude oil. The port of Rotterdam has a large refinery and petro-chemical industrial complex. At Shanghai some 60% of the annual turnover consists of dry bulk goods, mainly coal and iron ore. The Boashan steelworks along the Yangtze river, close to Shanghai, produce some 25 million tons of steel annually. This equals five times the annual production of the Hoogovens complex at Ijmuiden, The Netherlands [36]. The port of Rotterdam serves the hinterland along the river Rhine and large industrial centres in Germany and Switzerland. The port of Shanghai is the principal cargo hub for the industrial complexes along the Yangtze river, with the city of Wuhan as a major industrial centre within central China.

The ports of Rotterdam and Shanghai also show great differences. Most remarkable is the port layout. The port of Rotterdam has concentrated port areas such as: Waalhaven, Eemhaven, Peris, Europoort, Maasvlakte which are more or less linked together and form a single entity; The Port of Rotterdam. At Shanghai all berths are scattered along the Huang Pu and Yangtze rivers. Especially the berths along the Huang Pu river are surrounded by the city of Shanghai. This severely limits harbour expansion. When new berths are required often a free site along the Huang Pu or Yangtze river is selected. Thereby creating further division and scattering of Shanghai’s harbour.

2.2 Expected throughput at Shanghai for the year 2000 and 2010

The expected throughput figures for port of Shanghai are estimates made by the author. The annual throughput of the year 1994 was taken as reference. For each cargo commodity; coal, iron ore, oil, agriproducts, general cargo and containers growth scenario’s have been compiled with aid of available literature [14], [20], [30], [52]. This evaluation is made in Part II Harbour Development, chapter 2 Economic Developments, page 26.
The next table summarizes the throughput at Shanghai harbour for the year 1994 and the throughput estimates for 2000 and 2010.

**Table 23** Summary total throughput figures of Shanghai.

<table>
<thead>
<tr>
<th></th>
<th>Total throughput at Shanghai [million tons/year]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1994</td>
</tr>
<tr>
<td>Coal</td>
<td>56.22</td>
</tr>
<tr>
<td>Iron ore</td>
<td>29.96</td>
</tr>
<tr>
<td>Steel</td>
<td>12.11</td>
</tr>
<tr>
<td>Oil</td>
<td>17.92</td>
</tr>
<tr>
<td>Agriproducts</td>
<td>11.61</td>
</tr>
<tr>
<td>General cargo</td>
<td>27.40</td>
</tr>
<tr>
<td>Containers [million TEU]</td>
<td>1.20</td>
</tr>
<tr>
<td><strong>Totals</strong></td>
<td><strong>165.80</strong></td>
</tr>
</tbody>
</table>

It is assumed that the port of Shanghai can absorb some growth in throughput volume within the existing port installations. When new harbour areas will be available at Changxing Island some old port installations will be reorganised. The maximum cargo throughput capacities of the existing harbour installation are mentioned at page 31. Currently some reallocation processes are ongoing within the port of Shanghai. Old and small coal terminals within the city centre are converted to general cargo berths, while a new coal terminal is built at Luoqing along the Yangtze river.

### 2.3 Harbour installations at Changxing Island

The harbour at Changxing Island will become the major transfer hub of cargo flows from and to the upper branches of the Yangtze river. The old harbours of Shanghai along the Huang Pu and the Yangtze river will serve the industrial centres in and around Shanghai. The city of Wuhan, 1200 kilometres upstream from Shanghai is situated between the major east-west and north-south cargo flows within China. Wuhan is the major industrial centre within central China. Due to the limited height clearance of bridges over the Yangtze river, only small seagoing vessels and coasters up to 5000 dwt can reach Wuhan. Large sea-going vessel will transfer their cargo at the harbour installations at Changxing Island. Barges and push convos will establish a shuttle service between Changxing Island and the ports up-stream the Yangtze river.

The following harbour installations will be constructed at Changxing Island to serve the ports up-river:

**Coal terminal:**

Industrial centre’s such as Wuhan have a great demand for energy. Within China coal is the principle energy source. By the year 2000 it is expected that central China will have to import 190 million tons of coal from other provinces [20]. A large quantity of coal is transported by the railway network. The railway system is running to its maximum
limit and cannot cater any traffic volume growth. Therefore Chinese policy makers decided more coal should be transported by sea and inland water transport. Changxing Island will be the central transfer hub. The island will also provide room for strategic coal reserves.

Ore terminal:
The large steel making plans are situated at Wusong and Boashan, almost opposite Changxing Island. The island could act as a large storage area where large sea going vessels will discharge their cargo. Smaller barges will bring the ore across the Yangtze river to the steel-making factories.

Container terminal:
The container terminal at Changxing Island will be a vital node in the inland water transport of containers over the Yangtze river. Factories along the Yangtze river will put their products into containers. These containers will be transported by barge to Changxing Island, were they will be loaded on sea-going vessels.

General cargo terminal:
It seems rather strange to built a general cargo terminal on an island were no customers are. This general cargo terminal will mainly be used as a transfer hub for cargo to and from customers further up-stream along the Yangtze river.

The construction of an oil terminal at Changxing Island in not economically viable. The shipping of oil much depends on the 'economy of scale'. Larger vessels are substantially cheaper per ton cargo than the smaller ones. Even with the deepened access channel to CD-12.50 metre this water depth is still to shallow for the larger oil carriers to call at Shanghai. The port of Ningbo, 260 kilometres from Shanghai, is better equipped for receiving such vessels. A pipeline could bring the oil to the industries around Shanghai.
The two other commodities of Shanghai harbour: steel and agriproducts, are better handled close to their customers and not on an island. Any additional cargo handling will have a negative effect on the pricing of these products.

At Changxing Island four terminals will be constructed:
• A coal terminal
• An ore terminal
• A container terminal
• A general cargo terminal

These terminals can be operated effectively without a fixed link to the city of Shanghai. The harbours at Changxing Island will mainly serve the hinterland along the Yangtze river and to a lesser extent the greater Shanghai area. The up-river transport will be executed by feeder vessels and (push) barges. At a later stage a fixed land link could be constructed when this is required. But initially the harbour at Changxing island is designed to operate without a fixed land link. The next table gives the maximum expected throughput volumes which will be handled by the four new terminals at Changxing Island.
Table 24  
**Maximum throughput volumes by the new terminals at Changxing Island.**

<table>
<thead>
<tr>
<th>Throughput volume [million tonnes/year]</th>
<th>2000</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>35</td>
<td>63</td>
</tr>
<tr>
<td>Ore</td>
<td>8</td>
<td>36</td>
</tr>
<tr>
<td>Containers [million TEU]</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>General cargo</td>
<td>5</td>
<td>14</td>
</tr>
</tbody>
</table>

2.4 Required new land areas

The future space demands are based on two economic growth scenario’s: low economic growth and high economic growth. The economic growth and thereby growth of throughput volume determine the size of the future terminals. The efficiency which cargo is handled may vary for each port. The dwell time of cargo also effects the size of the terminal and storage areas. Larger dwelling times require larger storage areas. This throughput capacities may vary. inexperienced, low motivated crews will have low cargo throughput capacities. The two future economic growth scenario’s and the two different rates which cargo is handled by the harbour personnel give four possibilities for future space demands.

- Low - Low : Low economic growth and low cargo handling speed
- Low - High : Low economic growth and high cargo handling speed
- High - Low : High economic growth and low cargo handling speed
- High - High : High economic growth and high cargo handling speed

The calculation of required new land areas is done and described in Part II Harbour Development, Chapter 5 Space demands of new harbour areas, page 39. The following table summarizes the calculation results.

Table 25  
**Required new land areas at Changxing Island [hectares, 1 ha = 10000 m²]**

<table>
<thead>
<tr>
<th>Economic growth Throughput capacity</th>
<th>By 2000</th>
<th>By 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Low</td>
<td>200</td>
<td>350</td>
</tr>
<tr>
<td>Low High</td>
<td>120</td>
<td>216</td>
</tr>
<tr>
<td>High Low</td>
<td>233</td>
<td>552</td>
</tr>
<tr>
<td>High High</td>
<td>140</td>
<td>343</td>
</tr>
<tr>
<td>Low Low</td>
<td>300</td>
<td>1250</td>
</tr>
<tr>
<td>Low High</td>
<td>180</td>
<td>719</td>
</tr>
<tr>
<td>High Low</td>
<td>420</td>
<td>1723</td>
</tr>
<tr>
<td>High High</td>
<td>252</td>
<td>1075</td>
</tr>
</tbody>
</table>

By the year 2000 a minimum of 216 ha and maximum of 552 ha of land is needed to construct the new harbour installations at Changxing Island. For the year 2010 these figures are 719 and 1723 ha. These land areas only relate to the port extension at Changxing Island. At Changxing Island a coal, iron ore, container and general cargo terminal will be built. Other cargo commodities such as: oil, agriproducts and scrap metals will not be handled on Changxing Island. Throughput volume growth of these cargoes must be absorbed within the existing terminals or new terminals on land (see page 31, Part II).
For designing the future port installations at Changxing Island the maximum figures will be used. It is expected that the port of Shanghai will grow strongly, due to its great regional importance. The expected throughput volumes are conservative extrapolations, so of the deducted space requirements the maximum values are taken. By the year 2000 some 550 hectares of terminal installations will be constructed. The terminal area will grow to 1720 hectare by the year 2010.

2.5 Total quay length and number of berths

On Changxing Island four terminals will be constructed: A coal terminal, an ore terminal, a container terminal and a general cargo terminal. The general cargo terminal will mainly act as a depot or storage area for consumers upstream the Yangtze river.

The depth of the entrance channel limits the maximum vessel size. If the channel is dredged to CD-12.50 metres and the Mean High Water Spring (MHWS) tide of 4 metres above Chart Datum is available, the maximum draught of the vessel will be between the 12.7 and 13.8 metres. Taking a 30% to 20% keel clearance related to the maximum draught of the vessel. These figures are global first impressions to get an impression of the maximum vessel size. The depth of the port entrance channel and the harbour basins will be evaluated later in this chapter.

2.5.1 The coal terminal

Coal terminals include loading and unloading terminals. Loading is done by means of conveyor belts and cranes carrying bridges with conveyor belts in booms. Unloading is mostly done by large clamshells handling loads up to 50 tonnes. Bulk material handling systems, once designed, are difficult to expand. For example, a 50 Mt/year coal terminal cannot effectively or efficiently be created by combining two 25 Mt/year terminals, due to the complex operations that would occur with multiple flow paths and many material grades over 3 to 4 berths. The terminal should be planned for the maximum possibility, then developed in stages.

The coal terminal at Changxing Island will unload the larger sea-going vessels, up to 160000 dwt, partly loaded, depending on the available water depth. These vessels normally have a draught of some 18 metres. With a maximum depth of 13.8 metres the maximum load of the vessel is reduced to 115000 dwt. Smaller vessels and barges will be loaded for further transport up-river. These vessel require separate and smaller loading berths.

The annual throughput of coal will be 35 million tonnes by the year 2000 and 63 million tonnes by the year 2010. These quantities are immense related to European dimensions.³

³ During 1995 the annual throughput of coal in the Port of Rotterdam only amounted 18 million tonnes. Only 6% of the total annual throughput of Rotterdam. The port of Rotterdam is clearly specialised in liquid bulk goods.
The Port of Kooragang in New South Wales, Australia is shipping 50 million tonnes annually and considered the most efficient coal port ever built. The coal arrives by train and can be unloaded a 20000 tonnes per hour. The terminal has three berths for ships up to 140000 dwt. The three travelling type shiploaders have a capacity of 10500 tph each. The coal yard has a length of 2700 metre for a capacity of 7.2 million tonnes in four pile rows [2].

At Cora, Illinois, USA a high speed rail to barge coal transfer terminal has been designed for river transports. The barges are connected into five strings of five barges each, having a total capacity of 37500 tonnes. To achieve the design loading rate of 5700 tph a system was designed in which a continuous string of five barges could be loaded in a single pass. During the loading process the barges are hoisted forward by winches. When the fifth barge of the first string is loaded, the loader directs the outflow of coal to the first barge of the second string. The first string of barges is pulled away while loading operations continue [2]. See following figure.

The final design of a coal or ore terminal requires detailed engineering studies. For the terminals at Changxing Island only the number of berths are established. This is a very rough estimate and this issue can be studied in greater detail. For more detailed information about coal and ore terminals is referred to the enclosure: Coal and Ore Terminals.
Figure 14 Plan view of barge loading terminal. A stationary barge loader fills the barges. The loaded barges are moved forward by winches. When the last barge of the first string is loaded, the outflow of coal is directed to the first barge of the second string and the process continues.

Number of berths estimate at sea-side of the coal terminal
To determine the number of berth at the coal terminal the following assumptions are made:

1. Unloading capacity per berth : 5000 tonnes per hour
2. Working time (full week) : 168 hours
3. One year 50 weeks : 8400 hours per year
4. Actual working time : 80% of full working time
5. Annual throughput (2000) : 35 million tonnes
The new generation of continuous unloaders have unloading rates of about 5000 tonnes per hour on coal [45]. The usage of continuous unloaders is relatively new, so capacities will increase in the near future. Well known manufactures of continuous unloaders are Siwertell of Sweden and Kone of Finland [2].

The berth occupation strongly effects the average waiting time of vessels, queuing for an empty berth. A berth occupation of 70% means in during 70% of the total time the berths are occupied by vessels. Ship owners do not like waiting for their vessels to be serviced. Generally, it is accepted the coal and ore carriers have to wait longer before they are being serviced.

Coal and ore carriers sail various routes between the ports of loading and the port of unloading along China’s coast. Therefore the distribution of bulk carrier inter arrival times is represented by a negative exponential distribution (N.E.D.). The unloading of coal or ore carrier is a straightforward process and therefore also represented by a Erlang-k distribution with k=2. It is assumed that more than one berth will be needed. This results into a multi-server queue, written as M/E\(2\)/\(n\) system. See for detailed explanation of the queuing theory: [53].

- Full production per berth per year with 100% utilisation
  \[ \text{Unloading capacity per berth} \times 8400 \text{ h/y} = 42.0 \text{ Mt/y per berth} \]

- Actual production per berth per year with 100% utilisation
  \[ \text{Full production} \times \text{actual working time} = 42 \text{ Mt/y} \times 80\% = 33.6 \text{ Mt/y per berth} \]

Assume the average load of a ship is \(X\) tonnes. The average number of ships per year which can be handled at this berth is \(33.6 \text{ Mty}^1 / X\). The average number of ships calling at the terminal becomes \(35 \text{ Mty}^1 / X\) (year 2000) or \(63 \text{ Mty}^1 / X\) (year 2010).

This results into:

\[ \rho = (35/X) / (33.6/X) = 1.04 \quad \text{(year 2000)} \]

\[ \rho = (63/X) / (33.6/X) = 1.88 \quad \text{(year 2010)} \]

For bulk carriers it generally accepted that these vessels have to wait some time before they being served. The accepted waiting time for a coal carriers is expressed in units of the service time. For instance, the maximum waiting time is 0.30 units of the service time. If the service time is 30 hours, then the maximum accepted waiting time will be 0.30 \(\times\) 30 hours = 9 hours. The table next page gives the average waiting time of ships in a queue M/E\(2\)/\(n\) in units of the average service time. The utilization is \(\rho\) divided by the total number of berths.
<table>
<thead>
<tr>
<th>Utilization</th>
<th>1</th>
<th>2</th>
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<td>.45</td>
<td>.40</td>
<td>.36</td>
<td>.33</td>
<td>.03</td>
</tr>
</tbody>
</table>
The berths utilisation becomes:

\[ u_{2000} = \frac{\rho}{n} = 1.04 / 2 = 0.52 \text{ (year 2000)} \]
\[ u_{2010} = \frac{\rho}{n} = 1.88 / 3 = 0.63 \text{ (year 2000)} \]

From the table at the previous page the average waiting time in units of average service time can be read.

\[ W_{2000} = 0.29 \]
\[ W_{2010} = 0.27 \]

These figures are just below the boundary value of 0.30, but accepted. So, for the year 2000 two berths are needed and for the year 2010 three berths are required. To determine the maximum length of the sea-side waterfront three berths are taken, each capable of facilitating a 120000 dwt coal or ore carrier.

The largest vessel which calls the coal and ore terminal at Changxing is some 160000 dwt in size. This vessel can only enter the Yangtze delta partly loaded. This ship has a length of 300 metres and a beam of 45 metres. The largest berth will be some 360 metres (120\% of the maximum length). The two other berths will be smaller. These berths must be able to facilitate ships from 20000 dwt to 120000 dwt. The length of these ships ranges from 175 to 275 metres. These two berths will occupy 2 \* 275 m \* 110\% = 605 metres. The total length of the water front a the seaward side on the terminal will become 360 m + 605 m = 970 metres.

**Number of berths estimate at the coal barge terminal**

The coal and ore are shipped from the island by barges and small feeder vessels. At a later stage, when a fixed land link is completed, the coal and ore could also be transported by train. The barge terminal will have a higher berth occupation then the sea terminal. Empty barges can be held in stock allowing the loading process to continue. The barge terminal requires spacious water areas to provide room for manoeuvring with the barges. A sketch of a barge loader is given on page 76. The calculation of the number of berths for the barge terminal is similar to the calculation of the sea-side terminal. The maximum capacity of the barge loader is 5700 tonnes per hour, equal to the barge loader at Cora, USA [2]. The number of berths are:

- Full production per berth per year with 100\% utilisation
  \[ = \text{Unloading capacity per berth} \times \text{one year working} \]
  \[ = 5700\text{ tph} \times 8400 \text{ h/y} = 47.9 \text{ Mt/y per berth} \]

- Actual production per berth per year with 100\% utilisation
  \[ = \text{Full production} \times \text{actual working time} \]
  \[ = 47.9 \text{ Mt/y} \times 80\% = 38.3 \text{ Mt/y per berth} \]

Assume the average load of a ship is X tonnes. The average number of ships per year which can be handled at this berth is 38.3 Mty\(^{-1}\) / X. The average number of ships calling at the terminal becomes 35 Mty\(^{-1}\) / X (year 2000) or 63 Mty\(^{-1}\) / X (year 2010).
This results into:

\[ \rho = \frac{35}{X} / \frac{38.3}{X} = 0.91 \quad \text{(year 2000)} \]

or

\[ \rho = \frac{63}{X} / \frac{38.3}{X} = 1.64 \quad \text{(year 2010)} \]

The berths utilisation becomes:

\[ u_{2000} = \frac{\rho}{n} = \frac{0.91}{2} = 0.46 \quad \text{(year 2000)} \]
\[ u_{2010} = \frac{\rho}{n} = \frac{1.64}{3} = 0.55 \quad \text{(year 2000)} \]

From the table the average waiting time in units of average service time can be read.

\[ W_{2000} = 0.21 \text{ using 2 berths} \]
\[ W_{2010} = 0.16 \text{ using 3 berths} \]

To provide maximum operational flexibility the maximum number of berths will be four. This will also allow to faster unload the stacking area then loading. Thereby reducing the quantity of coal or ore in stack when this is required.

A strip of five barges linked together, see figure page 76, has a length of 5 * 78 metres = 390 metres. To allow manoeuvring and storage with empty and loaded barges additional quay length is required. A empty string, a partly loaded string and a loaded string of five barges take 3 * 390 = 1170 metres. Some 25% additional quay length for manoeuvring gives a berth length of 1465 metres. Movable barge loaders require less waterfront length. To load a strip of five barges some 430 metre of waterfront is needed. If the future ore terminal at Changxing Island has two stationary barge loaders and two travelling barge loaders, the total length of the waterfront will become: 2 * 1465 m + 2 * 430 m = 3790 metres.
2.5.2 The ore terminal

The ore terminal has similar characteristics to the coal terminal. To make maximum use of the 'economy of scale' these terminals are often large. Some of the most efficient terminals for handling of iron ore are in Japan where the steel industry is heavily dependent upon imports of iron ore and coal. Ore carriers are usually unloaded by means of grabs buckets. The grab-bucket type unloader is highly effective for unloading top cargo that can be easily reached by the grab-bucket. As unloading proceeds it becomes increasingly difficult for the grab-bucket to reach the remaining ore, situated at the bottom of the hold. At present, the largest unloading terminal, using five grab-bucket cranes, has a capacity of 10000 tonnes per hour [2], which is much lower than the loading capacity which ranges from 10000 to 20000 tonnes per hour. For more detailed information about coal and ore terminals is referred to the enclosure: Coal and Ore Terminals.

The calculation of the number of berths at the unloading terminals (sea-going vessels) and loading terminals (barges, smaller vessels) is similar to the number of berths calculation of the coal terminal. The unloading capacity is taken at 6000 tonnes per hour. This equals two cranes per ship. All other parameter are keep the same.

Number of berths estimate at sea-side of the ore terminal

The annual throughput volumes of iron ore for the year 2000 and 2010 are 8 million tonnes and 36 million tonnes respectively.

• Full production per berth per year with 100% utilisation
  = Unloading capacity per berth * one year working
  = 6000 tph * 8400 h/y = 50.4 Mt/y per berth

• Actual production per berth per year with 100% utilisation
  = Full production * actual working time
  = 50.4 Mt/y * 80% = 40.3 Mt/y per berth

This results into:

\[ \rho = \frac{8}{X} / (40.3/X) = 0.20 \quad \text{(year 2000)} \]

or

\[ \rho = \frac{36}{X} / (40.3/X) = 0.90 \quad \text{(year 2010)} \]

The berths utilisation becomes:

\[ u_{2000} = \frac{\rho}{n} = 0.20 / 1 = 0.20 \quad \text{(year 2000)} \]

\[ u_{2010} = \frac{\rho}{n} = 0.90 / 2 = 0.45 \quad \text{(year 2000)} \]

From the table the average waiting time in units of average service time can be read.

\[ W_{2000} = 0.19 \text{ using 1 berth} \]

\[ W_{2010} = 0.20 \text{ using 2 berths} \]
Both waiting times in units of the average service time are below the boundary value of 0.30. One berth will be able to facilitate the partly loaded 160000 dwt coal/ore carrier. The other berth will cater to the ships ranging from 20000 to 120000 dwt. The total waterfront length, taken by mooring facilities, will be $360 \text{ m} + 305 \text{ m} = 665 \text{ metres}$.

To create maximal operational flexibility of the terminal, two berths will be constructed by the year 2000. In case a damaged ship obstructs one berth, unloading operations can continue at the other berth. If only one berth was present the unloading process would stall. By 2010 throughput expansion is achieved by placing two additional cranes. The total terminal unloading capacity would then become 12000 tonnes per hour at effective capacity (see enclosure: Coal and Ore Terminals).

**Number of berths estimate at the ore barge terminal**
The loading capacity of barges and smaller vessels is taken at 5700 tonnes per hour. The calculation of the berth length is similar to that of the coal terminal berth length. The results are:
- By the year 2000: 2 berths
- By the year 2010: 2 berths

One stationary continuous loader and one travelling loader will require a waterfront length of: $1465 \text{ m} + 430 \text{ m} = 1895 \text{ metres}$. By 2000 two barge loading berths will constructed, for the same design considerations as for the sea-going vessel berths.
2.5.3 The container terminal

By designing a container terminal factors such as waiting times, equipment usage rates and required manning are essential when determining quay length, storage area, required equipment and utilities. Simulations and model studies will be helpful in the planning process. In this chapter only a rough estimate of the future quay length is given, based on throughput forecasts. The terminal layout requires detailed engineering by experts.

The container terminal expects to handle 1 million TEU by the year 2000 and 5 million TEU by the year 2010. For example, during 1995 the Port of Rotterdam handled 4.8 million TEU (source: Port Statistics 1996, Port of Rotterdam). The terminal at Changxing Island will have a cargo transit function, such as the container terminals of Hong Kong and Singapore. This requires great lengths of waterfront for all sizes of vessels to berth. Therefore a difference is made between mainline berths and feeder berths. The mainline berths handle the large sea-going vessels whilst the feeder berths load the smaller feeders and barges.

The number of berths calculation is done in a similar way as for the coal and ore terminals. A difference is made between the scheduled arrivals of the mainline vessel and the irregular arrival pattern of the feeders and barges. The following parameters are used, which are retrieved from [2] and [45]:

1. Unloading capacity per crane
   mainline : 25 containers per hour
   feeder  : 20 containers per hour

2. Average number of cranes per ship
   mainline : 3 cranes
   feeder  : 2 cranes

3. Working time (full week)
   : 168 hours

4. One year 50 weeks
   : 8400 hours per year

5. Berth occupation
   mainline : 50% of full occupation
   feeder  : 60% of full occupation

6. Actual working time
   : 80% of full working time

   : 1 million TEU

   : 5 million TEU

9. Container / TEU ratio
   : 1.5

10. Quay moves ratio mainline/feeder : 0.5

The container terminal is relatively large so many ships arrive. The inter arrival times is assumed more or less normally distributed. The same assumption is made for the service times. Therefore a $E_2/E_2/n$ system is considered. See for detailed explanation of the queuing theory: [53].

---

4 All containers are moved by water-transport. At this first development stage the terminal has no fixed rail or road connection to the mainland.

83
Mainline vessels

- Full production per berth per year with 100% utilisation
  = Unloading capacity per crane * number of cranes * one year working
  = 25 cont/h * 3 * 8400 h/y = 630000 cont/y per berth

- Actual production per berth per year with 100% utilisation
  = Full production * actual working time
  = 630000 cont/y * 80% = 504000 cont/y per berth

- Conversion TEU to containers
  = Annual throughput in TEU / TEU ratio
  = 0.5 million TEU / 1.5 = 333333 cont/y
  or
  = 2.5 million TEU / 1.5 = 1.67 million cont/y

Assume the average load of a ship is X tonnes. The average number of ships per year which can be handled at this berth is 504000 conty\(^1\) / X. The average number of ships calling at the terminal becomes 333333 conty\(^1\) / X (year 2000) or 1.67M conty\(^1\) / X (year 2010).

This results into:

\[
\rho = \frac{(333333/X)}{(504000/X)} = 0.66 \quad \text{(year 2000)}
\]
\[
\text{or}
\]
\[
\rho = \frac{(1.67M/X)}{(504000/X)} = 3.31 \quad \text{(year 2010)}
\]

For a container vessel the maximum accepted waiting time in units of the average service time will be taken between 0.1 and 0.2. Container vessels operators do not like to waiting.

With use of the following table the number of berths is selected. To use the table the berth utilisation has to be calculated. This is \(\rho\) divided to the number of berths, so:

\[
\nu_{200} = \frac{\rho}{n} = \frac{0.66}{2} = 0.33 \quad \text{(year 2000)}
\]
\[
\nu_{2010} = \frac{\rho}{n} = \frac{3.31}{5} = 0.66 \quad \text{(year 2000)}
\]
Table 27  Average waiting time in queue \( E_\mu/E/n \) in units of service time.

AVERAGE WAITING TIME OF CUSTOMERS IN THE QUEUE \( E_\mu/E/n \) (IN UNITS OF AVERAGE SERVICE TIME)

<table>
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<td>0.1</td>
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<td>0.2</td>
<td>0.0065</td>
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<td>0.3</td>
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<td>0.4</td>
<td>0.0576</td>
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<td>0.5</td>
<td>0.1181</td>
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<tr>
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<td>0.4123</td>
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<tr>
<td>0.8*</td>
<td>0.83</td>
</tr>
<tr>
<td>0.9*</td>
<td>2.0</td>
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</table>

Table IV

Year 2000
From the table with berth utilisation of 0.33 and 2 berths an average waiting time in units of service time of 0.03373 occurs. This figure is an interpolation between berth utilizations of 0.3 and 0.4. The waiting time in units of average service time is much lower than the accepted waiting time in units of service time of 0.2 maximum. This means vessels have to wait less often before being served. Using just one berth is not recommended in case of equipment break down.

Year 2010
The berth utilisation is 0.66 and the number of berths five. Interpolation from the table gives a value of 0.09. The boundary value of 0.2 is still not reached. Using four berths would exceed the boundary waiting time in units of service time limits.

85
Feeder vessels

The queuing theory can also be applied to calculate the number of berths needed for this terminal. The cranes used to load and unload feeder vessels are smaller than the cranes used at mainline vessels. At each feeder vessel berth two cranes will work simultaneously.

• Full production per berth per year with 100% utilisation
  \[= \text{Unloading capacity per crane} \times \text{number of cranes} \times \text{one year working}\]
  \[= 20 \text{ cont/h} \times 2 \times 8400 \text{ h/y} = 336000 \text{ cont/y per berth}\]

• Actual production per berth per year with 100% utilisation
  \[= \text{Full production} \times \text{actual working time}\]
  \[= 630000 \text{ cont/y} \times 80\% = 268800 \text{ cont/y per berth}\]

This results into:

\[\rho = \frac{(333333/X)}{(268800/X)} = 1.24 \text{ (year 2000)}\]

or

\[\rho = \frac{(1.67M/X)}{(268800/X)} = 6.21 \text{ (year 2010)}\]

The utilization becomes:

\[u_{2000} = \rho / n = 1.24 / 3 = 0.41 \text{ (year 2000)}\]
\[u_{2010} = \rho / n = 6.21 / 8 = 0.78 \text{ (year 2000)}\]

The waiting time in units of average service time, read from the table:

\[W_{2000} = 0.03 \text{ using 3 berths}\]
\[W_{2010} = 0.10 \text{ using 8 berths}\]
Final remarks involving the container terminal

The container throughput is expected to grow strongly. The volume growth, from 1 million TEU to 5 million TEU by the year 2010, must be facilitated by new terminals and increased crane production. For example, Singapore’s Tanjiong Pagar terminal handled 5.1 million TEU during 1990. The terminal has 10 berths, resulting into a production of some 500000 TEU/berth/year [45]. The following table summarizes global dimensions of container vessels [2].

<table>
<thead>
<tr>
<th>Type</th>
<th>Capacity [TEU]</th>
<th>Length [m]</th>
<th>Width [m]</th>
<th>Draft [m]</th>
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<td>150</td>
<td>85</td>
<td>13.0</td>
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<td>2nd generation</td>
<td>1500</td>
<td>210</td>
<td>30.5</td>
<td>10.5</td>
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<td>3rd generation</td>
<td>3000</td>
<td>285</td>
<td>32.2</td>
<td>11.5</td>
</tr>
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<td>290</td>
<td>32.2</td>
<td>11.6</td>
</tr>
<tr>
<td>Future (est.)</td>
<td>5000+</td>
<td>320</td>
<td>40+</td>
<td>13.0</td>
</tr>
</tbody>
</table>

Vessel with a width over 32.2 metres are called Panamax-plus vessels. New vessels are operational with a 6800 TEU capacity, with a length of 345 metres, width of 45 metres and a draft of 13.4 metres. This will be the largest vessel able to call the container terminals at Changxing Island. The length of two barges linked together and a push tow will be some 180 metres. This will also be the length of an average feeder vessel, rounded up to 250 metres. The required berth length will be:

By the year 2000:
- Mainline vessels: \(2 \times 345 \times 115\% \approx 800\) metres
- Feeder vessels: \(3 \times 250 \times 115\% \approx 900\) metres

By the year 2010:
- Mainline vessels: \(5 \times 345 \times 115\% \approx 2000\) metres
- Feeder vessels: \(8 \times 250 \times 115\% \approx 2300\) metres

These figures are global estimates to get an impression of the required new land areas and waterfront lengths. A basic harbour design will be derived from the estimated figures. When more information is available a detailed engineering design must be made of the container terminal. A recently completed study to a container terminal at Gadok, South Korea showed that by 5 million quay moves a total quay length of 7000 metres was required. A total of 45 quay cranes are needed to handle these containers (source: Gadok Port Consultants).
2.5.4 The general cargo terminal

During the last two decades the call for more effectiveness gave birth to new cargo handling methods. The introduction of the container led to the disappearance of the traditional freighter. Today, large container vessels, multi purpose vessels and roll-on/roll-off vessels are in use.

At Changxing island the general cargo terminal will be used as a transit-hub for customers further up-stream the Yangtze river. The general cargo terminal must have good operational flexibility; cargo handling must not be obstructed by large fixed structures. The future throughput volumes of general cargo for the year 2000 and 2010 are 5 million tonnes and 14 million tonnes respectively.

If the unloading capacity of a general cargo berth is about 90 tonnes per hour, using three gangs [45], then the annual production of a berth is about 756000 tonnes per year. Thereby taking the a berth occupation of 100% and actual working time of 80% of the total annual working time, this production rate reduces to 604800 tonnes per year.

\[ \rho_{2000} = \frac{5 \text{ million}}{604800 \text{ /} X} = 8.27 \quad \text{(year 2000)} \]
\[ \rho_{2010} = \frac{14 \text{ million}}{604800 \text{ /} X} = 23.15 \quad \text{(year 2010)} \]

The maximum waiting time in units of average service time is taken as 0.25. The irregular arrival pattern and less irregular service pattern in represented by a M/E_2/n system.

The berth utilization becomes:

\[ u_{2000} = \frac{\rho}{n} = \frac{8.27}{10} = 0.827 \quad \text{(year 2000)} \]
\[ u_{2010} = \frac{\rho}{n} = \frac{23.15}{26} = 0.890 \quad \text{(year 2010)} \]

The waiting time in units of average service time, read from the table at page 78:

\[ W_{2000} = 0.21 \text{ using 10 berths} \]
\[ W_{2010} = 0.14 \text{ using 26 berths} \]

With a design ship length of 200 metres the waterfront lengths will become:

By the year 2000  : 10 \* 200 m \* 115\% \approx 2300 metres
By the year 2010  : 26 \* 200 m \* 115\% \approx 6000 metres

The general cargo berths will be situated alongside the container terminal. If in the future shifts occur in cargo volumes, e.g. more containers, less general cargo, then general cargo berths can be converted into container berths. Thereby creating greater operational flexibility.
2.6 Summary key figures future terminals

At Changxing Island four new terminals are planned: a coal terminal, an ore terminal, a container terminal and a general cargo terminal. The principal characteristics of these terminals are summarized in the following table.

Table 29 Principal characteristics new terminals at Changxing Island.

<table>
<thead>
<tr>
<th></th>
<th>By 2000</th>
<th></th>
<th>By 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Terminal size [ha]</td>
<td>No. of berths</td>
<td>Quay length [m]</td>
</tr>
<tr>
<td>Coal Terminal</td>
<td>233</td>
<td>2</td>
<td>665</td>
</tr>
<tr>
<td>Sea-side</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barge-terminal</td>
<td>2</td>
<td>1895</td>
<td></td>
</tr>
<tr>
<td>Ore Terminal</td>
<td>27</td>
<td>2</td>
<td>665</td>
</tr>
<tr>
<td>Sea-side</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barge-terminal</td>
<td>2</td>
<td>1895</td>
<td></td>
</tr>
<tr>
<td>Containers</td>
<td>167</td>
<td>2</td>
<td>800</td>
</tr>
<tr>
<td>Mainline</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feeders</td>
<td>3</td>
<td>900</td>
<td></td>
</tr>
<tr>
<td>General cargo</td>
<td>125</td>
<td>10</td>
<td>2300</td>
</tr>
<tr>
<td>TOTALS</td>
<td>552</td>
<td>23</td>
<td>9120</td>
</tr>
</tbody>
</table>
GENERAL SITE CONDITIONS

This chapter outlines the climatic, hydrographic and topographic conditions of Shanghai. This data will be used when planning and designing the new harbour locations. Retrieving data from Chinese sources is difficult and often incomplete. Especially soil and geological data is hard to find. From two different sources a provisional geological profile has been compiled. This profile will be used when designing land reclamation or pile foundations.

3.1 Introduction

The Dong Hai (Eastern Sea), Huang Hai (Yellow Sea) and the Bo Hai (Gulf of Bohai) form one of the largest shelf areas in the world, with sediment thicknesses in excess of one kilometre. The main sources of these sediments have been the great rivers of China, the Yellow River and the Yangtze River. Broad shallow areas occur along the coast of China in the vicinity of latitudes 34°N (the former mouth of the Huang He) and 31°N (the mouth of the Yangtze River). Off most of the coasts, large tidal ranges and heavy sedimentation from the rivers produce a series of shoals and troughs [24].

3.2 Climatologic conditions

Wind

The climate is monsoonal with cold winds from the North prevailing from October to March. Warm winds occur from between Southwest to Southeast from June until the end of August. During the winter monsoon the average wind force is about 3 and gales on about 5-10% of occasions in December and January and 1-5% in the other winter months. Winds in the summer seldom reach force 3. From information of the Shanghai Investigation and Design Institute (SIDI) and the Royal Netherlands Meteorological Institute (KNMI) the Port and Delta Consortium (PDC) compiled climatological data for the Shanghai area. The results of the PDC research is quoted and supplemented with information from the China Sea Pilot of the British Admiralty.

<p>| Table 30 Wind data for the Shanghai area, speed m/s [52]. |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main direction</td>
<td>NNW - NW</td>
<td>SE - SSE</td>
<td>S - SSE</td>
</tr>
<tr>
<td>Mean velocity</td>
<td>8.6 - 9.4</td>
<td>6.6 - 7.2</td>
<td>6.9 - 7.4</td>
</tr>
<tr>
<td>Av. max. velocity</td>
<td>14.1 - 15.6</td>
<td>11.6 - 11.9</td>
<td>14.5 - 12.4</td>
</tr>
</tbody>
</table>

Typhoons occur once or twice a year from July to September. The main wind direction is NNE to NE. The Shanghai region is not to heavily exposed to typhoons. Typhoons more frequently occur at lower latitude, i.e. over Taiwan and Hong Kong. Some typhoons follow very irregular tracks which sometimes include loops.

The following table summarizes climatic data for Shanghai (31°10’N, 121°26’E) from observations made during 1920-70. The data was taken from the China Sea Pilot, volume III [24].

90
Table 31  Climatic Table of Shanghai for the period 1920 to 1970 [24].

<table>
<thead>
<tr>
<th>Units</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average pressure at MSL</td>
<td>mb</td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
</tr>
<tr>
<td>Mean daily maximum</td>
<td>°C</td>
</tr>
<tr>
<td>Mean daily minimum</td>
<td>°C</td>
</tr>
<tr>
<td>Mean highest</td>
<td>°C</td>
</tr>
<tr>
<td>Mean lowest</td>
<td>°C</td>
</tr>
<tr>
<td>Average humidity</td>
<td></td>
</tr>
<tr>
<td>0600 hrs.</td>
<td>%</td>
</tr>
<tr>
<td>1200 hrs.</td>
<td>%</td>
</tr>
<tr>
<td>Average cloud cover</td>
<td></td>
</tr>
<tr>
<td>0700 hrs.</td>
<td>oktas</td>
</tr>
<tr>
<td>1300 hrs.</td>
<td>oktas</td>
</tr>
<tr>
<td>Precipitation</td>
<td></td>
</tr>
<tr>
<td>Annual total</td>
<td>mm</td>
</tr>
<tr>
<td>Number of days with 0.1 mm or more</td>
<td>days</td>
</tr>
<tr>
<td>Mean wind speed</td>
<td></td>
</tr>
<tr>
<td>0630 hrs.</td>
<td>knots</td>
</tr>
<tr>
<td>1330 hrs.</td>
<td>knots</td>
</tr>
<tr>
<td>Number of days per year with gales</td>
<td>days</td>
</tr>
<tr>
<td>Number of days per year with fog</td>
<td>days</td>
</tr>
</tbody>
</table>

3.3 Hydrographic and topographic conditions

Tides
The tides along the coasts of East China are of the semi-diurnal type with mean tidal ranges between the 2 and 4 metre [52]. The tides near the mouth of the Yangtze rotates clockwise, a southward ebb flow is followed by a northward flow at maximum flood. Velocities in the bar area vary from 1.8 m/s during spring tide and 0.7 m/s during neap tide. The mean tidal range is 2.4 metre with variations between 1.3 metre at average neap and 3.4 metre at average spring tide.

Table 32  Tidal levels referred to local Chart Datum (approximately Lowest Astronomical Tide, Admiralty Tide Tables, 1994).

<table>
<thead>
<tr>
<th></th>
<th>Luhuashan</th>
<th>Sheshan</th>
<th>Dajishan</th>
<th>Wusong</th>
<th>Xuliujing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30°49'N</td>
<td>31°25'N</td>
<td>30°49'N</td>
<td>31°24'N</td>
<td>31°46'N</td>
</tr>
<tr>
<td>122°38'E</td>
<td>122°14'E</td>
<td>122°10'E</td>
<td>121°30'E</td>
<td>120°59'E</td>
<td></td>
</tr>
<tr>
<td>MHWS</td>
<td>4.3</td>
<td>4.1</td>
<td>4.3</td>
<td>3.5</td>
<td>3.3</td>
</tr>
<tr>
<td>MHWN</td>
<td>3.3</td>
<td>3.0</td>
<td>3.3</td>
<td>2.5</td>
<td>2.6</td>
</tr>
<tr>
<td>MLWN</td>
<td>2.0</td>
<td>1.6</td>
<td>1.7</td>
<td>1.4</td>
<td>1.6</td>
</tr>
<tr>
<td>MLWS</td>
<td>0.9</td>
<td>0.5</td>
<td>0.7</td>
<td>1.0</td>
<td>0.8</td>
</tr>
</tbody>
</table>

The tidal excursion varies with the tide and the river discharge. The flood excursion in the river mouth is about 6 kilometres during the wet season and 10 to 16 kilometres during the dry season. The ebb excursion varies between 15 and 30 kilometres.
The characteristic tidal velocities under spring tide conditions are approximately 1 m/s during flood and 1.2 m/s during ebb. The peak velocities can be 1.5 to 2.2 times larger. During neap tide conditions are 0.4 to 0.5 times smaller. Because of the variations in water depths the velocities may vary strongly within the area.

Figure 15 Locations of tidal recording stations, see table 24.

Yangtze River discharge
The Yangtze River is the third largest river in the world after the Nile and the Amazone. The Yangtze has a length of some 6300 kilometres. The annual mean discharge is some 28500 m³/s. The lowest discharge of some 10000 m³/s occurs in January and the highest discharge about 50000 m³/s in July. The highest ever discharge ever measured is 92600 m³/s and the lowest 4640 m³/s. Due to the construction of dams the future peak discharges may be lower and the minimum discharges higher.

Huang Pu River discharge
The city and the old harbours of Shanghai are situated along the Huang Pu river. The Huang Pu river has a length of 113 kilometre, a width of 400 to 800 metres and a depth of 10 to 20 metres. The mean river discharge is in the order of 300 m³/s. The Huang Pu river is used for transport, drainage and water supply.
Waves
Detailed wave studies for the Yangtze delta have been made by the Port and Delta Consortium. Based on information provided by the Chinese SIDI and the Dutch KNMI wave height estimates are made for offshore and sheltered deep water conditions. The effect of shoaling and refraction to which the waves are subjected while entering the Yangtze estuary is investigated with the ENDEC computer program; a wave propagation model of Delft Hydraulics. The next table shows extreme wave conditions, compiled of data from the SIDI and the KNMI. The offshore area is located at East China Sea, the Sheltered deep water area represents the Yangtze delta.

Table 33  Extreme wave conditions

<table>
<thead>
<tr>
<th>H_m</th>
<th>Offshore</th>
<th>Sheltered deep water^5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/10 years</td>
<td>8.9 m</td>
<td>8.7 m</td>
</tr>
<tr>
<td>1/30 years</td>
<td>10.3 m</td>
<td>9.7 m</td>
</tr>
<tr>
<td>1/50 years</td>
<td>10.9 m</td>
<td>10.2 m</td>
</tr>
</tbody>
</table>

The highest sea states with significant waves of approximately 6 metres will enter the Yangtze estuary during the typhoon from North to Northeast, occurring in the period July to September.

The annual distribution of wave heights for offshore conditions ranges from 1.0 to 1.5 meter. Inside the Yangtze estuary, of the coast of Waigaoqiao, normal wave heights vary between 0.7 and 1.0 metre.

Sediment properties
The sediments on the bottom of the navigation channels of the Yangtze River mainly consists of silt and some fine sand. Bed samples taken in the South Branch halfway of Changxing Island show grain sizes between 10 and 150 μm with a median diameter D₅₀ between 30 and 50 μm.

The annual sediment discharge of the Yangtze river varies between the 350 and 700 million tons. The long term annual mean average discharge is some 500 million tons. Of this annual sediment discharge between 80 to 90% is being delivered during the period April to September. About 20% of the annual sediment load is involved in accretion within the estuary, mainly within the northern branch. About 40% is deposited on the underwater delta of the Yangtze causing a eastward extension of the delta of some 100 metres per year. Another 20% of the annual sediment load is deposited in Hangzhou Bay, whereas the remaining 20% of the sediment is carried further along the south coast of Zhejiang province.

^5 Approximately the water area between tidal station 1 (Luhuashan) and station 2 (Sheshan).
In the North Passage of the Southern Branch of the Yangtze River annually some 10 million m$^3$ bed material is dredged. The navigation canal has a length of 25 kilometres and a depth CD-7.00 metres is maintained. From measurements in the hopper of the dredger the bulk density was some 1.4 to 1.5 ton/m$^3$. This equals a sediment dry mass concentration of 750 kg/m$^3$. In the months June, July, August and September about 50% of the dredging works is executed.

Typhoons are another important feature considering channel siltation. The main wind directions is NNE to NE. Typical wave heights during typhoons are of the order 2 metre in the Yangtze delta and 6 metre offshore. During typhoons rapid shoaling can occur which requires immediate dredging. In 1983 the typhoon Forrest crossed the coastal area near Shanghai. As a result the Southern navigation channel, which has been used since 1975, so rapidly silted that is was impossible to maintain the required navigable depth. A new channel, the North Passage, has to be deepened to provide the new navigation channel for Shanghai harbour during. The North Passage is in use since the spring of 1984 [6].

3.4 Soil conditions

Very little is known about the soil conditions around Shanghai. To compile a global impression of the soil conditions two different sources have been used:

[A] Information from the report published by the Port and Delta Consortium (PDC) in July 1995. This report investigates the regulation of the Yangtze estuary.

[B] An article published on the Fifth International Symposium on Land Subsidence, The Hague, October 1995. Three Chinese authors describe a computing model based on cyclic consolidation tests for the city of Shanghai.
Source [A] uses information provided by the Chinese authorities. At two locations along the Yangtze river, Waigaoqiao and Luchaoang, soil information is investigated. Source [B] describes a geological profile at the Shanghai Bus Station Number 2. The two sources are presented next to each other to get a global impression of the soil conditions at Shanghai. The next table describes the abbreviations which have been used.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL</td>
<td>Inorganic clay of low to medium plasticity, sandy clays, silty clays, lean clays</td>
</tr>
<tr>
<td>ML</td>
<td>Inorganic silts, silty of clayey fine sands with slight plasticity</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>kN/m$^3$</td>
</tr>
<tr>
<td>$\gamma'$</td>
<td>kN/m$^3$</td>
</tr>
<tr>
<td>$e$</td>
<td>-</td>
</tr>
<tr>
<td>$n$</td>
<td>-</td>
</tr>
<tr>
<td>w</td>
<td>%</td>
</tr>
<tr>
<td>$k_v$</td>
<td>cm/s</td>
</tr>
<tr>
<td>$k_h$</td>
<td>cm/s</td>
</tr>
<tr>
<td>$c'$</td>
<td>kPa</td>
</tr>
<tr>
<td>$\phi$</td>
<td>°</td>
</tr>
</tbody>
</table>

The figure next page shows two geological profiles. The upper profile is made from data provided by the Chinese SIDI and the Port and Delta Consortium (PDC); source [A]. The lower profile is quoted from source [B].

When determining soil properties it is usual practice to use the Unified Soil Classification system. The USC was proposed by A. Casagrande (1948) and considers the soil as:

- Coarse grained: more than 50 percent of the soil larger than 0.074 mm
  - Gravel: more than 50 percent of the soil is coarser than 4.76 mm.
  - Sand: more than 50 percent of the soil is between 4.76 and 0.074 mm.
- Fine grained: more than 50 percent of the soil is smaller than 0.74 mm

The USC symbols are: G (gravel), S (sand), M (silt), C (clay) and O (organic material). In the figure the expressions CL and ML are used.

CL Silty clay, slightly sandy, slight to moderate plasticity when wet.
ML Silt, contains a slight amount of fine sand.
### Table 35  Soil properties (provisional).

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>Soil properties</th>
<th>Permeability</th>
<th>Shear strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profile</td>
<td>depth</td>
<td>γ</td>
<td>γ'</td>
</tr>
<tr>
<td></td>
<td>m</td>
<td>kN/m³</td>
<td>kN/m³</td>
</tr>
<tr>
<td>Source [A]</td>
<td>0.0-10.0</td>
<td>19.0</td>
<td>9</td>
</tr>
<tr>
<td>CL/ML layer</td>
<td>10.0-45.0</td>
<td>18.0</td>
<td>8</td>
</tr>
<tr>
<td>Source [B]</td>
<td>0.0-15.8</td>
<td>17.1</td>
<td>7.1</td>
</tr>
<tr>
<td>Silty Clay</td>
<td>15.8-45.3</td>
<td>18.4</td>
<td>8.4</td>
</tr>
<tr>
<td>Clay</td>
<td>18.4</td>
<td>8.4</td>
<td>8.4</td>
</tr>
</tbody>
</table>

This geological data will later be used to design pile foundations or areas for land reclamation. Due to the limited available sources these geological profiles should be seen as provisional indicators of Shanghai's soil structure.
Figure 17 Geological profiles at Shanghai. Upper profile source [A, PDC et al.], lower profile source [B].
PORT DESIGN AT CHANGXING ISLAND

This chapter discusses the starting points used for the harbour design at Changxing Island. Problems associated with the layouts at ports were dealt by the PIANC ICORELS groups. PIANC stands for Permanent International Association of Navigation Congress. ICORELS means International Committee for the Reception of Large Vessels. This international body conducted intensive research to the optimal layout dimensions of maritime fairways in shallow seas, sea straits and maritime waterways. Some items of this research are quoted when related to port development at Changxing Island.

4.1 Port design process

The expected throughput volumes of cargo determine the size of the future terminals and the number of berths. The table on page 89 summarizes the required total hectares of land, the number of berths and the total waterfront length. These three items are the starting points for the port design process. The future port layout is strongly determined by navigational constraints. Ships can only safely operate within certain limits. Metrological conditions, for example typhoons, prescribe the orientation of the coal and ore terminals on land. To minimize dust pollution the stockpiles of these terminals are often aligned with the predominant wind direction. With these boundary conditions available several sketches of future harbours at Changxing Island are made. Within this chapter only the most promising sketch will be evaluated in greater detail. The various elements, resulting in this port design, will be motivated within the following chapters.

4.2 Project area at Changxing Island

The new harbour areas of Shanghai’s port will be situated between Changxing Dao and Heng Sha. See figure next page. Between these islands runs a shallow channel, Hengsha Gang. Hengsha Gang has a depth of some two metres below Chart Datum and a width of some 1400 metres. This channel is the basis of the future port layout. The northern end of this channel will be closed by means of a dam, thereby creating a harbour basin. This dam will prevent waves entering from a northerly direction. Especially during the typhoon season, very strong gale force winds enter the area from the North. The dam will reduce the typhoon induced wave action within the port basin. The harbour basin is only accessible from the south. The entrance of the harbour basin is connected to the already existing navigational channel to Shanghai’s harbours.

Next page:

Figure 18 Project area new port developments
4.3 Depth of the approach channel

It is important that the water reference level is clearly defined. The depth of an approach channel is related to its reference level, called Chart Datum. The next figure is a cross section of ship above the seabed. The following levels occur:

1. The **admissible draft** corresponds to the maximum immersion of a vessel's hull in calm water at zero speed.
2. The **nominal channel bed level** is by definition the level above which no obstacles to navigation exist.
3. The **gross underkeel clearance** is the margin between the keel of a vessel and the nominal channel bed level, measured at rest in calm water.
4. The **net underkeel clearance** is the minimum margin remaining between the keel of a vessel and the nominal channel bed level. The vessel is sailing at planned speed under the influence of the most severe wind and wave conditions (operational limit conditions).

![Diagram](image)

**Figure 19** Cross section of vessel above seabed. Water reference level related to channel bed level.

The ship's draft will depend upon the degree of loading. Some ships sail under trim. This means the draft at the rudder (aft) is larger than at the bow of the ship. Trim is the rotation of the ship about a horizontal cross axis. Ships sailing through water are also subjected to squat. Squat is the uniform sinking of ship, causing a increase of draft. Other vertical motions of ship are caused by waves. Waves induce vertical motions such as heave, pitch and roll. The actual motion of a ship depends upon the size of the ship, relative to the waves. For example, if a large bulk carrier with a 60 metre beam rolls 3°, its draft on one size will increase by: \(\frac{1}{2} \times 60 \times \sin 3^\circ = 1.6\) metre. A 3° roll is hardly noticeable on board such a large vessel, but gives a substantial increase of draft.
These response characteristics may vary significantly between vessels of the same size and class. The determination of the depth of an approach channel has been, and still is, subject of many studies. The first general regulations have been made by the PIANC ICORELS report, published in 1985. These deterministic rules give a first impression of the channel depth required. Later, more sophisticated methods have been developed, including the use of probabilistic theories. The next chapter describes both methods of depth determination.

4.3.1 The PIANC ICORELS method

The commission PIANC ICORELS makes the following recommendations on keel clearances:

- Open sea areas with strong swell: gross underkeel clearance about 20% of the maximum draft of ships.
- Waiting areas and channel sections exposed to long and strong swell: gross underkeel clearance about 15% of the draft.
- Channel sections exposed to less swell: gross underkeel clearance about 10% of the draft.
- Manoeuvring and berthing areas exposed to swell: gross underkeel clearance should be about 10% to 15% of the draft.
- Manoeuvring and berthing areas protected from swell: gross underkeel clearance should be about 7% of the draft.

These percentages are based on extensive studies at the entrance to the Port of Rotterdam and involve vessels of 200000 dwt and over. Local circumstances or smaller vessels may require different gross underkeel clearances. At Shanghai, depths of the Yangtze river are subjected to constant changes due to sedimentation and dredging operations. Therefore the higher gross underkeel clearance value (15%) is taken.

The entrance channel to the new harbours at Changxing island will be dredged to CD-12.50 metres. The reference level of chart datum is taken at Lowest Astronomical Tide. The maximum high water spring tide is some four metres above Chart Datum. A 15% gross underkeel clearance of the maximum draft is taken. This result into a maximum draft of a vessel, entering at high water spring tide: (12.50 m + 4 m) / 115% = 14.3 metres. At low water spring the maximum draft of a vessel is reduced to 11.50 metres. This will be the largest draft of a vessel entering the harbour without making use of the tidal benefit.
4.3.2 The probabilistic method

The question arises is: Is the chance that a ship hits the channel bottom during its passage substantially low? To determine the probability distribution for the exceedance of given levels, the following probability density distributions have to be known:

1. The response of the ship to wave motions ($S_\omega$)
2. Water level variation, tides ($T_\omega$)
3. Channel bottom irregularities ($R_\omega$)

The first point (or points) of the ships' bottom that hits the seabed is called the critical point. The spectrum of the distance between the critical point and the sea bottom ($Z_\omega$) can be described as the summation of the spectra's of ship motions, water level variations and bottom irregularities:

$$Z_\omega = S_\omega + T_\omega + R_\omega$$  \hspace{1cm} (2)

With $\omega$ being the wave frequency, assuming that these spectra can be expressed as multiple harmonic functions. A ship hits the bottom when the keel clearance spectra ($Z_\omega$) exceeds the average keel clearance provided. This average keel clearance provided is written as:

$$\bar{k} = \bar{T} + \bar{D} - d - sq$$  \hspace{1cm} (3)

With $\bar{T}$ is the mean tide level during channel transit
$\bar{D}$ is the mean channel depth
$d$ is the draught of the vessel
$sq$ is the squat and trim of the vessel

A ship will hit the seabed when formula (2) exceeds formula (3):

$$Z_\omega > \bar{k}$$  \hspace{1cm} (4)

For determining the channel depth an evaluation has to be made between the acceptable probability of a ship touching the seabed and economic aspects, such as annual maintenance costs, ship damage costs and consequential damage costs.

For more detailed information, about determining the channel depth with the probabilistic method, is referred to the literature [45], [27] and the various publications by the PIANC organisation. In case of the entrance channel to Changxing Island harbour the channel depth involves the inverse question: Given a depth of CD-12.50 metre, what is the maximum draught of a vessel to enter the channel? This maximum draft depends largely on the skill and experience of the ships' captain. Given the external conditions such as waves and tides a captain has to decide whether a safe port entry is possible. Since the captain carries the ultimate responsibility for his ship and cargo he may refuse to pass through the channel, even though the harbormaster did not close the channel his vessel.
4.3.3 Final remarks

Due to the great many insecurities in the determination of the factors affecting vessel underkeel clearance, establishing a final safe water depth and maximum draft remains an approximation process. The probabilistic approach provides more flexibility. Actual stochastical process such as waves, swell and ship responses can be better incorporated within the model. This increased model accuracy may result in depths smaller than for the deterministic (PIANC) approach. Consequently this may result in substantial cost savings.

In case of Changxing Island Harbour the inverted question arise: Given a channel depth, what is the maximum draught of a vessel to enter safely? To get a first impression the maximum draught derived from the deterministic method is taken. This draft is a conservative estimate and represents the lower boundary value. Experienced captains may decide to increase the draft of their vessel after they become familiar with the conditions at the deepened entrance channel.

A detailed determination of the maximum draught of a vessel is outside the scope of this study. During this sketch design phase only a impression of the maximum size vessel is needed. Later, in the detailed engineering phase, draft optimization studies must be conducted.

4.4 Width of the approach channel to Changxing Island Harbour

At Hengsha Anchorage the entrance to Changxing Island harbour will be situated. At this point there must be sufficient space for vessels to manoeuvre and to make the turn into the harbour basin. The length of the necessary canal section equals the stopping distance of the vessels, depending on their speed within the access channel, and a margin. The width of the water area must also take in account the drift during the stopping and turning manœuvres, especially with reverse propulsion with single screw vessels. The width of a one-way channel varies from 4 to 10 times the beam of a ship. At Changxing this results into a port entrance channel width of some 450 to 600 (10*B) metres. Thereby assuming the vessel control system (VTS) of Shanghai will regulate traffic within the port areas. This new VTS system is recently (1995) installed by Krupp-Atlas electronics of Germany.

4.5 Harbour entrance

When vessels arrive at the harbour entrance at Changxing Island they will be assisted by tugs. Especially the larger coal and ore carriers will need tug assistance. The entrance of Changxing Island harbour is similar to the entrance to the Maasvlakte at the port of Rotterdam. Only this harbour can receive much larger vessels, including the world’s largest ore carrier: the Berge Stahl. This ship is 342 metres long, has a beam of 64 metres and a draught of 22.86 metres when loaded with 360000 ton iron ore. The Beer- canal connects the Maasvlakte terminals to the main navigation channel of Rotterdam’s port.
The harbour entrance to Changxing Island’s ports must be wide enough for safe access by ships and at the same time limit the entrance of wave energy. Luckily the harbours at Changxing Island are sheltered from the highest waves entering from the north to northeast during the typhoon season from July to September.

Turning into the port
Trails in Hamburg with unloaded 250000 dwt vessels showed that even large vessels can make a 90° turn within a lane width of three times the ships beam and holding a radius of five times the ships’s length [2]. For the entry to Changxing Island a radius of 4500 metres is taken to get a global impression. This equals fifteen times the length of a design vessel of 300 metres. Normally the curve radius should be greater than ten times the length of the vessel. In exceptional cases a radius of five times the length of the vessel can be used, but the channel must be widened [45].

Cross currents
Cross currents in front of the harbour entrance causes greater problems for entering ships. At the Hengsha anchorage these currents vary between the 4.2 and 4.4 knots. These are peak values, occurring during spring tide conditions. Therefore the harbour entrance must be wide enough to provide safe port entry. When the vessels sail in the Northern main navigation channel to Shanghai, vessels encounter these currents either head-on or from aft. When the vessels turn north towards Changxing Island, these currents become cross currents. Groynes and training dams at Heng Sha and Changxing Dao will reduce the current forces as vessels approach the harbour entrance. The spatial layout and configuration of these groynes has to be investigated in greater detail, but is outside the scope of this study. The limit state condition of the maximum cross current in front of the harbour entrance is set at 2.5 knots.

If the maximum drift angle of a ship is taken at $14^\circ$ ($\tan \alpha = \frac{1}{4}$) the maximum speed a vessel has to maintain can be calculated from:

$$V_{EFF} = 4 \ (u \ sin \alpha)$$

(5)

With $V_{EFF}$ is the vessel speed related to the channel bottom
$u$ is the current velocity
$\alpha$ is angle between the current and the channel axis

With the maximum current velocity of 2.5 knots and an angle of $80^\circ$ the vessel speed $V_{EFF}$ becomes some 10 knots (18 km/h).

The harbour entrance will be 600 metres wide. This is possible due to the limited wave action. This wide harbour entrance exceeds the length of the longest vessel (345 m). In case of a failed harbour entry attempt, this vessel will not immediately run aground and block the port entrance.
Stopping distance
Vessel within the port area need some time to come to a full stop. First the vessel has to reduce its speed to some 4 knots for the tugboats to tie up. The main engine of the vessel is used to come to a full stop. The tugs are used to assist the steering of the vessel and not for stopping or 'breaking'. During this manoeuvre of reducing speed, connecting the tugs and stopping the ship some 2500 to 3500 metres might have been travelled. This distance strongly depends the experience of the tugboat crews and environmental conditions.
In case of Changxing Island Harbour some 3000 metres is available to preform the stopping manoeuvre. When the vessel comes to a full stop it will be in, or close to, the turning circle. Bulk carriers can be towed backwards to coal and ore terminals, easterly to the main channel.

4.6 The port basin
The waterway between Changxing Dao and Heng Sha is called the Hengsha Gang. The Hengsha Gang will become the future harbour basin. Both embankments on either side will be used. The width of 600 metres at the entrance of the basin will be maintained along the basin. This gives the smaller vessels up to 150 metres the possibility to turn on their own power.
The larger bulk carriers and container vessels will be assisted by tugs [2]. Due to the limited forces of maximum 3 beaufort, the turning manoeuvre within the port areas should not give to much problems. Once or twice a year a typhoon might hit the area. During the gale-force winds of a typhoon all harbour activities will be suspended.
The available width of the basin of shipping is some 600 metres. The total width of basin is some 2300 metres. This means jetties, trestles, loading platforms, mooring and breasting dolphins have to be built to berth the vessels. Most of the berths along the Yangtze river are of the jetty type. The Chinese have rich experience constructing these berthing jetties.

At high water spring tide vessels with a maximum draught of 14.3 metres can sail though the entrance channel. These vessels must be able to stay alongside their berth at low water tides. Therefore the depth alongside the berths exceeds the depth of the harbour basin and entrance channel. The water depth along the quay will be CD-15.30 metres, providing some 7% gross underkeel clearance of the vessel’s maximum draft.

Number of vessel occupying the port basin at any one time
The turning basin is situated in the centre of the new harbour basins and will mainly be used by the large bulk carriers. During the turning manoeuvre, assisted by tugs, the vessels will obstruct the waterway to other vessels. The enclosure: Annual Number of Vessels gives a prediction of the number of vessels entering Changxing Island Harbour for the years 2000 and 2010.
For the year 2010 an approximation of the occupation of the turning circle is made. The activities at the turning circle can be divided into two different processes:
Process 1 : Ships sailing through the turning circle
Process 2 : Ships making a turn
The two processes can not be done simultaneously. A turning ship with tugs will fully occupy the turning basin. The inter arrival times can be read in the table in the enclosure Annual Number of Vessels, seventh collum: ships/hour. Only the 115000 dwt and 50000 dwt bulk carriers will make a turning manoeuvre. Other vessels will sail straight through the turning circle. Sailing through will take 6 minutes. This is considered as a 'service time'. The turning manoeuvre will take 15 minutes, also a 'service time' of the turning basin. With aid of the queuing theory, see [53], the processes are represented by two M/M/1 systems with negative exponential distributed inter arrival times and service times.

Table 36 Occupation of turning circle by the year 2010.

<table>
<thead>
<tr>
<th></th>
<th>Process 1</th>
<th>Process 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sailing</td>
<td>Turning</td>
</tr>
<tr>
<td>Inter arrival time</td>
<td>$\lambda^*$</td>
<td>hours/ship</td>
</tr>
<tr>
<td>Arrival rate $^*$</td>
<td>$\lambda$</td>
<td>ships/hour</td>
</tr>
<tr>
<td>Service time</td>
<td>$\mu^*$</td>
<td>hours/ship</td>
</tr>
<tr>
<td>Service rate</td>
<td>$\mu$</td>
<td>ships/hour</td>
</tr>
<tr>
<td>Utilization</td>
<td>$\rho = \lambda / \mu$</td>
<td></td>
</tr>
<tr>
<td>Av. waiting time</td>
<td>$W = \rho*(1-\rho)/\mu^*$</td>
<td>hours</td>
</tr>
</tbody>
</table>

The turning circle is used by both turning and sailing vessels. This results into a combined utilisation of the turning circle of $\rho = 0.3871$. The average, weighted service rate becomes $\mu = 11.34$ ships per hour. This results into an average waiting time of 0.557 hours, about 3.5 minutes. This is an acceptable delay. The Vessel Traffic control System (VTS) and the harbour master could minimize this delay by giving good instructions to the vessels entering the harbour.

$^*$ See the enclose for the determination of these figures.
4.7 Alignment of water areas in relation to prevailing winds

At Shanghai wind forces are moderate. During the winter the average wind force is about 3 beaufort, while winds during the summer seldom reach 3 beaufort. The prevailing winds enter from the North. The main wind direction during typhoons is North-Northeast to Northeast. The moderate winds during the summer period from July to September enter from the South to Southeast. The moderate wind forces will have limited effect on shipping and harbour activities. The predominant wind direction is important in relation to the orientation of the ore and coal stockpiles on land. To minimize environmental damage these stockpiles are orientated parallel to the main wind direction. At Changxing Island the stockpiles will have a North-South orientation.

4.8 Spatial layout of Changxing Island Harbours

The figure next pages gives the spatial layout of the new harbour between the two islands Changxing Dao and Heng Sha. The vessels enter the harbour basin from the south (bottom of the page). The shipping lane is indicated by the dotted lines. The water depth between the dotted lines will be CD-12.50 metres, equal to water depth of the entrance channel. The width of the shipping lane is 600 metres. With usage of the Vessel Traffic control System (VTS) and pilots two way traffic can be allowed. At the port entrance the water surface is some 3000 metres wide, but only the 600 metres between the dotted lines can be used by large draught vessels.

At northern part of the basin a dam between Changxing Dao and Heng Sha will be constructed. This dam creates a confined port area with waves and tides only entering from the south. Hydraulic conditions from southerly directions are least severe.

The port's water area align with the original orientation of the Hengsha Gang, the canal between the two islands. To the east of the Hengsha Gang a new port basin will be dredged. This basin facilitates the coal and ore terminals. These terminals have a north-south orientation due to the prevailing winds. The turning circle at the beginning of the basin can be used by the large bulk carriers. The barge loading terminals are situated along the shallow banks of the Hengsha Gang. The jetty-type berthing facilities for barges and feeder vessels are represented by the long rectangular boxes, situated along the banks of Heng Sha Island.

To the West of the Hengsha Gang two new port basins will be constructed. The first basin will be used by general cargo and container vessels. The second basin is totally dedicated to container vessels. All berths along these two basins will have straight, vertical walls. This results into quick and easy access of loading and unloading equipment to the vessels. The general cargo terminal can be converted to a container terminal if container traffic volume growth exceeds expectations.

Next page:

*Figure 20 Changxing Island Harbour projected onto Changxing Dao and Heng Sha islands.*

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4.9 Project phasing

The figure at page 107 shows the port layout at planned for the year 2010. It is uneconomical to start constructing this harbour at once. By the year 2000 less terminal areas and quay length is required. The figure on the next page illustrates the port layouts for the year 2000 and 2010. By the year 2000 the Hengsha Gang (the main North-South channel) is deepened and the east and west ports basins constructed. The arrows indicate directions of which the port basin and terminals can be expanded. This port design incorporates great flexibility. Each terminal can be expanded in two directions: increased quay length or increased terrain depth. Port expansions all take place at the edges of terminal areas. Thereby limiting the inconvenience of daily port operations.

Next page:

Figure 21 Project phasing of port construction.
PORT HYDRAULICS

This chapter analyses the sensitivity of the port design of Changxing Island Harbour to resonance for long, standing, waves. If these waves exceed operational limits loading and unloading operations have to be suspended. This is undesirable situation, so the port design should prevent the occurrence of these waves whenever possible. Sedimentation is another major problem facing Changxing Harbour Island. This chapter estimates the quantity of sediment which each tide cycle will leave behind. Sediment discharges by the Yangtze river have a strong seasonal distribution. The annual maintenance dredging quantities will be estimated.

5.1 Schematisation of the port basin

For further hydraulic analysis of Changxing Island Harbour the port is schematised into rectangular boxes linked together. See figure next page. The water area between the dotted lines is the deep draught channel for vessels with a maximum draft of 14.3 metres. Long waves, such as tidal waves, have a wavelength which exceeds many times the maximum length of the port basin. Therefore this schematisation is valid. For the analysis of short waves the actual harbour geometry should be used and this schematisation would not be valid. Short waves effects such as refraction and diffraction are not studied, although they are very important. Wave action at Changxing Island is very moderate due to its sheltered position.

Next page:
Figure 22 Changxing Island Harbour schematisation.
5.2 Occurrence of seiches

Seiches are free standing wave oscillations in a closed body of water. These oscillations can be caused by atmospheric pressure variations or by earthquakes below the seabed. Tidal influences and long period swell in the adjacent ocean can excite seiches in harbours. Oscillations periods range from 30 seconds to 1 hour. When a harbour is connected to the sea, a node can be found at the entrance and an antinode will be found at the end of the harbour basin. The harbour basin length equals a quarter of the wave length. See figure.

![Standing wave oscillation in a harbour connected to sea.](image)

*Figure 23 Standing wave oscillation in a harbour connected to sea.*

The speed of waves travel through shallow water is:

$$c = \sqrt{gh}$$  \hspace{1cm} (7)

With:  
$c$ is the wave speed  
$g$ is the acceleration of gravity  
$h$ is the mean water depth

The wave length is the wave speed times the wave period:

$$\lambda = c \times T$$  \hspace{1cm} (8)

With:  
$\lambda$ is the wave length  
$c$ is the wave speed  
$T$ is the wave period

Combining formula's (7) and (8) results into:

$$T = \frac{\lambda}{\sqrt{gh}}$$  \hspace{1cm} (9)
In case of a harbour basin connected to the sea, the critical length of the basin becomes:

$$L = \frac{\lambda}{4}$$  \hspace{1cm} (10)

With:

- $L$ is harbour basin length

To calculate the wave periods which could resonate within the harbour basin, formula (10) is substituted into formula (9). The occurrence of seiches within harbours depends upon both the water depth and the basin length:

$$T = \frac{4L}{\sqrt{gh}}$$  \hspace{1cm} (11)

The following table gives calculation results of formula (11) when both water depth ($h$) and basin length ($L$) are varied. The used basin length are these length which occur in the port design of Changxing Island Harbour. For example the main port basin has a length of 7200 metres. The distance from the port entrance to the end to the east basin equals 4600 metres. Likewise, the distances from the port entrance to the end of the first and second westerly ports basins is 6750 and 8350 metres respectively.

<table>
<thead>
<tr>
<th>From port entrance to end of:</th>
<th>Basin length [metres]</th>
<th>$h = 6 \text{ m}$</th>
<th>$h = 10 \text{ m}$</th>
<th>$h = 12.5 \text{ m}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>East basin</td>
<td>4600</td>
<td>0.67</td>
<td>0.52</td>
<td>0.46</td>
</tr>
<tr>
<td>West 1 basin</td>
<td>6750</td>
<td>0.98</td>
<td>0.76</td>
<td>0.68</td>
</tr>
<tr>
<td>Main basin</td>
<td>7200</td>
<td>1.04</td>
<td>0.81</td>
<td>0.72</td>
</tr>
<tr>
<td>West 2 basin</td>
<td>8350</td>
<td>1.21</td>
<td>0.94</td>
<td>0.84</td>
</tr>
</tbody>
</table>

The previous table shows that the port basins at Changxing Island are sensitive for long waves with periods ranging from 30 minutes to $1^{13}_2$ hours. Detailed wave analysis and (computer) model studies are required to determine the effects of long waves at Changxing Island harbour. The vertical displacement of a seiche is usually very small. However, especially at a node, the horizontal displacement of the water mass can be significant. Ships, moored close to a node, are drawn along the water. This surging of ships hinders cargo handling operations. The entrance of long waves into ports can hardly be prevented. By varying water depths and basin length of a port the responses of the water mass to a driving force could be limited. Often harbours are laid out with irregularly shaped basins trying to minimize direct reflections.
5.3 Exchange mechanisms between port and river

Various authors, Booy (1987), Dursthoff (1970) and Vollmers (1976), describe three flow exchange mechanisms of matter between a harbour and a tidal river:

1. Exchange as a result of a velocity difference between the flow of the river along the harbour entrance and the flow within the harbour.

2. Exchange as a result of a net inflow through the harbour entrance (tides).

3. An exchange flow driven by a density difference between the river water and the water in the harbour.

These three exchange mechanisms occur simultaneously and also interact. Therefore superposition of the three exchange mechanisms is not valid. Generally, when the flow mechanisms coincide, the density-driven exchange flow gives the largest exchange of water between harbour and river [9]. Generally, the exchange of water matter is reduced by decreasing the density difference by water mixing, decreasing the cross section of the harbour entrance or decreasing the water depth. The last two measures conflict with nautical requirements for safe port entry by ships. Therefore some annual maintenance dredging have to be accepted. Knowledge of the exchange mechanisms and good port design might reduce annual maintenance dredging costs.

ad 1. Flow along the harbour entrance
The river water flows with a certain velocity. At the harbour entrance the width of the river increases and the water velocity near the entrance drops. Between the river and the harbour a mixing layer is built up where water is exchanged between the river and the harbour. Within the harbour a circulating flow is generated as a result of entrainment of river water into the harbour. So, for the transport of matter from the river into the harbour two phenomena are important: (1) the creation of a mixing layer between the river and the harbour entrance, (2) the circulating flow, a gyre, in the harbour entrance. See next figure.
Figure 24 The mixing layer.

The exchange flow rate of water between a harbour and a river can be described as:

\[ Q_{ex} = C u_r B_e h \]  \hspace{1cm} (11)

With \( Q_{ex} \) is the flow rate in m³/s
\( C \) is a coefficient that depends on the geometry of the harbour. Booij (1986) obtained \( C \approx 0.032 \) for \( \alpha = 90 \) degrees, \( C \approx 0.05 \) for \( \alpha = 45 \) degrees and \( C \approx 0.02 \) for \( \alpha = 135 \) degrees
\( u_r \) is the velocity of the river water in m/s
\( B_e \) is the width of the entrance in metres
\( h \) is the water depth at the entrance in metres

ad 2. A net inflow through the harbour entrance
Tidal variations result into exchange of water between the sea and the harbour entrance. At the back wall of the harbour there is no exchange of water (\( Q=0 \)). Therefore the flow of water through the entrance of the harbour can be written as:

\[ Q_s = A_h \frac{d\zeta}{dt} \]  \hspace{1cm} (12)

With \( Q_s \) is the water flow rate into the harbour in m³/s
\( A_h \) is the storage area of the harbour
\( \zeta \) is the local water level variation
In case of Changxing Island harbour the rate of exchange of water, due to tidal water level variations would be:

\[ Q_s = 17.7 \cdot 10^6 \text{ m}^2 \cdot \frac{4 \text{ m}}{6 \text{ hours} \cdot 3600 \text{ sec/hour}} = 3300 \text{ m}^3/\text{s} \] (14)

The storage area \( A_h \) is obtained from the figure at page 111, the water level variations from the table at page 91.

ad 3. Density driven exchange flow

The density differences are associated with differences in salinity, temperature, silt content or a combination of these factors. Generally, the difference in salinity is the most important factor that induces the exchange flow. Measurements of Roelfzema and Van Os (1978) showed that, when the three exchange mechanisms occur simultaneously, the exchange due to density differences will be some 75 percent of the total exchange of water between the harbour and the river [9].

If the density of the river water is larger than that of the water in the harbour, river water enters along the bottom, while water from the harbour leaves near the surface. The reversed process occurs when the river water density is lower than that of the water inside the harbour. See the following figure.

![Figure 25 Density flows between river and harbour.](image)

The densities in the harbour and river are not constant in space and time. Fresh water is present in front of the harbour entrance during ebb, while salt water is present during flood. Due to tidal influences, the direction of the density-driven exchange flow in the harbour entrance continuously reverses. The exchange of water is given by (Schijff and Schönfeld, 1953):

\[ Q_{ex} = \frac{1}{4} B_s h \sqrt{\varepsilon g h} \] (15)

With \( \varepsilon \) being the relative density: \(|\rho_r - \rho_h|/\rho_h\). Due to fiction losses the experienced discharge exchanges will be some 10 percent smaller than given by equation (15). The water velocity is \( u_h = \frac{1}{2} \sqrt{egh} \), assuming that both the layer depths are half the water depth. In practice the coefficient \( \frac{1}{2} \) is a bit too large, a value between 0.3 and 0.4 gives better results.
5.4 Harbour siltation

The new harbours at Changxing Island are further schematized to the following figure to get an impression of the annual siltation:

![Diagram of harbour siltation]

*Figure 26 Schematization of Changxing Island Harbour*

With: L is the length of the harbour basin in metres  
B is the width if the harbour entrance in metres  
B₀ is the width at the bottom in metres  
h is the water depth in metres  
Δh is the tidal range metres

With aid of literature [9] and [27] an estimate will be made of the annual total amount of sediment that remains inside the harbour. The following starting parameters are used:

<table>
<thead>
<tr>
<th>Description</th>
<th>Symbol</th>
<th>Unit</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin length</td>
<td>L</td>
<td>metres</td>
<td>7200</td>
</tr>
<tr>
<td>Surface width</td>
<td>B</td>
<td>metres</td>
<td>1750</td>
</tr>
<tr>
<td>Bottom width</td>
<td>B₀</td>
<td>metres</td>
<td>600</td>
</tr>
<tr>
<td>Water depth</td>
<td>h</td>
<td>metres</td>
<td>12.50</td>
</tr>
<tr>
<td>Tidal range</td>
<td>Δh</td>
<td>metres</td>
<td>4</td>
</tr>
<tr>
<td>Max. river density</td>
<td>ρ_max</td>
<td>kg/m³</td>
<td>1015.75 (PDC)</td>
</tr>
<tr>
<td>Min. river density</td>
<td>ρ_min</td>
<td>kg/m³</td>
<td>1006.70 (PDC)</td>
</tr>
</tbody>
</table>

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The relative density $\delta'$ is defined as:

$$\delta' = \frac{\rho_{\text{max}} - \rho_{\text{min}}}{\bar{\rho}} = \frac{1015.75 - 1006.70}{1011.23} = 8.95 \cdot 10^{-3}$$  \hspace{1cm} (15)$$

The average water depth $\bar{h}$ of the harbour is:

$$\bar{h} = 12.5 + \frac{1}{2} \cdot 4 = 14.5 \text{ m}$$  \hspace{1cm} (16)$$

The average flow area $A_e$ of the entrance is:

$$A_e = \frac{1}{2} (600 + 1750)(14.5) = 17038 \text{ m}^2$$ \hspace{1cm} (17)$$

The tidal prism, $P$, of the harbour is the volume of water supplied per tide by the filling current:

$$P = (7200)(1750)(4) = 50.4 \cdot 10^6 \text{ m}^3$$ \hspace{1cm} (18)$$

From source [52], volume A.1, page 4-38, the depth average sediment concentration of the Yangtze river is taken at 140 mg/l. This concentration was measured close to the future harbour location. The sediment in suspension in the Yangtze estuary consists of silt with a diameter of 20 to 50 μm, with settling velocities of the order of 1 mm/s. The clay particles can be considered as wash load in the fresh water region of the estuary, but become important in the saline region as flocculation occurs.

The amount of sediment transported into the harbour by the filling current of the tide equals some:

$$s_f = 50.4 \cdot 10^6 \cdot 140 \cdot 10^{-3} = 7.06 \cdot 10^6 \text{ kg/tide}$$ \hspace{1cm} (19)$$

The density current travels with a velocity of:

$$u_d = 0.35 \cdot \sqrt{\delta' \bar{g} h} = 0.35 \cdot \sqrt{8.95 \cdot 10^{-3} \cdot 9.81 \cdot 14.5} = 0.39 \text{ m/s}$$ \hspace{1cm} (20)$$

This equals some 1400 metre/hour. To fully exchange the present harbour water by saline sea water, the salt tongue has to travel two times the harbour basin length; to the end of the harbour basin and back to the entrance. During the flood period some 6 hours and 12 minutes are available. This means the salt tongue can travel some 8700 metres. So, the density current does not fully exchange harbour water by saline water. Only some 60% is exchanged. This water volume $V_o$ equals some:

$$V_o = 0.6 \cdot 17038 \text{ m}^2 \cdot 7200 \text{ m} = 73.6 \cdot 10^6 \text{ m}^3$$ \hspace{1cm} (21)$$

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The intruding salt tongue, entering along the bottom, brings the amount of sediment $s_{DI}$ of:

$$s_{DI} = 73.6 \cdot 10^6 \cdot 140 \cdot 10^{-3} = 10.3 \cdot 10^6 \text{ kg/tide}$$  \hspace{1cm} (22)

The other half of the exchange water enters the harbour along the surface as the salt tongue retreats. Since the surface water in a river usually contains less sediment, it transports relatively less sediment into the harbour. It is assumed that this surface current of the Yangtze river only contributes of 35% of the sediment found in the other currents in the harbour, $s_{D2}$ becomes:

$$s_{D2} = 73.6 \cdot 10^6 \cdot 0.35 \cdot 140 \cdot 10^{-3} = 3.6 \cdot 10^6 \text{ kg/tide}$$  \hspace{1cm} (23)

The total inflow of sediment, during a tidal cycle becomes:

$$s_T = s_f + s_{DI} + s_{D2} = 7.06 \cdot 10^6 + 10.3 \cdot 10^6 + 3.6 \cdot 10^6 = 20.96 \cdot 10^6 \text{ kg/tide}$$  \hspace{1cm} (24)

With $s_T$ is total harbour siltation per tide in kg/tide

$s_f$ is the filling current by the tide

$s_{DI}$ is the density current inflow

$s_{D2}$ is the density current outflow

For the silt density, situated at the bottom, $\rho = 1200 \text{ kg/m}^3$ is taken. This means every 1 m$^3$ of sediments contains 318 kilograms of dry mass. The 20.96 $10^6$ kg/tide occupies a volume of: $(20.96 \cdot 10^6 \text{ kg/tide}) / (318 \text{ kg/m}^3) = 66.0 \cdot 10^3 \text{ m}^3/$tide. Each year some 706 tidal cycles occur. The annual accumulation of sediment in the harbour is $66.0 \cdot 10^3 \text{ m}^3$/tide $\cdot$ 706 tides/year = $46.6 \cdot 10^6 \text{ m}^3$/year. This volume is spread over the harbour bottom in a layer which is:

$$\Delta d = \frac{46.6 \cdot 10^6 \text{ m}^3}{7200 \text{ m} \cdot 1750 \text{ m}} = 3.7 \text{ metres}$$  \hspace{1cm} (25)

This means annually some four metres have to be dredged to keep the harbour open.

Final Remarks

This annual dredging quantity is a very provisional first order estimate. Obtaining adequate data from Chinese governmental institutions is somewhat awkward. The calculation shows the importance of the density current within the sedimentation process. Some 60% of the total quantity of exchanged water is delivered by the density current. This corresponds well with findings by Roelfzema and Van Os (1978) and Langendoen (1992) that the exchange due to density differences can be 75 per cent of the total exchange of water between a harbour and a river.

Further siltation research is essential. The calculated four metre annual siltation is only a very rough impression. Detailed calculation could show much lower values or, worse, higher values. If the annual siltation quantities exceed the dredging capabilities then this port design is not feasible.
PART IV
ENTRANCE CHANNEL DREDGING SIMULATION MODEL

The Chinese government decided to deepen the access channel to Shanghai harbour. The water depth will be increased from CD-7.00 metre to CD-12.50 metre. The Port and Delta Consortium (PDC) has conducted a ten year long study to the feasibility of this project. They concluded that the combination of constructing a training dam, along the north side of the navigation channel, and a large scale dredging operation would be one of the most promising alternatives.

This part focuses on the dredging of the entrance channel. With aid of a computer driven dredging simulation model different dredging scenarios will be evaluated. Eventually, the model will optimize the usage of available dredgers, the dredging regime, travelling distances to deposit areas and loading times.

1 INTRODUCTION

A model is a schematization of reality. A model is used instead of the system itself because the actual experimentation with the system is not possible or to expensive. When a computer is used to simulate the reality than this is often called digital simulation. With PROSIM language, developed at the Delft University of Technology, the reality will be described and translated into a computer program. To see whether the computer program simulates reality, two checks have to be preformed:

Verification of the model: this involves a series of tests to check if the behaviour of the model is satisfactory. Is the model stable when some parameters slightly changed? Is the actual model correctly translated into computer code?

Validation of the model: does the model represent the reality correctly? Or is the data generated by the model equal to the data obtained from reality? Often the model needs to be calibrated, which is difficult because most models represent a non-existing reality of a future desired situation.

Before writing the model the boundaries of the system have to be determined. In case of the Shanghai entrance channel dredging simulation model, the two important boundary conditions are:

1. The dredging model assumes the usage of self propelled trailer suction hopper dredges. Other types of dredging equipment are not evaluated within the model.

2. The quantities of material to be dredged are taken from the river morphology studies of DELFT HYDRAULICS and PDC. Their estimates of capital and maintenance dredging quantities are input variables of the model.

Later in this part these items will be discussed in greater detail. First a global description of the PROSIM language is given in the next chapter.
THE PROSIM LANGUAGE

The Prosim Language is a very powerful tool to simulate real life processes with a computer. For instance, the process of a trailing suction hopper dredger, in its very basic form, is:

1. Sail to dredging area
2. Dredger until the hopper is full
3. Sail to dumping area
4. Dump the load
5. Repeat this process from phase 1

While the dredger is executing this process, all kinds of external constraints are effecting dredging operations. High waves, winds, fogs and typhoons cause dredging to be suspended. The Prosim language allows these boundary conditions to be generated independently and linked to the dredging process. So the dredging process stops when, for instance, a gale occurs.

This chapter describes the key elements of the Prosim Language. So the reader can better understand the program listings of the Shanghai entrance channel dredging simulation model. For the complete listing of the program is referred to enclosure VI.

2.1 Components and Attributes

A component is a part of the simulation model. At the Shanghai entrance channel dredging simulation model, some important components are: the dredgers, the channel sections, the weather conditions and the sea conditions. Components represent the physical elements of the model. Within the model several dredgers are working at the same time. This means a single dredger is part of a set (class) of dredgers. Therefore a dredger is a component belonging to a class component. At the dredging site there is one leading figure: the project manager. He assigns dredger to channel sections where the must work. Within the model the project manager is a single component.

Each component within the model has some characteristics, called attributes. To attributes a value can be assigned. See the following table, which gives some attributes of a dredger and a section.
Table 39  Some components with attributes of the model.

<table>
<thead>
<tr>
<th>Component</th>
<th>Attributes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dredger</td>
<td>Dredger name</td>
</tr>
<tr>
<td></td>
<td>Dredger size</td>
</tr>
<tr>
<td></td>
<td>Dredger loading rate</td>
</tr>
<tr>
<td></td>
<td>Dredger draft loaded</td>
</tr>
<tr>
<td></td>
<td>Dredger draft empty</td>
</tr>
<tr>
<td></td>
<td>Dredger sailing speed loaded</td>
</tr>
<tr>
<td></td>
<td>Dredger sailing speed empty</td>
</tr>
<tr>
<td>Section</td>
<td>Section number</td>
</tr>
<tr>
<td></td>
<td>Section length</td>
</tr>
<tr>
<td></td>
<td>Section initial depth</td>
</tr>
<tr>
<td></td>
<td>Section current depth</td>
</tr>
<tr>
<td></td>
<td>Section material volume</td>
</tr>
</tbody>
</table>

The component dredger is an active component, because it preforms the dredging process. The section does not preform any activity. It patiently waits until the dredger is finished. Therefor a channel section is a 'dead' component. Such component are just information carriers and called data components. During the dredging process the section material volume decreases. These new volumes are stored in the data component: section; with its attribute: section material volume.

Each attribute of a component needs to be specified. The most frequently used attributes are specified as:
- Integer, ranging from -32768 to + 32768
- Real, ranging from ±8.43E-37 to ±3.37E38 with six significant digits
- Character, with a maximum length of 128 characters
- Logical, these constants are either TRUE or FALSE

A very important attribute is: Reference to <class component>. For instance, the dredger has a attribute Reference to section. This attribute allows cross references between the dredger component and the section component. The dredger must know the number of the section were it is currently working. The section must know the name of the dredger currently dredging. The Reference to <class component> deals with these cross references. Proper assignment of these references is very important for correct functioning of the model.

For the other, less frequently used, attribute specifications is referred to the Prosim User Manual and the Prosim Reference Manual.

2.2  The key modules

Each Prosim model consists of at least two parts. The first part, called the define section, shows of which components the model is built, what names are used for the attributes and how the attributes are specified. This module is called DEFINE. The second part of the model, called the dynamic section, describes the behaviour of the components. This module is called MAINMOD.
3 DESCRIPTION OF THE MODEL

The entrance channel dredging simulation model will be used to obtain a impression of the total time and costs of deepening navigation channel to Shanghai. This chapter specifies the final results of the model and how these results can be used. Further is described how the model is constructed and which key elements it contains. Finally each model has its limitations. The limitations and assumptions concerning the entrance channel dredging simulation model are also specified in this chapter.

3.1 Specification of final target

The goal of the entrance channel simulation model is to determine which trailing suction hopper dredgers can used to reach the final desired channel depth of CD-12.50 metre. Large dredgers (10000 m³ and over) have loaded draught of some 10 metres. When the dredging operation starts these vessels can not sail fully laden through the channel, unless they use a high water period during a tidal cycle. An other solution is using a combination of more smaller (5000 m³) and medium (8500 m³) size vessels which are less effected by their draught. Sets of dredgers will be fed into the model. With a dredger set the model will simulate the entrance channel dredging operation. The output of this simulation will be: the total dredging time and total dredging costs. Rerunning a simulation various times, with the same initial parameters, give the possibility of a statistical evaluation of the project. This information can be used in evaluating the feasibility of the project. The statistical data can also be used for bench-marking and monitoring purposes while the 'real' project is executed.

3.2 Spatial alignment of the entrance channel

The entrance channel, used within the model, has a length of 70 kilometres. This channel is the deepened and extended version of the present Northern Passage to Shanghai. The channel is divided into seven sections of 10 kilometres each. The channel starts close to Changxing Island (KP0, kilometre point zero) and runs eastward to Changjiang Kou (KP70). The dredged material is disposed into two dump areas at sea. The location of these size and the sailing distance, related to the end of the channel (KP70), will be specified later in Part IV.
Figure 27 Spatial layout of the entrance channel
3.3 Model format and main components

The simulation program is made up out of various modules. Between the modules there is a hierarchy. The dredging work of deepening the entrance channel is called the project. The project is finished when the desired depth has been achieved. The project can also stop for various other reasons, for instance the contractor goes bankrupt or legal disputes between the two contact parties. These other reasons to stop the project have primarily non-technical nature. If no disputes occur and the final channel depth has not been achieved, then the dredging process starts. The trailing suction hopper dredgers continue dredging until the desired final depth is reached. The dredgers execute the following cycle: loading the vessel, sailing to the dump site, dumping the load and sailing back to the dredging area. Each cycle of a dredger is called a job. After many preformed jobs by the dredger, the channel will have reached its final depth. The following figure graphically represents the three key elements of the entrance dredging simulation model.

![Diagram of Dredging Process]

Figure 28 The hierarchy between the key elements of the model.

This modular approach to constructing the model provides greater flexibility to future model expansion. Other processes can be added to the project. Before dredging operations start the seabed has to be surveyed. A model of surveying process can be added as a module to the total project. If the survey shows old ship wrecks on the seabed, these wrecks will have to be removed. This wreckage clearing operation can also be modeled and added to the simulation program. For now only the dredging operation by trailing suction hopper dredgers is incorporated within the model. Other processes might be added at a later stage when the model is refined.
3.4 Model limitations

This entrance channel dredging simulation model is a successor to studies conducted by the Port and Delta Consortium (PDC). PDC has made intensive investigations to the regulation of the Yangtze estuary. The results from their river morphological studies is used in the dredging simulation models. For instance, the annual maintenance and capital dredging quantities are quoted, see page 137. These dredging volumes are distributed over the seven sections of the channel model, related to the initial water depth of a section. This is a simplification of the real situation, where siltation and erosion for each channel section may vary. The model assumes siltation conditions evenly distributed over the channel.

Another simplification involves the channel width. The channel width is taken at one metre. The model only calculates for two channel dimensions: length and depth. The channel can be seen as seven boxes of equal length (sections), each with a initial quantity of sediment. Dredging removes sand from the boxes, siltation fills the boxes. Eventually all the boxes are empty. This represents a channel depth of 12.50 metre below Chart Datum. The figure below shows the seven channel sections, named A to G. Each section has a length of ten kilometres, resulting into a total channel length of 70 kilometres.

![Diagram of entrance channel schematization into seven sections (side view).](image)

*Figure 29 Entrance channel schematization into seven sections (side view).*

The dumping areas are situated at sea. The exact location of these size requires detailed coastal engineering investigation. The model assumes the presence of two dumping sites. The sailing distance to these sizes is related to the end of the entrance channel (KP70). These distances can be fed into the model as an initial parameter. The exact locations of these sites and sailing distances need to be investigated into greater detail.

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3.5 Characteristics of Trailing Suction Hopper Dredgers

The simulation model assumes the use of trailing suction hopper dredgers. The main advantages of these vessels are:
- relative immunity to weather and sea conditions
- independent operation
- minimal effect on other shipping
- the ability to transport dredged material over long distances
- relatively high rate of production
- simple mobilisation procedure

There are also some disadvantages, which include the inability to dredge strong materials and the dilution of dredged material during the loading process. The size of trailer dredgers is expressed to its maximum hopper capacity, which ranges from 750 to 10000 cubic metres. Recently new dredgers have been built with hopper capacities up to 20000 cubic metres. The next figure gives the main features of a trailing suction hopper dredger.

Figure 30 Main features of trailing suction hopper dredgers
The hopper design and dimensions have a strong influence on the settlement of soil grains within the hopper. Turbulence within the hopper should be minimised. Most dredgers are designed to carry a full load of fine grained material. Due to the greater density of sand or gravel, the vessels can only carry a 80 per cent of the full hopper capacity of these materials.

In case of dredging the entrance channel to Shanghai the bed material mainly consist of fine silt and clay. These fine materials may not settle from suspension within the hopper during the dredging process. Often the dredging process stops when the full hopper capacity is reached with a suspension of bed material and water. The productive unit of a dredger has to be modified by the bulking factor, $B$, which takes account of the bulking of the dredged material, which is the ratio of volume of the hopper to the in situ volume. This bulking factor will vary widely depending on the soil type. For coarse granular material the bulking factor ranges between 1.15 and 1.35. For well consolidated fine cohesive sediments the bulking factor ranges between the 1.10 and 3.50.

The dredging cycle of a trailing suction hopper dredger consists of four main components: loading (dredging), turning, sailing to and from the disposal ground and discharging the dredged material. The graphs below can be used to estimate the production of a hopper dredger. First the total unproductive cycle time is calculated. This is the time spend during sailing, dumping and turning the dredger. This time is set of on the left hand scale of the graph. The tangent to the loading curve from this point will touch the loading curve at the time that the loading should be stopped. To continue loading is not efficient. The loading time, $t_l$, and the hopper filling factor, $f_r$, can then be read off the graph [1].
Figure 31 Trailing suction hopper dredger loading graphs.
The maximum output of a trailing suction hopper dredger can now be calculated. \( P_{\text{max}} \) represents the output obtained during a period of productive and non-productive working time.

\[
P_{\text{max}} = \frac{H \cdot t_0}{B \left( \frac{3.91 \cdot t_0}{l} + \frac{1.02 \cdot g}{V_t} \right)} \quad \text{m}^3 \text{hour}^{-1}
\]

With \( P_{\text{max}} \) is the productivity \textit{in situ} volume per hour

H is the hopper capacity in cubic metres

\( V_t \) is the fully laden sailing speed of the dredger in knots

g is the distance to the disposal site in kilometres

l is the length of the dredging area in kilometres

\( t_0 \) is the time it takes to discharge of the dredged material (hours)

\( t_t \) is the time it takes to turn the dredger (hours)

\( t_l \) is the loading time (hours)

\( f_e \) is the hopper filling factor, read from the graph

B is the bulking factor, depending on the sediment type, ranging between 1 and 3.5

Formula (26) and the graphs at page 130 can be used to make a provisional estimate of productivity levels. For the dredging work at the entrance channel to Shanghai a first estimate will be made with the following parameters:

\[
\begin{align*}
H &= 8000 \text{ m}^3 \\
V_t &= 14 \text{ knots} \\
g &= 20 \text{ kilometres} \\
l &= 10 \text{ kilometres (for each of the seven channel sections)} \\
t_0 &= 0.083 \text{ hours (5 minutes)} \\
t_t &= 0.066 \text{ hours (4 minutes)}
\end{align*}
\]

First the unproductive cycle time is calculated. This is the time it takes to: (a) turn the vessel, (b) sail to and from the disposal site and (c) to dump the load.

\[
(a) \cdot (b) \cdot (c) = \frac{3.91 \cdot t_0}{l} + \frac{1.02 \cdot g}{V_t} + t_c
\]

The values 3.91 and 1.02 are used for converting knots and kilometres per hour. The loading time \( t_c \) is not known in advance. Therefore some iteration is required. If the dredging of fresh unconsolidated silt is assumed, then the loading time equals some 0.4 hours. See the lower graph at page 130. Dredging for more than 0.4 hours does not result into a further filling of the hopper. So, the total unproductive cycle time becomes 1.55 hours \((a + b + c)\). This value is plotted at the left hand side axis of the lower graph. A tangent is drawn to the Fresh unconsolidated silt curve. The value of \( f_e \) can be read from the vertical axis. The hopper filling factor is some \( f_e = 0.55 \). The bulking factor for fresh unconsolidated silt is taken at 1.50. Using these values base productive unit \( P_{\text{max}} \) can be found of some 1300 m³ per hour of in situ material.

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This value of 1300 m³ per hour is a very provisional figure. It does not take in account any delays due to weather or mechanical break-down. The total volume of bed material that have to be removed from the entrance channel equals some 155 million cubic metres. This single 8000 m³ trailing suction hopper dredger would need some 14 year to complete the job and not suffering any breakdown. Obviously more, and even larger, dredgers are needed to complete the job in some four years.

Some features of hopper dredgers are [1]:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Small dredger</th>
<th>Medium dredger</th>
<th>Large dredger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum water depth to operate:</td>
<td>4 metres</td>
<td>75 metres</td>
<td>8500</td>
</tr>
<tr>
<td>Maximum water depth to operate:</td>
<td>45 metres</td>
<td>17 knots</td>
<td>9.0</td>
</tr>
<tr>
<td>Maximum sailing speed:</td>
<td>75 metres</td>
<td>14</td>
<td>10.5</td>
</tr>
<tr>
<td>Minimum turning circle:</td>
<td>5 metres</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>Maximum wave height:</td>
<td>3 knots</td>
<td>2.5</td>
<td>120</td>
</tr>
<tr>
<td>Maximum cross current:</td>
<td>5 metres</td>
<td>2.5</td>
<td>160</td>
</tr>
</tbody>
</table>

Within the entrance channel dredging simulation model three sizes of dredgers will be used. Several of these dredgers can be used to execute the dredging job. A mixture of various dredger sizes is also possible. The data was taken from [1], added with oral information by experts.

Table 40 Characteristics of the dredgers used in the model

<table>
<thead>
<tr>
<th>Feature</th>
<th>Small dredger</th>
<th>Medium dredger</th>
<th>Large dredger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hopper capacity (m³)</td>
<td>5000</td>
<td>8500</td>
<td>15000</td>
</tr>
<tr>
<td>Maximum draught (m)</td>
<td>6.5</td>
<td>9.0</td>
<td>10.5</td>
</tr>
<tr>
<td>Minimum draught (m)</td>
<td>2.0</td>
<td>3.7</td>
<td>5.0</td>
</tr>
<tr>
<td>Laden speed (knots)</td>
<td>12</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>Production rate¹ (m³/min)</td>
<td>80</td>
<td>120</td>
<td>160</td>
</tr>
<tr>
<td>Limiting wave height (m)</td>
<td>1.5</td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Maximum wave height (m)</td>
<td>2.5</td>
<td>3.5</td>
<td>4.0</td>
</tr>
</tbody>
</table>

¹ This production rate refers to 'Far East Mud' and a maximum hopper filling of some 65% of the total hopper capacity.
MODEL BOUNDARY CONDITIONS

While dredging the entrance channel, the dredging work is subjected to all kinds of operational limitations. The most important delays are caused by the weather and waves. Other delays are induced by other, larger, vessels using the entrance channel and down-time of the dredging equipment, due to machine failures. The trailing suction hopper dredger have operational limits. If wave heights exceed four metres then dredging operations have to be suspended.

The effects of typhoons, gales, fogs and waves are not evenly distributed over the entire year. For instance, typhoons most frequently occur during the summer months from June to September. On the other hand, gales mostly occur during the winter months. The entrance channel dredging simulation model accounts for these annual distributions of weather events. Graphs in enclosure V give the cumulative annual distribution of weather events. Sources for these distributions are the China Sea Pilot and the study conducted by the Port and Delta Consortium, which has its data from the Royal Netherlands Meteorological Institute (KNMI).

4.1 Other shipping

During the dredging process the entrance channel is still in use by other vessels. These vessels might influence the dredging operations. An estimate is made of the total number of vessels that will sail through the channel annually for the years 2000 and 2010. The distribution of vessel sizes and annual ship quantities is worked out in Enclosure IV Number of Vessels through Entrance Channel. The dredging model assumes the use of trailing suction hopper dredges. These dredgers, while operational, do not inflict to much hindrance other vessels. The model assumes a temporary delay in dredging operations when a large ship (120000 dwt and over) passes the dredger. Small vessels have limited effect on the dredging operations. Each of the seven dredging section of the channel has a length of 10 kilometres. This allows the dredger to fill the hopper in a single track. Only one turn has to be made; to return to the dumping site. This minimizes the effect to other vessels.

4.2 Wave heights

The Port and Delta Consortium (PDC) and the Royal Netherlands Meteorological Institute (KNMI) have conducted wave research within the Shanghai area. Their findings are quoted here.

The figure below shows the area in which the wave research has been conducted. Waves can enter the area from 345° to 225°. The area is sheltered for waves entering from the other directions. Therefore this area is called the sheltered area.
Figure 32 Location of wave research.

The following table gives the relative and cumulative frequencies of wave height distributions per year. The wave climate at the entrance channel to Shanghai is relatively mild.

Table 41 Annual wave height distribution.

<table>
<thead>
<tr>
<th>Wave height [m]</th>
<th>Relative frequency</th>
<th>Cumulative frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00 - 0.25</td>
<td>.2252</td>
<td>.2252</td>
</tr>
<tr>
<td>0.25 - 0.75</td>
<td>.1869</td>
<td>.4121</td>
</tr>
<tr>
<td>0.75 - 1.25</td>
<td>.2270</td>
<td>.6391</td>
</tr>
<tr>
<td>1.25 - 1.75</td>
<td>.1616</td>
<td>.8007</td>
</tr>
<tr>
<td>1.75 - 2.25</td>
<td>.0971</td>
<td>.8978</td>
</tr>
<tr>
<td>2.25 - 2.75</td>
<td>.0409</td>
<td>.9387</td>
</tr>
<tr>
<td>&gt;2.75</td>
<td>.0613</td>
<td>1</td>
</tr>
</tbody>
</table>

During some 90% of the time in one year the larger 8500 m³ and 15000 m³ trailing suction hopper dredgers will not be affected by wave influences. These dredgers can still effectively operate as long as the wave height is below the 2.5 metre. The smaller 5000 m³ dredger can be operational for some 80% of the time during one year.

The highest sea states with significant waves of approximately 6 metre will enter the Yangtze estuary during the typhoon from a prevailing direction North to Northeast, occurring in the period July until September. The waves effecting the small, medium and large dredgers with a relative frequencies of 0.0971, 0.0409 and 0.0613 respectively are generated by the model, taking in account the annual wave occurrence distributions from the graph in enclosure V.
4.3 Winds and other metrological conditions

The wind climate around Shanghai is relatively moderate. Winds in the summer seldom reach force three. During the winter months the average wind force is about three Beaufort, with the occasional gale. Typhoons occur once or twice a year from July to September. The main wind direction is NNE to NE. The Shanghai region is not to heavily exposed to typhoons. Typhoons more frequently occur at lower latitude, i.e. over Taiwan en Hong Kong. Some typhoons follow very irregular tracks which sometimes include loops.

A difference is made between gales and typhoons, because they have different annual distributions. Long term statistical data shows between one and three typhoon occurrences per year. First, the number of typhoons is generated by a random generator. This results into one, two or three typhoons in a single year. Secondly, for each typhoon a new random number is generated, ranging between zero and one. This number is plotted along the vertical axis of the cumulative annual typhoon distribution graph in enclosure V. Now the day number this typhoon occurs can be read from the horizontal axis. This day number is stored into a file and will suspend dredging operation when the current day number in the model equals the day of a typhoon.

A similar exercise is performed with the gale occurrences. Data from the China Sea Pilot [24] shows 26 days with gales during one year. The presidency of a gale is taken at one day. During a storm or gale all dredging operation are suspended. Enclosure V gives a graph of cumulative frequency distribution of a gale occurrence. This graph will be used to simulate gales within the simulation model.

Fog is another metrological effect which influences dredging operations. Often fog causes dredging operations to be suspended. Dredgers normally have sophisticated navigation equipment on board, but other vessels within the entrance channel may lack this equipment. In fog conditions dredgers remain stationary to prevent collision with other vessels. Each year some 43 days with fog occur within the Shanghai area [24]. It is assumed that the fog will persists for one day. The graph of the cumulative frequency distribution of fog occurrences is displayed in enclosure V.

Other metrological effects have less impact at dredging operations. Rain does not usually directly trailing dredging operations. The temperature around Shanghai ranges from -8 °C to 38 °C. These long term mean values are within the operational limits of a trailing suction hopper dredger. Ice might effect dredging operations, but is not relevant for the dredging operations in the Shanghai area.
4.4 Tides

The tides along the coasts of East China are of the semi-diurnal type with mean tidal ranges between the 2 and 4 metre [52]. The tides near the mouth of the Yangtze rotates clockwise, a southward ebb flow is followed by a northward flow at maximum flood. At the location of the entrance channel the following tide ranges are derived:

<table>
<thead>
<tr>
<th>Tide Condition</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean high water spring, MHWS</td>
<td>4.2 metre</td>
</tr>
<tr>
<td>Mean high water neap, MHWN</td>
<td>3.2 metre</td>
</tr>
<tr>
<td>Mean low water neap, MLWN</td>
<td>1.6 metre</td>
</tr>
<tr>
<td>Mean low water spring, MLWS</td>
<td>0.6 metre</td>
</tr>
</tbody>
</table>

Each tidal cycle has a period of 12 hours and 25 minutes. The maximum tidal amplitude occurs during spring tides, the minimum during neap tides. Some 347.76 hours pass between a neap-spring-neap tide period. This equals some fourteen days; the period between full moon and new moon. During the fourteen day period 28 tidal cycles occur (28 cycles * 12 hours and 25 minutes = 347.76 hours). The tidal movement of the water surface is modelled by the superposition of the cosines function with a 347.76 hours period and the amplitude of a single tidal cycle. The figure below gives the water level movement during fourteen days (336 hours).

![Figure 33 Water level movement during a fourteen day period](image-url)
4.5 Sediment properties and quantities

The sediments found in the navigational channel to Shanghai mainly consists of silt and fine sand. A typical grain size of $D_{50}$ 60 µm is found in the North Passage. The bulk density of the mud that was studied was about 1500 kg/m³. No other details of this study are known [52].

The Port and Delta Consortium (PDC) conducted intensive research to the possible regulation of the Yangtze estuary. With aid of a river-morphologic computer model, the dredging quantities have been estimated. Two different types of bed material have to be removed from the seabed; the top layer consists of freshly deposited material, the lower layers consist of consolidated sediments. Annually a new layer of fresh sediment is deposited on the seabed. The removal of this layer is called maintenance dredging. To increase the depth of the entrance channel more bed material will have to be removed. The dredging of, older, consolidated sediment layers is called capital dredging. The following table summarizes the quantities of maintenance and capital dredging, as found by PDC [52].

Table 42 Maintenance and capital dredging quantities during a four year project.

<table>
<thead>
<tr>
<th>Channel depth [metres]</th>
<th>Capital dredging [million m³]</th>
<th>Maintenance dredging [million m³]</th>
<th>Total dredging per year [million m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD-8.50</td>
<td>30</td>
<td>10</td>
<td>40</td>
</tr>
<tr>
<td>CD-10.00</td>
<td>35</td>
<td>15</td>
<td>50</td>
</tr>
<tr>
<td>CD-11.50</td>
<td>50</td>
<td>24</td>
<td>74</td>
</tr>
<tr>
<td>CD-12.50</td>
<td>40</td>
<td>30</td>
<td>70</td>
</tr>
<tr>
<td>TOTAL</td>
<td>155</td>
<td>79</td>
<td>234</td>
</tr>
</tbody>
</table>

During the four years that the project is running some 155 million cubic metres of in situ bed material have to be removed to reach the desired depth of 12.50 metre below Chart Datum. Some 79 million cubic metres of maintenance dredging have to be executed during the project. As a result some 234 million cubic metres of sediment will have be dredged to deepen the entrance channel from CD-7.00 to CD-12.50 metre during the four years of the project.

The four year project duration is only used as an example. The total quantities that have to be dredged increases with the project duration. The 155 million cubic metres of capital dredging is a fixed value. The total maintenance dredging increases as the project takes longer to complete. The annual maintenance dredging quantities are related to the current channel depth. As the channel becomes deeper, more maintenance dredging will have to be preformed. The relation current channel depth and maintenance dredging quantities is given in the table above.
4.6 Operational costs

While the dredging model is running, the costs of the dredging operation will be continuously calculated and displayed. The costs are expressed in Dutch Guilders per week (f/week). Three types of dredgers will be used: a 5000 m³, a 8500 m³ and a 15000 m³ hopper capacity dredger. The table summarizes some cost indications of these dredger sizes (source: VGbouw, Cost Nominal Standards).

**Table 43 Weekly costs (f/week) of trailing suction hopper dredgers.**

<table>
<thead>
<tr>
<th></th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dredger</td>
<td>dredger</td>
<td>dredger</td>
</tr>
<tr>
<td>5000 m³</td>
<td>312501</td>
<td>471368</td>
<td>750538</td>
</tr>
<tr>
<td>8500 m³</td>
<td>95859</td>
<td>144591</td>
<td>230226</td>
</tr>
<tr>
<td>15000 m³</td>
<td>70000</td>
<td>93000</td>
<td>116250</td>
</tr>
<tr>
<td>Depreciation + Interest</td>
<td>7000</td>
<td>9300</td>
<td>11625</td>
</tr>
<tr>
<td>Maintenance + Repairs</td>
<td>99000</td>
<td>99000</td>
<td>99000</td>
</tr>
<tr>
<td>Fuel</td>
<td>38344</td>
<td>57837</td>
<td>92091</td>
</tr>
<tr>
<td>Lubricants</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crew (30 persons)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Insurance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SUBTOTAL (f/week)</strong></td>
<td>622704</td>
<td>875096</td>
<td>1233730</td>
</tr>
</tbody>
</table>

These figures are based on a full continue dredging operation of 168 hours per week. Each week some 155 hours are effectively spend on dredging, thirteen hours per week are used for maintenance, repairs and bunkering of fuel. These figures are based on information by experienced dredging operators.

These costs are only the gross costs. In normal practice some 20% to 30% is added for overhead costs such as: taxes, inflation, financing, supervision. Commercial dredging operators also include a profit margin.

The gross costs are used within the model to give governmental institutions an impression of the dredging costs if they would preform the dredging operation themselves.
4.7 Final remarks

The following figure schematizes the dredging process and all the boundary conditions effecting dredging operations. The Prosim model allows each of the boundary conditions to be generated independently and have its effect on the dredging process.

Figure 34 The dredging process with constrains
DESCRIPTION OF MODEL PROCESSES

The Shanghai entrance channel dredging simulation model is made up out of several modules. The function of each module and its relation with other modules is described in this chapter. The complete listing of the program, together with additional program information is submitted to enclosure VI.

5.1 Program modules and relations

The next figure is a graphical representation of the most important modules of the program and their relations. Each Prosim program is activated from the module MAINMOD.

MAINMOD
This is the central body of the program. First all the project data is read from files. The characteristics of the dredgers are stored in the file: Dredgers, the section data in the file: Section, the weather and wave boundary conditions in the file: Limits and the tidal data is retrieved from the file called: Tidefile. After these files are read, MAINMOD activates a generator to created the weather and wave boundary conditions. This module is called GENERATORS. Next the tide generator is activated. If the dredging project is not finished, then the PROJECTMANAGER is activated.

GENERATORS
This module reads all the typhoon, gale, fog, wave and sediment data from the files and creates down-time days for one year. The occurrences of these typhoons, gales, fogs and waves follow statistical distributions, given by the user of the program.

PROJECTMANAGER
The project manager is the central figure in the model. He assign dredgers to sections.

BOUNDARY
This module puts external constrains to the dredging operations such as typhoons, gales, fogs, waves and channel siltation.

DREDGING
All the activities a dredger has to perform are stated in this module. This include dredging, sailing to dump site, dumping the load and sailing back to the dredge area.

Note:
The figure next page is only a partial representation of the program structure. For a complete view of the program configuration is referred to enclosure V, page 180.
Figure 35 The most important program modules and relations.

The figure above is the framework or backbone of the entrance channel dredging simulation model. For a fully detailed explanation of the program structure is referred to enclosure VI. Each of the five modules in the figure above has its own process. To activate a process each process has a name. The next chapters describe the five main processes of the program, as mentioned in the list below.

<table>
<thead>
<tr>
<th>Module name</th>
<th>Process name</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAINMOD</td>
<td>no name required, Mainmod</td>
</tr>
<tr>
<td>GENERATORS</td>
<td>Generator</td>
</tr>
<tr>
<td>PROJECTMANAGER</td>
<td>Manager</td>
</tr>
<tr>
<td>BOUNDARY</td>
<td>Badweather</td>
</tr>
<tr>
<td>DREDGING</td>
<td>Dredger</td>
</tr>
</tbody>
</table>

LEGEND

A component in module A activates a component in module B

Data from module C is used in module D
Start

Read boundary data
   Read tidal data

Activate creation of boundary conditions

Activate creation of tidal water levels

Activate the Project Manager

Project ready?
   NO
      Wait

   YES

Finish
5.2 Process description of MAINMOD

The MAINMOD module is the central module in a Prosim program. Each Prosim program starts from MAINMOD. The entrance channel dredging simulation model starts with reading boundary conditions data from file.

<table>
<thead>
<tr>
<th>File</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limits</td>
<td>This file contains all the annual distributions of typhoons, gales, fogs, waves and sediments. These distribution are stored in the computer’s memory and later used for generating limiting boundary conditions.</td>
</tr>
<tr>
<td>Dredgers</td>
<td>All the dredgers used during the simulation are stored in this file. The model can deal with three classes of dredgers; small -, medium - and large size dredgers. See for the characteristic of these dredgers page 132 of this part.</td>
</tr>
<tr>
<td>Sections</td>
<td>The entrance channel is divided into a number of sections, in this case seven sections. All the initial section characteristics is stored in this file.</td>
</tr>
<tr>
<td>Tidefile</td>
<td>This file contains the tidal characteristics for each section. The model generated tidal water level movements. In the beginning of the project the depth of the channel is too shallow for the large dredgers to be completely loaded. The model calculates the maximum allowable draft of a dredger under the given tidal limits.</td>
</tr>
</tbody>
</table>

The next step of the MAINMOD process is to activate the generation boundary conditions such as typhoons, gales, waves, fog and annual channel siltation volumes.

Next the project manager is activated to start the actual dredging process. The MAINMOD module waits until the project manager signals that the project is ready.

Previous page:
Figure 36 Process of MAINMOD

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5.3 Process description of GENERATOR

The generator is only activated once a year. For the entire year days are created that typhoons, gales, fogs or waves occur. The annual sedimentation quantity in converted and distributed into weekly fractions. During the months April to September some 80% of the total annual siltation occurs. This results into different amounts of the weekly fractions, which are larger during the summer months. For each boundary condition lists are created:

Typhoonlist List containing day numbers that a typhoon occurs.
Galelist List containing day numbers a gale occurs.
Foglist List containing day numbers a foggy day occurs.
S_wavelist List containing day numbers a small dredger will have to suspend dredging operations
M_wavelist List containing day numbers a small and medium dredger will have to suspend dredging operations.
L_wavelist List containing day numbers a small, medium and large dredger can not work.
Sedimentlist This list contains the weekly channel siltation quantities.

The creation of the day numbers of a boundary condition occurrence is explained at page 135, using the graphs of enclosure V. During the simulation the current day number is constantly check against a day of week number in the lists above. If simday = badweatherday or badwaveday then the dredging process will be halted until the bad weather of waves have passed.
5.4 Process description of BADWEATHER

This process constantly checks if the current simulation day number (simday) equal a day of bad weather (nextbadweatherday) of next bad waves (nextbadwavesday). This process is also the central time keeper of the dredging simulation model. If a week passes some weekly values are updated such as total project costs and siltation quantity. If an entire year has passed then new boundary conditions have to be generated.

At some days a bad weather condition occurs together with a bad waves condition. If this happens the bad weather condition prevails. The dredging process is halted for 12 hours. The signal to the dredger is set at weather\_down = TRUE. Now the dredger knows it cannot work, until weather\_down becomes FALSE.

The BADWEATHER process is cancelled when the project manager sends the signal project\_ready = TRUE. This indicates the desired depth has been achieved.
Start Manager

Is the project finished? (project_ready = TRUE)

YES

Wait until all dredgers are finished and have returned

NO

Wait until a dredger is available and a section is available for the dredger to work

Select a dredger from the freedredgerslist and join this dredger to the active dredgers list

Select a section from the freesectionlist and join this section to the active sections list

Activate the dredger to work in its assigned section

Repeat from start

Finish Manager
5.5 Process description of MANAGER

The manager is the central figure in the model. The deepening of the channel continues until the manager signals: \textit{project\_ready} = TRUE. The manager select an available dredger and sends this dredger to an available section. Available dredgers and sections are listed in \textit{freedredgerlist} and \textit{freesectionlist} respectively. The manager removes a dredger and a section from these list and puts them on the lists: \textit{activedredgers} and \textit{activesections}. At this way the manager knows which dredgers and sections are occupied and which ones are free.

\textit{Previous page:}
\textit{Figure 39 Process of MANAGER}
Start Dredging

FOR EACH DREDGER:
WAIT UNTIL BAD WEATHER OR DELAY IS OVER

FOR EACH DREDGER DREDGE UNTIL:
1. HOPPER IS FULL
2. BAD WEATHER
3. SHIPPING DELAY
4. TIDAL LIMITS
5. JOB FINISHED

STOP DREDGING

SAIL TO DUMPSITE

DUMP HOPPER LOAD

SAIL TO DREDGE AREA

END JOB
dredger_active = FALSE
dredger is joined to free-dredgers list

Finish process of Dredger 152
5.6 Process description of DREDGER

The dredger is activated by the manager. The status *dredger_active* is made *TRUE*. Before the dredger can start working it has to check if the working conditions are suitable. If not, the dredger must wait until the bad weather, bad waves or delay is over. During dredging operations bad weather or bad wave conditions may occur. Dredging operations will be suspended. Eventually, when the dredger is loaded it will proceed to the dumpsite. After dumping it sails back to the dredging area. The dredger status is made to *dredger_active = FALSE*. This indicates to the manager this dredger is available for a new dredging job.

*Previous page:
Figure 40 Process of a DREDGER*
SIMULATION RUNS

After the technical explanation of the entrance channel dredging simulation model, the program can now be used to evaluate the best way of dredging the entrance channel to Shanghai. This chapter describes the working of the program and evaluates the results of various simulation runs.

6.1 Introduction

When the program is running a simulation the user will see the following image on the screen. The screen is divided into three separate parts. Two horizontal boxes occupy the better part of the screen. The top horizontal box is a side view of the entrance channel. The seven sections can be distinguished. The top horizontal line represents the water level at Chart Datum. Section one has an initial depth of 9 metres below Chart Datum. During the simulation the depth of the seven sections will increase.

The second horizontal box gives a side view of the two dumpsites. The dumpsites are represented as two huge holes in the seabed. After the first dump site one is full, the dredgers will proceed to the second dumpsite.

The vertical box at the right side of the screen displays working conditions during the simulation. The actual tidal water level height in each of the seven sections is displayed at the top right position of the screen. Because the entrance channel is some 70 kilometres long there is a tidal phase difference between the beginning and the end of the channel. Below the tide graph the simulation year and day numbers are displayed. Currently two days were dredged. The dredging costs and remaining volume give an indication of the work’s progress. Within the box at the bottom right of the screen the remaining volume quantity will also be displayed graphically.
Figure 41

User screen during simulation, showing side views of the channel and dump sites.

After some time the user screen will look like the figure below. Dump site one is almost full. Sections six and seven have already been dredged to the desired depth of 12.50 metres below Chart Datum. The in the middle right side of the screen gives the current weather of wave condition. At the moment dredging operations are suspended due to waves.
Figure 42 User screen after 1 year and 97 days of simulating, showing side views of the channel and dump sites. Dump site 1 is almost full.

6.2 Case 1: Determining the optimum number of vessels

The model can deal with three kinds of dredger sizes; small, medium and large dredgers. First the optimum number of vessels is determined. This can also be a combination of small, medium and large dredgers. Small dredgers have less tidal restrictions and could therefore easily deployed at shallower sections.

NOTE: For the complete numerical output of the simulations runs is referred to enclosure VI: Summary Simulation Results. Within these chapters only the results are presented.

For each simulation run three important parameters are determined:
1. The total working time
2. The total project costs
3. The total dredged volume
The total project costs are divided by the total dredged volume, giving the unit price of \( f \) per m\(^3\).
This page is left empty.
number of: large size dredgers / medium size dredgers / small size dredgers

Duration of dredging works in years
Previous page:

**Figure 43 Work duration versus unit price and dredger employment**

The rather complex figure at the previous page summarizes the results of several simulation runs with different dredger employment. For the absolute values is referred to enclosure VI: Summary Simulation Results.

**X - axis**: The duration of the dredging work in years

**Y - axis**: The unit price: total project costs divided by the total dredged quantity.

The numbers next to the points in the graph indicate the number of dredgers employed. Combinations of dredger are represented by:

- number of: large dredgers / medium dredgers / small dredgers

For example:

- 8: Eight large dredgers employed
- 5/1: Five large dredgers and one medium size dredger employed.
- 3/2/1: Three large dredgers, two medium dredgers and one small dredger have been used to preform the dredging work.

Two large dredgers will take eleven years to bring the desired channel depth of 12.50 metres below Chart Datum (total right side of the graph). This is the absolute minimum number of vessel to be used. These dredgers can never leave the project! As the depth of the channel increases, so does the annual siltation quantity. These two vessels are also needed to keep the channel at its desired depth. During the summer months, with the highest siltation quantities, these two dredgers can only just cope with the presented sediment discharge. If one dredger would break down the channel depth will decrease. For the harbour authorities this is a very undesirable situation. To create some redundancy at least three dredgers should be employed to keep the channel at 12.50 metres below Chart Datum.

Apparently the employment of eight of seven large dredgers seems to make no difference in the total project duration (total left side of the graph). This is not true. The configuration of the model by the user causes this effect. The channel was divided into seven sections. The computer model only allows one dredger to work in one section. So, when configuring the model it is best to always have more sections than dredgers. Otherwise the dredgers have to wait much longer before a new section comes available.

The optimum number of dredger that should work in the channel depends strongly of authority of the model user. In case of Shanghai there are three parties which could use the model.

The Ministry of Water Resources

This ministry is responsible for the river management within China. It has no commercial interest in the Port of Shanghai. This ministry is keen to keep the dredging costs as low as possible. Therefore they would be happy of deepen the channel with two or three dredgers in some ten years.
Commercial (foreign) dredging operator

Any commercial dredger operator prefers to see a quick return on investments. Therefore they are keen to employ seven or more large dredgers to deepen the channel within less then three years. This will certainly be the next 'dredging job of the century', after the Hong Kong dredging project!

The Ministry of Communications and the Shanghai Harbour Bureau

The world’s third largest fleet owner, COSCO, is under the responsibility of this ministry. The China Ocean Shipping Company (COSCO) has a very strong commercial interest in the port of Shanghai. Currently some of their container vessels can only call the Shanghai terminals partly loaded. Waiting ten years before the channel has reached its minimum depth is commercially not interesting. Global economic markets may have sifted or changed during such a long period. Therefore an economic horizon of the total dredging project duration would be three to four years. During that period new terminals can be constructed. Deepening of the entrance channel immediately benefits the existing harbours of Shanghai.

The graph at page 158 shows that combinations of large, medium and small dredgers are commercially not interesting. For example, five large dredgers take some 3.3 years to deepen the channel at some five \( f/m^2 \). Four large dredgers and a medium dredger (4/1) will work at the same unit price but take some 3.7 years. Four large dredgers and a small dredger (4/0/1) take just over four year at a slightly higher unit price. So, if five dredgers are to be employed it is best to work with five large dredgers. Resulting the smallest project duration at the lowest unit price.

This project, which large volumes and great sailing distances calls for the usage of large, fast sailing dredgers. The graph at page 158 shows the large dredger numbers as the lower boundary. A line could be drawn from right to left through points with 2, 3, 4, 5, 6 and 7 large dredgers. Between point 4 and 5 the gradient of the curve is about one. This is the optimum point, resulting in the employment of 4 to 5 large dredgers. Using more than five dredgers results in a sharp costs increase at a small time reduction. Using less than four dredgers saves only little at the project costs, but results into a substantial longer project duration.

For the remainder for simulation runs, five large dredgers are evaluated. The characteristics of this project are:

- Project duration: 3 years 155 days
- Project costs: \( f 1 123 571 \ 000,-\)
- Total dredged volume: \( 222 \ 518 \ 000 \ m^3 \)
- Unit price: \( 5.0494 \ f/m^2 \)
This page is left empty.
Increase project costs versus bulking factor

$y = 0.4112x^{1.1675}$

$R^2 = 0.9906$
6.3 Case 2: Varying the bulking factor

The bulking factor is a very important parameter of the dredging process. During the dredging process in situ bed material is stirred, moved and mixed with water before it ends up in the dredger's hopper. Thus, when a dredger lifts material off the seabed, the volume which this material occupies in the hopper is usually larger than the volume it occupied in the ground. This volume increase can be expressed as a factor of the in situ volume. This factor is called the bulking factor. Bulking factors vary greatly for different types of soil, different particle size distributions and for different methods of dredging [1]. See also page 129 of this part.

A number of simulations have been run with different bulking factors. Each simulation assumed the usage of five large trailing suction hopper dredgers (the reference situation). See for the numerical results enclosure VI.

The graph a on the previous page shows the relation between the increase of the bulking factor and the effect it has at the increase of the total project costs. A 200% error in the first estimate of the bulking factor result into a 245% total project costs increase. Because of the progressive non-linear relation between this parameters it is very important to conduct proper research in determining the bulking factor of the seabed material.

The straight solid black line in the graph is a trend line. The function of this line is given next to the line, with \( x \) being the increase bulking factor. A increase bulking factor of 250% give a cost increase of \( 0.4112 \times 250^{1.1975} = 306 \% \) The value of \( R^2 \) indicates the variability in the data explained or accounted for by the regression model. The trend line accounts for 99.06% of the variability in the data. A sufficient close match. In the literature \( R^2 \) is called the Coefficient of Determination.

Previous page:
Figure 44 Relation between bulking factor versus project costs.

6.4 Case 3: Varying boundary conditions

The reference situation is, again, the employment of five large trailing suction hopper dredgers of 15000 m\(^3\) each. The graph next page summarizes the results when some boundary conditions are slightly altered. A 40% increase of sailing distance to the dump results into a 16% increase of the total project costs. So, an error in the dumpsite sailing distance has a less profound effect at the total project costs than an error in the bulking factor as mentioned in the previous chapter.

The reference simulation is run without any disturbances by commercial shipping to the dredging process. Trailing suction hopper dredgers are self propelled and very manoeuvrable. Shipping normally does not hinder dredging operations. The entrance channel to Shanghai is very busy. Therefore is assumed that large bulk carriers, passing a dredger, will suspend dredging operations for ten minutes. Accounting for shipping during simulation gives a 1% costs increase to the total project costs. See the next page graph. This one percent equals a value some 11.2 million guilders! Project planners should decide if they accept this insecurity in budgeting the total project.
The cancellation of all boundary conditions during simulation gives a 13% costs reduction. This is a very substantial error. The boundary conditions such as typhoons, gales, fogs and waves are of great importance to the dredging process. The delays caused by these boundary conditions cannot be neglected. At the beginning of the dredging process the depth of some channel sections is to shallow for a fully laden large dredger. This results in partly loaded dredgers, especially at the beginning of the dredging works. Not accounting for these tidal restrictions results into a 5% under estimation of the total project costs.

The simulation model uses two different bulking factors; one for the maintenance dredging material and one for the capital dredging material. The simulation is also run with one, weighted, bulking factor instead of two separate ones. A single bulking factor of 1.57 instead for the original bulking factors of 1.3 and 1.7 results into a 4% costs under estimation. The importance of the determination of the bulking factor is outlined in the previous paragraph.

Costs increase versus different simulation conditions

Figure 45 Costs increase versus different simulation conditions
CONCLUSION AND RECOMMENDATIONS

A computer simulation model is a powerful tool to derive a first impression of the total effort it takes to deepen the entrance channel to Shanghai. The Chinese call this project the largest civil engineering challenge next to the construction of the Three Gorges Dam in the Yangtze river. Both projects are received by the Western world with great scepticism. The deepening of the entrance channel to Shanghai is certainly a great challenge. This is only possible when additional river works are executed. Research by PDC and Delft Hydraulics shows that training dams, attached to Heng Sha island will change flow patterns and thereby reduce the annual siltation quantities. Five large 15000 m³ trailing section hopper dredgers could do the job in some 3.5 years. The gross project costs of the dredging works will amount to some 1.12 billion Dutch Guilders (US$ 660 million). These values a only first impressions. The model needs further calibration with local site data. Most important parameter within the model in the bulking factor: the increase of material in situ volume to the volume of the material in the dredger’s hopper. Errors in the bulking factor estimate have a progressive impact at the total project costs.

7.1 Alternative dredging method

A new dredging method is called water injection dredging (WID). WID is based on a very simple concept: vessel mounted pumps inject water directly into the sediment voids through low pressure jets mounted on a long horizontal pipe. This fluidizes the sediment, creating a gravity driven density current that can flow down very mild slopes. The density current transports shoal material to deeper water, where it can settle without impending navigation. The sediment can also be carried farther away by stronger natural currents. The dredging equipment is very simple to operate with minimal crew or other support. The dredgers are self propelled and cause no disturbance to other vessels sailing in the vicinity. WID offers a potentially low-cost alternative to traditional dredging for appropriate locations. Advantages of WID when compared to other methods of dredging include lower costs for mobilisation/demobilization, potentially lower operating costs and potentially higher production rates than dredgers with comparable horsepower (under certain soil and bathymetric conditions). WID is not generally suitable were sand-sided material above the 0.2 mm has to be moved. The D₉₀ grain size in the entrance channel to Shanghai is some 60 µm, found in the North Passage. The bulk density of the mud that was studied was about 1500 kg/m³ [52]. This very fine sand-silt fraction is very suitable for water injection dredging. Trail test with a pump power of 750 hp in sand with a D₉₀ of 0.18 mm showed production rates of some 1000 m³ per hour. With larger pumps and the seabed conditions at Shanghai, much higher production rates can be achieved, perhaps 2000 m³/h and over.
Figure 46 Self propelled water injection dredger
7.2 Recommendations for further research

The entrance channel dredging model has a flexible setup and allows new modules to be added. Such a new module could be the process of Water Injection Dredging (WID). New simulations with combined employment of trailing suction hopper dredgers and water injection dredgers can be run. Further research steps will be:

1. Adaption of the entrance channel dredging simulation model for combined employment of trailing hopper dredgers with water injection dredgers.

2. Calibration of the updated model with already completed dredging works. This could very well be an ex post calculation of projects executed in other countries.

3. Executing simulation runs for the entrance channel to Shanghai with combined TSHD and WID employment.

4. Preforming dredging trails at location to see whether WID lives up to the expectation.

The estimated costs for deepening the entrance channel to Shanghai are already estimated at some US$ 600 million and over. Therefore, any money invested in the research of innovative new dredging techniques, is very well spend. The future cost savings might exceed the research costs. If not, then at least some valuable lessons have been learned, which will benefit future dredging projects in China.
ENCLOSURE I  DANGEROUS CARGOES IN TUNNELS

Another way to link the island to the mainland is by means of a tunnel. For road tunnels a maximum downgrade slope of 4% and a maximum upgrade slope of 3% is desirable. Due to the average engine and break condition of a typical Chinese truck lower slopes are preferable. To provide a good drainage installation the slopes should not be less than 1%. One major problem with tunnels is not all types of cargo can be transported through a tunnel. Cargo goods have been classified into various classes (Wet Gevaarlijke Stoffen, februari 1996):

- Class 1 : Explosive goods and materials.
- Class 2 : Compressed gasses
- Class 3 : Inflammable liquids
- Class 4.1 : Inflammable solid materials
- Class 4.2 : Spontaneous igniting materials
- Class 4.3 : Materials, developing inflammable gasses if brought in contact with water.
- Class 5.1 : Oxidizing materials
- Class 5.2 : Organic peroxides
- Class 6.1 : Toxic materials
- Class 6.2 : Infectious materials
- Class 7 : Radioactive goods
- Class 8 : Aggressive, corrosive goods
- Class 9 : General dangerous goods and materials

In the Netherlands the law of Transportation of Dangerous Cargoes (Wet Gevaarlijke Stoffen) deals with the transportation of dangerous cargoes over land. The various rules are specified in the Rules of Transporting Dangerous Cargoes over Land (Reglement betreffende Vervoer over Land van Gevaarlijke stoffen). Most tunnels are built to two different categories:

- Category I : Tunnels suitable for transporting inflammable goods.
- Category II : Tunnels excluded of transporting inflammable goods.

A tunnel linking a harbour with the mainland should be built to Category 1 standards. Through a Category I tunnel all classes 2 to 9 goods may be transported. Class 1 goods are mainly munition and explosives for military use. Governmental regulation could ban such goods from a harbour situated on a island.
ENCLOSURE II COAL AND ORE TERMINALS

General
The capacity of the unloading equipment largely determines the throughput capacity of the terminal. The efficiency of equipment usage varies within time. Three levels of equipment utilisation are known [45]:

1. Peak capacity, also known as cream digging rate, is the maximum unloading rate under optimum circumstances: a full hold, an experienced crane operator, etc. This unloading rate is the design capacity of all down stream plant equipment to prevent blockages of cargo flows.

2. Rated capacity, also known as the free digging rate, is defined as the unloading rate under average conditions and established during a certain length of time.

3. Effective capacity is defined as the average hourly tonnage moved during unloading the entire cargo of the ship.

For a grab unloading system the three capacities relate to 2.5 : 2 : 1. A continuous unloading system has smaller differences and can maintain the rated capacity during almost the entire unloading time. An equipment designer is interested in the peak capacity, whereas the port planner’s interest is in the effective capacity.

Coal Terminals
Coal terminals include loading and unloading terminals. Loading is based on conveyor belts and cranes carrying the bridges with belts in booms. Unloading is mostly done by large clamshells. The clamshell at the EMO terminal in Rotterdam is capable of handling 85 tonnes of coal. This results into a maximum unloading capacity of 4200 tonnes per hour on coal. Modern continuous unloaders are being developed with higher production capacities [2].

The following table gives the loading or unloading capacities of some coal terminal around the world. The data is taken from [2].

<table>
<thead>
<tr>
<th>Coal Terminal</th>
<th>Unloading capacity [tph]</th>
<th>Loading capacity [tph]</th>
<th>Equipment type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Richards Bay, SA</td>
<td></td>
<td>10000</td>
<td>Chute</td>
</tr>
<tr>
<td>Hamburg, BRD</td>
<td>1100</td>
<td></td>
<td>Grab</td>
</tr>
<tr>
<td>Baltimore, USA</td>
<td></td>
<td>7000</td>
<td>Chute</td>
</tr>
<tr>
<td>Cora, USA</td>
<td></td>
<td>5700</td>
<td>Barge loader</td>
</tr>
<tr>
<td>Kooragang, Australia</td>
<td></td>
<td>10500</td>
<td>Ship loader</td>
</tr>
<tr>
<td>Kooragang, Australia</td>
<td>6600</td>
<td></td>
<td>Train unloader</td>
</tr>
<tr>
<td>Rotterdam, Netherlands</td>
<td>4200</td>
<td></td>
<td>Grab</td>
</tr>
<tr>
<td>Cont. unloader (1992)</td>
<td>5000</td>
<td></td>
<td>Continuous</td>
</tr>
</tbody>
</table>
Ore Terminals
There is a great similarity between coal and ore terminals. The loading and unloading processes at the quayside are equal. Due to the higher density of ore, higher hourly production rates can be achieved. These terminals are often large to maximize the benefits of ‘economics of scale’. Some examples of ore terminals are:

<table>
<thead>
<tr>
<th>Ore Terminal</th>
<th>Unloading capacity [tph]</th>
<th>Loading capacity [tph]</th>
<th>Equipment type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port Tubarao, Brazil</td>
<td></td>
<td></td>
<td>Ship loader</td>
</tr>
<tr>
<td>Nippon Steel, Japan</td>
<td>2500</td>
<td>16000</td>
<td>Grab</td>
</tr>
<tr>
<td>Narvik, Norway</td>
<td></td>
<td>11000</td>
<td>Ship loader</td>
</tr>
<tr>
<td>Conneaut, USA</td>
<td>10000</td>
<td></td>
<td>Five grabs</td>
</tr>
</tbody>
</table>

New developments
One of problems with the grab type unloader now in use is the improvement of efficiency. The grab type unloader is highly effective for unloading top cargo that can be easily reached by the grab bucket. As unloading proceeds, the remaining cargo becomes harder to reach. Unloading speeds drop. Because unloading by the grab-type bucket unloader is intermittent, its efficiency is not high. The grab-bucket unloader have reached their maximum economic size of about 85 tonnes.

To improve unloading capacities, continuous unloaders have been developed. By means of belts, buckets or rotating bucket wheels cargo is continuously retrieved from the hold and transferred to the stacking areas. The vertical and horizontal transport of cargo from the hold to the stack is fully enclosed and therefore less environmentally damaging. The free digging rates of the biggest unloaders is some 5000 tph (1992) [45].
ENCLOSURE III  ANNUAL NUMBER OF VESSELS

With aid of a spreadsheet program an estimate of the total number of vessels, calling at Changxing Island Harbour, is made. The first table gives the approximation for the year 2000, the second table for the year 2010. Both tables have eight columns:

**Column 1 ITEM**
Cargo commodity; coal, ore, containers and general cargo. These are the four products that will be handled by the terminals at Changxing Island Harbour.

**Column 2 IN/OUT**
The following columns deal with either incoming cargo or outgoing cargo. All the cargo will be transported by water. The terminals at Changxing act as a cargo transit hub for the hinterland up-stream along the Yangtze river.

**Column 3 THROUGHPUT**
Coal, ore and general cargo in million tonnes year. Containers in million TEU/year.

**Column 4 SHIP SIZE**
The size of the vessel in DWT. The outgoing vessels are smaller feeder vessels and barges. The container vessel size is expressed in TEU (Twenty feet Equivalent Unit).

**Column 5 SHARE**
The fraction of the total throughput, carried by vessel size in the previous column.

**Column 6 NUMBER OF SHIPS/YEAR**
Calculated by (THROUGHPUT times SHARE) divided by SHIP SIZE.

**Column 7 SHIPS/HOUR**
A year is represented by 365 days times 24 hours equals 8760 hours. The NUMBER OF SHIP/YEAR is divided by 8760 hours/year. This value is \( \lambda \) of the queuing theory.

**Column 8 HOUR/SHIP**
For the queuing theory is value in known as the inter arrival time of the vessels: \( \lambda^{-1} \). This is the times that passes between the arrival of two vessels.
### YEAR 2000

<table>
<thead>
<tr>
<th>ITEM</th>
<th>THROUGHPUT YEAR 2000</th>
<th>SHIP SIZE</th>
<th>SHARE</th>
<th>NUMBER OF ships/year</th>
<th>ship/hour</th>
<th>hour/ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>COAL</td>
<td>In</td>
<td>35000000</td>
<td>115000</td>
<td>.50</td>
<td>152</td>
<td>.017</td>
</tr>
<tr>
<td></td>
<td>Out</td>
<td>35000000</td>
<td>50000</td>
<td>.50</td>
<td>350</td>
<td>.040</td>
</tr>
<tr>
<td>ORE</td>
<td>In</td>
<td>80000000</td>
<td>115000</td>
<td>.50</td>
<td>35</td>
<td>.004</td>
</tr>
<tr>
<td></td>
<td>Out</td>
<td>80000000</td>
<td>50000</td>
<td>.50</td>
<td>80</td>
<td>.009</td>
</tr>
<tr>
<td>CONTAINERS</td>
<td>In</td>
<td>5000000</td>
<td>4000</td>
<td>1.00</td>
<td>125</td>
<td>.014</td>
</tr>
<tr>
<td></td>
<td>Out</td>
<td>5000000</td>
<td>800</td>
<td>1.00</td>
<td>625</td>
<td>.071</td>
</tr>
<tr>
<td>GENERAL</td>
<td>In</td>
<td>25000000</td>
<td>15000</td>
<td>1.00</td>
<td>167</td>
<td>.019</td>
</tr>
<tr>
<td>CARGO</td>
<td>Out</td>
<td>25000000</td>
<td>3000</td>
<td>1.00</td>
<td>833</td>
<td>.095</td>
</tr>
</tbody>
</table>

### YEAR 2010

<table>
<thead>
<tr>
<th>ITEM</th>
<th>THROUGHPUT YEAR 2010</th>
<th>SHIP SIZE</th>
<th>SHARE</th>
<th>NUMBER OF ships/year</th>
<th>ship/hour</th>
<th>hour/ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>COAL</td>
<td>In</td>
<td>63000000</td>
<td>115000</td>
<td>.50</td>
<td>274</td>
<td>.031</td>
</tr>
<tr>
<td></td>
<td>Out</td>
<td>63000000</td>
<td>50000</td>
<td>.50</td>
<td>630</td>
<td>.072</td>
</tr>
<tr>
<td>ORE</td>
<td>In</td>
<td>36000000</td>
<td>115000</td>
<td>.50</td>
<td>157</td>
<td>.018</td>
</tr>
<tr>
<td></td>
<td>Out</td>
<td>36000000</td>
<td>50000</td>
<td>.50</td>
<td>360</td>
<td>.041</td>
</tr>
<tr>
<td>CONTAINERS</td>
<td>In</td>
<td>2500000</td>
<td>4000</td>
<td>1.00</td>
<td>625</td>
<td>.071</td>
</tr>
<tr>
<td></td>
<td>Out</td>
<td>2500000</td>
<td>800</td>
<td>1.00</td>
<td>3125</td>
<td>.357</td>
</tr>
<tr>
<td>GENERAL</td>
<td>In</td>
<td>14000000</td>
<td>15000</td>
<td>1.00</td>
<td>933</td>
<td>.107</td>
</tr>
<tr>
<td>CARGO</td>
<td>Out</td>
<td>14000000</td>
<td>3000</td>
<td>1.00</td>
<td>4667</td>
<td>.533</td>
</tr>
</tbody>
</table>

Σ 3.628

The last two columns represent optimum value conditions with 100% utilization and full year working. These values give the most positive conditions, with the largest inter arrival times of the vessels. Later, within the engineering phase, these values must be refined. For now, they serve as a first global approximation.
ENCLOSURE IV  NUMBER OF VESSELS THROUGH ENTRANCE CHANNEL

The entrance channel to the Port of Shanghai will be used by various vessels in various sizes and cargo types. The entrance channel will also be used by vessels sailing up-stream the Yangtze river to ports such as: Zhangjiagang, Zhenjiang, Nanjing and Wuhan. The following spreadsheet gives an impression of the annual number of vessels sailing through the entrance channel. The annual throughput of a port is shipped by vessels of different sizes. Each vessel size represents a fraction of the total annual throughput volume. The number of vessels needed to transport that volume faction is given in the last coluim.

<table>
<thead>
<tr>
<th>YEAR 2000</th>
<th>THROUGHPUT</th>
<th>SHARE</th>
<th>SHIP SIZE</th>
<th>NUMBER OF SHIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mil. tonnes</td>
<td></td>
<td>dwt</td>
<td></td>
</tr>
<tr>
<td>Shanghai</td>
<td>2.6e8</td>
<td>.4</td>
<td>115000</td>
<td>904</td>
</tr>
<tr>
<td></td>
<td>.3</td>
<td>20000</td>
<td>3900</td>
<td></td>
</tr>
<tr>
<td></td>
<td>.2</td>
<td>10000</td>
<td>5200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>.1</td>
<td>5000</td>
<td>5200</td>
<td></td>
</tr>
<tr>
<td>Zhangjiagang</td>
<td>3e7</td>
<td>.2</td>
<td>20000</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>.5</td>
<td>10000</td>
<td>1500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>.3</td>
<td>5000</td>
<td>1800</td>
<td></td>
</tr>
<tr>
<td>Zhenjiang</td>
<td>3e7</td>
<td>.2</td>
<td>20000</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>.4</td>
<td>10000</td>
<td>1200</td>
<td></td>
</tr>
<tr>
<td></td>
<td>.4</td>
<td>5000</td>
<td>2400</td>
<td></td>
</tr>
<tr>
<td>Nanjing</td>
<td>5e7</td>
<td>.4</td>
<td>20000</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>.4</td>
<td>10000</td>
<td>2000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>.2</td>
<td>5000</td>
<td>2000</td>
<td></td>
</tr>
<tr>
<td>Wuhan</td>
<td>4e7</td>
<td>.6</td>
<td>5000</td>
<td>6800</td>
</tr>
<tr>
<td></td>
<td>.4</td>
<td>2000</td>
<td>8000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>TOTAL NUMBER OF SHIPS</td>
<td>40504</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### YEAR 2010

<table>
<thead>
<tr>
<th></th>
<th>THROUGHPUT (mil. tonnes)</th>
<th>SHARE</th>
<th>SHIP SIZE (dwt)</th>
<th>NUMBER OF SHIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shanghai</td>
<td>4.5e8</td>
<td>.4</td>
<td>115000</td>
<td>1565</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.2</td>
<td>50000</td>
<td>1800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.2</td>
<td>20000</td>
<td>4500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.1</td>
<td>10000</td>
<td>4500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.1</td>
<td>5000</td>
<td>9000</td>
</tr>
<tr>
<td>Zhangjiagang</td>
<td>5e7</td>
<td>.4</td>
<td>20000</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.4</td>
<td>10000</td>
<td>2000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.2</td>
<td>5000</td>
<td>2000</td>
</tr>
<tr>
<td>Zhenjiang</td>
<td>5e7</td>
<td>.4</td>
<td>20000</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.4</td>
<td>10000</td>
<td>2000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.2</td>
<td>5000</td>
<td>2000</td>
</tr>
<tr>
<td>Nanjing</td>
<td>9e7</td>
<td>.5</td>
<td>20000</td>
<td>2250</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.4</td>
<td>10000</td>
<td>3600</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.1</td>
<td>5000</td>
<td>1800</td>
</tr>
<tr>
<td>Wuhan</td>
<td>7e7</td>
<td>.7</td>
<td>5000</td>
<td>9800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.3</td>
<td>2000</td>
<td>10500</td>
</tr>
<tr>
<td><strong>TOTAL NUMBER OF SHIPS</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>59315</strong></td>
</tr>
</tbody>
</table>

By the year 2000 some 40000 vessels will use the entrance channel to the Yangtze river. This number of vessels increases to some 60000 by the year 2010. As the entrance channel gets deeper, the cargo volume fraction transported by larger vessels, increases.

By the determination of the total number of ships for the year 2000 and 2010 it is assumed that the average ship size will increase. The increase depth of the entrance channel allows greater ships to call at Shanghai. Currently the total throughput of Shanghai is achieved by many, small ships. If future ship size increase does not occur then the total number of ships will become in the order of 50000 and 70000 ships for the year 2000 and 2010 respectively.
ENCLOSURE V ENTRANCE CHANNEL DREDGING SIMULATION MODEL

This enclose contains the graphs of the annual distribution of boundary conditions and listings of the Prosim entrance channel dredging simulation model. Next to the listings additional information is given about each module or macro. The reader should bear in mind that Prosim is a process orientated language and therefore the program structure is different then that of Pascal, C or C++.

[Graphs of Cumulative annual typhoon and gale distributions]
The figure next pages shows how the modules and macro's of the program relate to each other. MAINMOD is the central body of each Prosim program. This module activates three other modules:

TIDEGEN
This module creates the tidal water level movement for each section used in the model.

PROJECTMANAGER
This is the central module during the dredging process. The project manager select available dredgers and send these dredgers to available sections.

GENERATORS
Within this module all the limiting and boundary conditions of the model are generated and assigned to the various queues, lists and sets. Days are created that typhoons, gales, fogs and waves occur.

The actual dredging of the entrance channel starts when the PROJECTMANAGER is activated. The project stops when the desired depth of the channel is reached. This module, in turn, activates three other modules:

BOUNDARY
This module activates the boundary conditions that effect the dredging process. The time record is also kept in this module. If a current simulation day number equals the day number of a bad when occurrence, then a signal is send to the dredger. This is indicated by the dashed line between this module and the module DREDGING.

DREDGING
The actual dredging process is described in this module.

SHIPGENERATOR
This module generates ships sailing to and from Shanghai. Trailing suction hopper dredger operations are normally not effected by commercial shipping. This model allows shipping to hinder dredging operations. For the better part of the simulation runs the SHIPGENERATOR was not activated. SHIP1 are ships sailing to Shanghai, SHIP2 are ships sailing from Shanghai.
Figure 47 The modules and macro's of the program
Model DEFINE

This part of the entrance channel dredging simulation model contains the definition of all the model components. The most important components and classes of components are:

Generator
The component generates the bad weather and bad waves conditions which effect dredging operations. This module uses the class of components such as typhoons, gales, fogs, waves and sediments.

Manager
The module represents the project manager of the dredging works. He keeps record of the total quantity of material that is removed. The project manager also selects section of the dredgers to work in and assigns the dredgers to the sections. When the remaining material quantity becomes zero, the project managers tell the dredgers to stop and the project is finished.

Badweather
This module is, together the generator mentioned earlier, responsible for creating the restricting weather conditions.

Job
This class of component is used to store project data while the dredging process is ongoing.

Typhoon, gale, fog, sediment and wave
These are all data class components.

Section
This class of component is a data component. For each section the remaining dredging volumes are stored and modified when a dredger has been active in a section.

Dredger
This is the most important active class of components in the model. The dredgers are eventually doing the hard work! Dredgers are activated by the project manager.

Dumpsite
This is where the dredgers dispose their load. Dumpsites are data class components.

Level
Water level height are calculated to determine the maximum allowable loaded draft of a dredger. Levels are data class components.
MODEL SHANGHAI
MOD DEFINE

1 COMPONENT : generator manager badweather
2
3 CLASS : typhoon gale fog wave sediment tide
4 : section dredger dumpsite job ship1 ship2
5 : level
6
7 ATTRIBUTES OF generator :
10 : ASx[I] ASy[I] annualsiltation cum_sed_fration
11 : weeklyshare cum_channel_depth avg_channel_depth
12 : fogday
13 INTEGER : total typhoons newtyphoon typhoon day
14 : total gales newgale galeday
15 : totalfogs newfog
totalsediments newsediment sediment week
16 : total_s_waves total_m_waves total_l_waves
17 : newwave waveday
18 : sday ntp nsp nsp nsp nmp nds nsp list length
19 : direction
20 CHARACTER(6) : nextwavename
21 : reference TO section : currentsection
22 : reference TO fog : currentfog
23 : reference TO gale : currentgale
24 : reference TO SET : badweatherlist badwaveslist
25
26 ATTRIBUTES OF manager :
27 REAL : total project quantity
28 LOGICAL : ship_down sed_ready
29 : reference TO section : man_section
30 : reference TO dredger : man_dredger
31 : reference TO dumpsite : man_dumpsite
32 : reference TO job : man_job
33 : reference TO level : man_level
34
35 ATTRIBUTES OF badweather :
36 INTEGER : nexttyphoon day nextgaleday nextfogday sed
37 : nextwave day nextbadweather day nextbad wave day
38 LOGICAL : weather down large_wave down medium_wave down
39 : small_wave down
40 CHARACTER(6) : dredger down
41 : reference TO sediment : bad_sediment
42 : reference TO section : bad_section
43 : reference TO dredger : bad_dredger
44
45 ATTRIBUTES OF job :
46 INTEGER : job dredger number job section number
47 REAL : job number job dredged quant
48 : reference TO dredger : job dredger
49 : reference TO section : job section
50 : reference TO dumpsite : job dump
51 LOGICAL : job ready
52
53 ATTRIBUTES OF typhoon :
54 REAL : typhoon day
55
56 ATTRIBUTES OF gale :
57 REAL : gale day
58
59 ATTRIBUTES OF fog :
60 REAL : fog day
61
62 ATTRIBUTES OF sediment :
63 REAL : sediment fraction
64
65 ATTRIBUTES OF wave :
66 REAL : wave day
67 CHARACTER(5) : wavename
68
69 ATTRIBUTES OF section :
70 INTEGER : section number
71 CHARACTER(1) : section name
72 REAL : section length
73 : section init depth
74 : section current depth
75 : section maint vol
76 : section cap vol
77 : section bulk fac maint
78 : section bulk fac cap
79 LOGICAL : section free section ready
80 : reference TO dredger : section dredger
81
82
83 ATTRIBUTES OF dredger :
84 CONTINUOUS(1) : actual_production
85 INTEGER : dredgernumber
86 dredgerjobnumber
87 dredgingsection
88 CHARACTER(9) : dredgername dredgertype dredgerclass
89 REAL : dredgercapacity
90 dredgermaxcapacity
91 dredgerproduction
92 dredger_current_load
93 dredger_current_draft
94 dredger_draft_loaded
95 dredger_draft_empty
96 dredger_speed_loaded
97 dredger_speed_empty
98 dredger_weekly_costs
99 dredger_sailing_time
100 dredger_sailsec_time
101 LOGICAL : dredger_active dredger_ready
102 REFERENCE TO section : dredger_section
103 REFERENCE TO job : dredger_job
104 REFERENCE TO dumpsite : dredger_dump
105 REFERENCE TO level : dredger_level
106
107 ATTRIBUTES OF dumpsite :
108 INTEGER : dumpnumber
109 REAL : dumpcapacity
110 dump_current_load
111 dump_bulking_fac
112 dump_sailing_distance
113 REFERENCE TO dredger : dump_dredger
114
115 ATTRIBUTES OF level :
116 INTEGER : levelsection
117 REAL : levelheight
118
119 TABLE(4) : typhoonable galetable fogtable sedimenttable
120 wavetable
121 TABLE(5) : siltationtable
122
123 QUEUE : typhoonlist galelist foglist sedimentlist
124 s_wavelist m_wavelist l_wavelist joblist
125 dumpsite_list shipsection(7) sectionedown(7)
126 shiplist ship2list levelist
127 ATTRIBUTES OF MAINTENANCE :
128 INTEGER : g j k n m f totsections totdredgers
129 n_small_dredgers n_medium_dredgers
130 n_large_dredgers special
131 simhour simday simweek simmonth simyear
132 TPCURVE TCURVES
133 REAL : daynumber i total_costs waterlevel starttime
134 T1 T2 S_CU DT DT_LAST A B T_AF_LW R_CU
135 T_T_AF N H1 H2 WMT(7,26) WST(7,26) LEVTIME
136 LEBAR(7) DEPTH(7) ETD draftreduction
137 TIDESEC(7) total Moved
138 REFERENCE TO SET : sectionlist freesectionlist activesections
139 REFERENCE TO SET : dredgerlist freedredgerlist activedredgers
140 LOGICAL : project_ready year_ready tides_check animation
141 fish
142
143 RANDOMSTREAM : r_typh r_gale r_fog S_wave M_wave L_wave sample
144 interval
145 INPUTSTREAM : limits sections dredgers tidefile
146 TIMEUNIT : hours
147 FIGURE : ftidesection(7) fdepthsection(7) fvdump(2)
148 ftotquant ftotcosts fday fyear fquant fjoke
149 fstatus(4)
150
Module MAINMOD

This is the central module of a Prosim program, where each simulation starts.

Lines  Events
1 - 8   The random number of typhoons, gales, fog, small -, medium - and large wave occurrences are reshaped to normal distributions. For instance, annual typhoon occurrences are normally distributed with a mean of two occurrence each year and a deviation of one typhoon per year.

10 - 11 The macro’s Initialize and Readtides are called to read all the boundary conditions parameters from file. The parameters involve the annual distributions of typhoons, gales, fog, waves and siltation. The macro Readtides reads the tidal data from file. This data is used to generate tidal water level differences.

13 - 15 A special dredger assignment means that the project manager sends the smallest dredgers to the shallowest sections. So these dredgers have the smallest loading reductions factors when they have to work during low water conditions. The normal dredger assignment works at a First In First Out (FIFO) basis.

17   The generation of bad weather and wave conditions is started.

18   The generation of tidal water level movements is started.

20 - 23 The Project manager is activated. The MAINMOD module waits until the project manager signals the dredging project is finished. If the project is ready all ongoing processes are cancelled and the program in terminated.

23 - 28 Start of the dredging simulation program.
MODEL SHANGHAI
MOD MAINMOD

1 RESHAPE r_typh AS SAMPLED FROM DISTRIBUTION NORMAL WITH PARAMETERS MEAN(2) DEVIATION(1)
2 RESHAPE r_geal AS SAMPLED FROM DISTRIBUTION NORMAL WITH PARAMETERS MEAN(26) DEVIATION(2)
3 RESHAPE r_fog AS SAMPLED FROM DISTRIBUTION NORMAL WITH PARAMETERS MEAN(43) DEVIATION(2)
4 RESHAPE s_wave AS SAMPLED FROM DISTRIBUTION NORMAL WITH PARAMETERS MEAN(35) DEVIATION(1)
5 RESHAPE M_wave AS SAMPLED FROM DISTRIBUTION NORMAL WITH PARAMETERS MEAN(15) DEVIATION(1)
6 RESHAPE L_wave AS SAMPLED FROM DISTRIBUTION NORMAL WITH PARAMETERS MEAN(22) DEVIATION(1)
7 SPECIFY actual_production PRECEPT(actual_production' < dredgerproduction)
8 RESHAPE interval AS SAMPLED FROM DISTRIBUTION NORMAL WITH PARAMETERS MEAN(16) DEVIATION(2)

10 CALL initialize @ Read all project data from files
11 CALL readtides @ Read tidal data
12
13 $WRITE " Normal (0) or special (1) dredger assignment " WITH IMAGE a
14 $special < CHREAD
15 special < 0 @ Random dredger to section alloc.
16 start:
17 ACTIVATE generator FROM start IN generators
18 ACTIVATE tidegen FROM start IN tidegenerator IF tidegen IS NOT ACTIVE
19 CANCEL manager IF manager IS ACTIVE
20 ACTIVATE manager FROM start IN projectmanager
21 $tides_check < FALSE
22
23 WAIT WHILE (project_ready = FALSE) @ Start the dredging project
24 IF project_ready = TRUE
25 $ WRITE "baggerwerk afgelopen..." WITH IMAGE a
26 CANCEL ALL @ Project is ready
27 TERMINATE @ End of program
29
30

185
Module GENERATORS

Within this module all the limiting and boundary conditions of the model are generated and assigned to the various queues, lists and sets.

Lines   Events

23 - 29   The generation of typhoons. A random number is generated. This number is called sample. The typhoon table represents the cumulative annual distribution of typhoon occurrences over a single year. Via the typhoon table this sample is linked to a specific daynumber. This daynumber is the day in a single year that a typhoon occurs, for instance day 172. The generated typhoon is joined to the typhoon list, which holds all the day numbers of typhoon occurrences.

32 - 45   The generation of days with a gale is similar to the generation of typhoons. The gales are joined to a single gale list. This list is sorted by daynumber.

48 - 61   The creation of days with fog.

65 - 115  The creation of annual siltation quantities. The annual distribution of sediment is read from a table. The annual siltation quantity is distributed over 52 weeks. But not every week delivers the same fraction of the annual siltation quantity. During the summer months, with high river discharges, the sediment flow is greater than during the winter months. Therefore, each weekly sediment fraction is converted to subscribe the annual distribution. The parameter annualsiltation is the total annual siltation quantity in cubic metres. This value is distributed over the 52 weeks.

117 - 166 The creation of waves which cause the dredging operations temporarily to be suspended. The model can deal with the three sizes of dredgers: small-, medium and large dredgers. Each dredger class has its own limiting maximum wave height. Therefore also three waves classes are generated. Large waves cause all dredgers to stop working. Medium waves immobilizes the medium and small dredgers. Small dredgers also have to stop working when small waves enter the dredging area. Small waves do not affect the medium and large size dredgers. All the generated waves are sorted by daynumber and joined to a single list: badwaveslist.
MODEL SHANGHAI
MOD GENERATORS

@ Module Generators
@ Within this module all the limiting and boundary conditions of the model
@ are generated and assigned to the various queues and lists.

@ start:
@ Generating boundary conditions
@ Typhoons, gales, fogs, sediments and
@ small-, medium- and large waves

@ badweatherlist < NEW SET CALLED "badweatherlist"
@ badwaveslist < NEW SET CALLED "badwaveslist"

@ SEED OF r_typ < 3856593 * sample @ New seed for creating typhoons
@ SEED OF r_fog < 3139947 * sample @ New seed for creating fogs
@ SEED OF r_gale < 8233526 * sample @ New seed for creating gales
@ BSEED OF S_wave < 9369235 * sample @ New seed for creating small waves
@ BSEED OF M_wave < 3431475 * sample @ New seed for creating medium waves
@ BSEED OF L_wave < 3234585 * sample @ New seed for creating large waves

@ Generating days with typhoons
@ Total number of annual typhoons
@ FOR i < 1 TO totaltyphoons
  @ THIS typhoon < NEW typhoon
  @ typhoonday < VALUE OF typhoonable AT(sample)
  @ Intercept from table
  @ typhoon_day < CEIL(typhoonday)
  @ Assign day number
  @ JOIN THIS typhoon TO typhoonlist RANKED BY typhoonday @ Sort by daynumber
@ END

@ Generating days with gales
@ Total number of annual gales
@ FOR i < 1 TO totalgales
  @ THIS gale < NEW gale
  @ galeday < VALUE OF galetable AT(sample)
  @ Intercept from table
  @ gale_day < CEIL(gale/day)
  @ Assign day number
  @ JOIN THIS gale TO galelist RANKED BY galeday
  @ Sort by daynumber
@ END

@ Storing gales by day
@ THIS gale < FIRST gale IN galelist
@ FOR i < 1 TO listlength
  @ galeday < @ gale_day OF THIS gale
  @ STORE (i/listlength) VERSUS galeday AS "gales"
@ END

@ THIS gale < SUCC OF THIS gale IN galelist

@ Generating days with fog
@ Total number of annual fogdays
@ FOR i < 1 TO totalfogs
  @ THIS fog < NEW fog
  @ fogday < VALUE OF fogtable AT(sample)
  @ Intercept from table
  @ fog_day < CEIL(fogday)
  @ Assign day number
  @ JOIN THIS fog TO foglist RANKED BY fogday
  @ Sort by daynumber
@ END

@ Storing fogs by day
@ THIS fog < FIRST fog IN foglist
@ FOR i < 1 TO listlength
  @ fogday < @ fog_day OF THIS fog
  @ STORE (i/listlength) VERSUS fogday AS "fogs"
@ END

@ THIS fog < SUCC OF THIS fog IN foglist

@ Generating weeks with siltation
@ Sediment fraction is the weekly
@ FOR i < 1 TO CEIL(Sx[2]/7)
  @ Sediment fraction < NEW sediment
  @ fraction on the total annual
@ END

@ Sediment fraction < Sy[2]/CEIL(Sx[2]/7)
@ JOIN THIS sediment TO sedimentlist @ The first (Sx[2]/7) weeks

@ FOR i < 1 TO CEIL(Sx[3]/7) @ The next few weeks
  @ Sediment fraction < (Sy[3]-Sy[2])/CEIL((Sx[3]-Sx[2])/7))
  @ JOIN THIS sediment TO sedimentlist @ The next few weeks
@ END

@ Generating weeks with siltation
@ FOR i < 1 TO CEIL(Sx[3]/7) @ The last few weeks
  @ Sediment fraction < NEW sediment
  @ sediment fraction < (1-Sy[3]/52-CEIL(Sx[3]/7))
  @ JOIN THIS sediment TO sedimentlist @ The next few weeks
@ END

@ Storing siltation by week
@ THIS sediment < FIRST sediment IN sedimentlist

81 listlength < LENGTH OF sedimentlist
82 THIS sediment < FIRST sediment IN sedimentlist
83 cum_sed_fraction < 0  @ Making a graph of the cumulative
84 FOR i < 1 TO listlength  @ distribution of weekly(1) sed.
85 cum_sed_fraction = cum_sed_fraction + sediment_fraction OF THIS sediment
86 STORE cum_sed_fraction VERSUS i AS "siltation"  @ Week number is (1)
87 THIS sediment < SUCCEEDS THIS sediment IN sedimentlist
88 END
89
90 @ Generating annual siltation quantities based on the average present channel
91 @ depth. The siltation quantity is drawn from the siltation table.
92 @
93 cum_channel_depth < 0  @ Cumulative depth of all sections
94 avg_channel_depth < 0  @ Average depth of the sections
95 THIS section < FIRST section IN sectionlist
96 FOR i < 1 TO LENGTH OF sectionlist
97 currentsection < THIS section
98 cum_channel_depth = cum_channel_depth + section_current_depth OF currentsection
99 THIS section < SUCCEEDS THIS section IN sectionlist
100 END
101 avg_channel_depth = cum_channel_depth/LENGTH OF sectionlist
102 annualsiltation = VALUE OF siltationtable AT(avg_channel_depth)
103 @DISPLAY "AVG. CHANNEL DEPTH, beginning of the year:"; avg_channel_depth AT LINE 11 POSITION
20 COLOUR 14 ON 1 WITH IMAGE a***.**
104
105 @ Generating weekly siltation quantities by combining the total annual
106 @ siltation quantity (annualsiltation) and the list with the weekly sediment
107 @ fractions of the total siltation quantity (sedimentlist).
108 @
109 THIS sediment < FIRST sediment IN sedimentlist  @ List with weekly fractions
110 FOR i < 1 TO 52  @ Annual number of weeks
111 sediment_fraction = sediment_fraction * annualsiltation
112 THIS sediment < SUCCEEDS THIS sediment IN sedimentlist
113 END
114 @
115 @ The sediment fraction now contains the weekly siltation quantity in m3
116
117 @ Generating waves effecting small-size dredgers
118
119 total_s_waves < CEIL(S_wave)  @ Annual number of waves
120 FOR i < 1 TO total_s_waves
121 THIS wave < NEW wave  @ Generate new wave
122 wave_day < VALUE OF wavetable AT(sample)  @ Interpolate from table
123 wave_day < CEIL(wave_day)  @ Assign day number
124 JOIN THIS wave TO S_wavelist RANKED BY wave_day
125 END
126 listlength < LENGTH OF S_wavelist  @ Storing small waves
127 THIS wave < FIRST wave IN S_wavelist
128 FOR i < 1 TO listlength
129 wave_day < wave_day OF THIS wave
130 STORE (i/listlength) VERSUS wave_day AS "S_waves"
131 THIS wave < SUCCEEDS THIS wave IN S_wavelist
132 END
133
134 @ Generating waves effecting medium-size dredgers
135
136 total_m_waves < CEIL(M_wave)  @ Annual number of waves
137 FOR i < 1 TO total_m_waves
138 THIS wave < NEW wave  @ Generate new wave
139 wave_day < VALUE OF wavetable AT(sample)  @ Interpolate from table
140 wave_day < CEIL(wave_day)  @ Assign day number
141 JOIN THIS wave TO M_wavelist RANKED BY wave_day
142 END
143 listlength < LENGTH OF M_wavelist  @ Storing medium waves
144 THIS wave < FIRST wave IN M_wavelist
145 FOR i < 1 TO listlength
146 wave_day < wave_day OF THIS wave
147 STORE (i/listlength) VERSUS wave_day AS "M_waves"
148 THIS wave < SUCCEEDS THIS wave IN M_wavelist
149 END
150
151 @ Generating waves effecting large dredgers
152
153 total_L_waves < CEIL(L_wave)  @ Annual number of waves
154 FOR i < 1 TO total_L_waves
155 THIS wave < NEW wave  @ Generate new wave
156 wave_day < VALUE OF wavetable AT(sample)  @ Interpolate from table
157 wave_day < CEIL(wave_day)  @ Assign day number
158 JOIN THIS wave TO L_wavelist RANKED BY wave_day
159 END
160 listlength < LENGTH OF L_wavelist  @ Storing large waves
161 THIS wave < FIRST wave IN L_wavelist
162 FOR i < 1 TO listlength
163 wave_day < wave_day OF THIS wave
164 STORE (i/listlength) VERSUS wave_day AS "L_waves"
165 THIS wave < SUCCEEDS THIS wave IN L_wavelist
166 END
A compiling a single bad weather list called 'badweatherlist'

A
170 THIS typhoon < FIRST OF typhoonlist
171 THIS gale < FIRST OF galelist
172 THIS fog < FIRST OF foglist
173 AFOR i < 1 TO LENGTH OF galelist
174 A daynumber < gale_day OF THIS gale
175 A JOIN THIS gale TO badweatherlist RANKED BY daynumber
176 A THIS gale < SUCC OF THIS gale IN galelist
177 END
178 AFORE i < 1 TO LENGTH OF typhoonlist
179 A daynumber < typhoon_day OF THIS typhoon
180 A JOIN THIS typhoon TO badweatherlist RANKED BY daynumber
181 A THIS typhoon < SUCC OF THIS typhoon IN typhoonlist
182 END
183 AFORE i < 1 TO LENGTH OF foglist
184 A daynumber < fog_day OF THIS fog
185 A JOIN THIS fog TO badweatherlist RANKED BY daynumber
186 A THIS fog < SUCC OF THIS fog IN foglist
187 END

A compiling a single bad waves list called 'badwaveslist'

A
191 THIS wave < FIRST wave IN S_wavelist
192 FOR i < 1 TO LENGTH OF S_wavelist
193 daynumber < wave_day
194 wavename OF THIS wave < "S-wave"
195 JOIN THIS wave TO badwaveslist RANKED BY daynumber
196 THIS wave < SUCC OF THIS wave IN S_wavelist
197 END
198 THIS wave < FIRST wave IN M_wavelist
199 FOR i < 1 TO LENGTH OF M_wavelist
200 daynumber < wave_day
201 wavename OF THIS wave < "M-wave"
202 JOIN THIS wave TO badwaveslist RANKED BY daynumber
203 THIS wave < SUCC OF THIS wave IN M_wavelist
204 END
205 THIS wave < FIRST wave IN L_wavelist
206 FOR i < 1 TO LENGTH OF L_wavelist
207 daynumber < wave_day
208 wavename OF THIS wave < "L-wave"
209 JOIN THIS wave TO badwaveslist RANKED BY daynumber
210 THIS wave < SUCC OF THIS wave IN L_wavelist
211 END
212 i<0
213 PASSIVATE
Macro INITIALIZE

This macro reads all the data, needed to generate typhoons, gales, fogs, waves and siltation, from file. The data file is called Limits. Another file, called Sections, contains all the information related to the sections of the entrance channel. The file Dredgers has the total number of dredgers and characteristics of the dredgers used during simulation.
MODEL SHANGHAI
MAC INITIALIZE

1 © Macro Dataread with reads all generator data from file ©
2
3 ntp < READ FROM limits © Reading annual typhoon distribution
4 Tx[1] < 0
5 Ty[1] < 0
6 Tx[2] < READ FROM limits
7 Tx[3] < READ FROM limits
8 Tx[4] < READ FROM limits
9 Ty[2] < READ FROM limits
10 Ty[3] < READ FROM limits
11 Ty[4] < READ FROM limits
12 FOR i < 1 TO ntp+1
13 TABULATE Tx[i] IN typhoon table AT Ty[i]
14 END
15
16 ngp < READ FROM limits © Reading annual gale distribution
17 Gx[1] < 0
18 Gy[1] < 0
19 Gx[2] < READ FROM limits
20 Gx[3] < READ FROM limits
21 Gx[4] < READ FROM limits
22 Gy[2] < READ FROM limits
23 Gy[3] < READ FROM limits
24 Gy[4] < READ FROM limits
25 FOR i < 1 TO ngp+1
26 TABULATE Gx[i] IN gale table AT Gy[i]
27 END
28
29 nfp < READ FROM limits © Reading annual fog distribution
30 Fx[1] < 0
31 Fy[1] < 0
32 Fx[2] < READ FROM limits
33 Fx[3] < READ FROM limits
34 Fx[4] < READ FROM limits
35 Fy[2] < READ FROM limits
36 Fy[3] < READ FROM limits
37 Fy[4] < READ FROM limits
38 FOR i < 1 TO nfp+1
39 TABULATE Fx[i] IN fog table AT Fy[i]
40 END
41
42 nsp < READ FROM limits © Reading annual sediment distribution
43 Sx[1] < 0
44 Sy[1] < 0
45 Sx[2] < READ FROM limits
46 Sx[3] < READ FROM limits
47 Sx[4] < READ FROM limits
48 Sy[2] < READ FROM limits
49 Sy[3] < READ FROM limits
50 Sy[4] < READ FROM limits
51 FOR i < 1 TO nsp+1
52 TABULATE Sx[i] IN sediment table AT Sy[i]
53 END
54
55 nsv < READ FROM limits © Reading annual siltation quantities
56 FOR i < 1 TO nsv
57 ASx[i] < READ FROM limits © Annual siltation quantities versus
58 ASy[i] < READ FROM limits © average channel depth
59 TABULATE ASx[i] IN siltation table AT ASy[i]
60 END
61
62 nwp < READ FROM limits © Reading annual wave distribution
63 Wx[1] < 0
64 Wy[1] < 0
65 Wx[2] < READ FROM limits
66 Wx[3] < READ FROM limits
67 Wy[2] < READ FROM limits
68 Wy[3] < READ FROM limits
69 FOR i < 1 TO nwp+1
70 TABULATE Wx[i] IN wave table AT Wy[i]
71 END
72
73 nds < READ FROM limits © Reading dumpsite data
74 FOR i < 1 TO nds
75 THIS dumpsite < NEW dumpsite
76 dumpnumber < READ FROM limits
77 dumpcapacity < READ FROM limits
78 dump_current_load < 0
79 dump_bulking_fac < READ FROM limits
80 dump_sailing_distance < READ FROM limits
81 JOIN THIS dumpsite TO dumpsitelist RANKED BY dumpnumber
82 END
@ Reading section characteristics from file sections
@ freeesessionlist < NEW SET CALLED "freeesessions"
sectionlist < NEW SET CALLED "sectionlist"
FOR i < 1 TO 7
THIS section < NEW section
sectionname < CHREAD FROM sections
sectionnumber < READ FROM sections
section_maint_vol < READ FROM sections
section_cap_vol < READ FROM sections
section_init_depth < READ FROM sections
section_current_depth < section_init_depth
section_length < READ FROM sections
section_bulk_fac_maint < READ FROM sections
section_bulk_fac_cap < READ FROM sections
total_project_quantity < total_project_quantity + section_maint_vol + section_cap_vol
JOIN THIS section TO sectionlist
JOIN THIS section TO freeesessionlist
END
totsections < LENGTH OF sectionlist
@ Reading dredger characteristics
freedredgerlist < NEW SET CALLED "freedredgers"
dredgerlist < NEW SET CALLED "dredgerlist"
_n_small_dredgers < READ FROM dredgers
_n_medium_dredgers < READ FROM dredgers
_n_large_dredgers < READ FROM dredgers
totdredgers < n_small_dredgers+n_medium_dredgers+n_large_dredgers
FOR i < 1 TO totdredgers
THIS dredger < NEW dredger
dredgernumber < i
dredgername < CHREAD FROM dredgers
dredgerclass < CHREAD FROM dredgers
dredgercapacity < READ FROM dredgers
dredgerproduction < READ FROM dredgers
dredger_current_load < READ FROM dredgers
dredger_draft_loaded < READ FROM dredgers
dredger_draft_empty < READ FROM dredgers
dredger_speed_empty < READ FROM dredgers
dredger_speed_loaded < READ FROM dredgers
dredger_weekly_costs < READ FROM dredgers
JOIN THIS dredger TO dredgerlist
JOIN THIS dredger TO freedredgerlist
END

activedredgers < NEW SET CALLED "activedredgers"
activesections < NEW SET CALLED "activesections"
project_ready < FALSE
ship_down < FALSE
sed_ready < TRUE
year_ready < TRUE
tides_check < TRUE
animation < TRUE
fish < TRUE
sunday < 0
simyear < 0
@ At project start:
@ No shipping
@ No siltation
@ No year change
@ Check water levels
@ Store animation data
@ First day
@ First year
MODEL SHANGHAI
MOD PROJECTMANAGER

1 @ Module Projectmanager
2 @
3 @ This module co-ordinates all the dredging activities. The project manager
4 @ is the central controlling 'person' within the entrance channel dredging
5 @ simulation model.
6 @
7 start:
8 project_ready < FALSE
9 REMOVE EACH dredger IN activedredgers FROM activedredgers IF activedredgers IS NOT EMPTY
10 REMOVE EACH section IN activesections FROM activesections IF activesections IS NOT EMPTY
11
12 start1:
13 CANCEL badweather IF badweather IS ACTIVE
14 ACTIVATE badweather FROM start IN boundary
15 deactivate shipgen FROM start IN shipgenerator
16 WAIT UNTIL (freedredgerlist IS NOT EMPTY) & (freesectionlist IS NOT EMPTY)
17
18 start2:
19 WHILE (project_ready = FALSE)
20 WAIT UNTIL (freedredgerlist IS NOT EMPTY) & (freesectionlist IS NOT EMPTY) & (sed_ready =
21 TRUE) & (year_ready = TRUE)
22
23 IF ship1list IS NOT EMPTY
24 ACTIVATE EACH ship1 IN ship1list FROM start IN shipping1
25 BEND
26 IF ship2list IS NOT EMPTY
27 ACTIVATE EACH ship2 IN ship2list FROM start IN shipping2
28 BEND
29
30 i < i+1
31 CALL dredgerassign @ Assigns a dredger to a section
32
33 THIS job < NEW job
34 dredger < THIS dredger @ The current dredger
35 dredger_section < THIS section @ The current section
36 dredger_job < THIS job @ The current job
37 jobnumber < i @ Updating job data
38 jobsectionnumber < sectionnumber
39 dredgerjobnumber < jobnumber
40 dredger_active < TRUE @ Updating dredger data
41 dredgingsection < sectionnumber
42 dredgerjobnumber < i
43 dredgernaxcapacity < dredgercapacity
44 sectionfree < FALSE @ Updating section data
45
46 JOIN THIS dredger TO activedredgers
47 JOIN THIS section TO activesections
48 REMOVE THIS section FROM freesectionlist
49 REMOVE THIS dredger FROM freedredgerlist
50 ACTIVATE THIS dredger FROM startdredge IN dredging
51 END
52
53 finish:
54 WAIT UNTIL activedredgers IS EMPTY @ Wait for the remaining dredgers
55 WAIT UNTIL activesections IS EMPTY @ and sections to finish
56
Module PROJECTMANAGER

This is module is the central part of the entrance channel dredging simulation model. The project manager sends dredger to sections where they have to dredge. When the desired depth of 12.50 metres below Chart Datum is reached and all the material is removed from the sections, the project manager changes the parameter project_ready to project_ready = TRUE. This indicates the dredging work is finished.

Lines   Events
14      The badweather process is activated. The process keep track of the current day number of the simulation. When the current day number equals a day number of the typhoonlist, galelist, foglist, badwaveslist, then the dredging operations are temporarily suspended.
15      The simulation model can also account for disturbances to the dredging process inflicted by commercial shipping. The @ sign indicates the shipping generator is currently not active. Trailing suction hopper dredgers are not to much disturbed by other vessels.
16      The project manager has to wait until a dredger comes available and a section is available for the dredger to work in.
22 - 27 The commercial vessels a sailing though the channel. Currently this procedure is not active, indicated by the @ signs.
30      This macro assign a dredger to a section.
50      The dredger is activated and commences dredging operations
53 -55 The project is finished because the desired depth has been achieved. The program waits until the last active dredgers have returned from the dump site.
Module BOUNDARY

This module activates the boundary conditions that affect the dredging process. The time record is also kept in this module. Simday is the day number of the simulation. When simday equals the day number of a bad weather condition or a bad wave condition the simulation is halted.

<table>
<thead>
<tr>
<th>Lines</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 - 31</td>
<td>Initializing the bad weather process. The first day numbers of typhoon, gale, fog and wave occurrences are read from the corresponding lists.</td>
</tr>
<tr>
<td>34</td>
<td>Procedure Badweathers is the starting point of checking bad weather and bad waves days.</td>
</tr>
<tr>
<td>51 - 56</td>
<td>If a week passes some weekly updates are preformed. The total project costs, siltation quantity and the average channel depth are calculated once a week.</td>
</tr>
<tr>
<td>65 - 70</td>
<td>If one year is passed the dredging process in halted to generate new boundary conditions for the next year.</td>
</tr>
<tr>
<td>73</td>
<td>At this line the first day of bad weather condition is selected.</td>
</tr>
<tr>
<td>83 - 92</td>
<td>If the next day of a bad weather of wave condition is smaller than the current day number, then the current day is a good day for dredging operations. One day is waited, before the simday is raised with another day. The procedure is repeated from line 34.</td>
</tr>
<tr>
<td>95 - 148</td>
<td>This routine starts when the simday number equals the day number of a bad weather occurrence. The status of the logical parameter weather_down is changed to weather_down = TRUE. Changing this parameter will hold dredging operations. The next step in this routine is checking the kind of bad weather. Also is checked if the next bad weather day occurs at the same simulation day. This routine is repeated until the next bad weather day does not equal the current day number.</td>
</tr>
<tr>
<td>150 - 197</td>
<td>This routine checks the day number of a bad wave occurrence. Allowance is made for the occurrence of several wave conditions at the same day. For instance, if at a single day first small waves occur and later large waves, then the large waves condition is representative for this day. Large waves will effect all dredgers in the model.</td>
</tr>
</tbody>
</table>
200 - 213 When a bad weather situation occurs all vessels will have to wait for 12 hours before the can resume dredging operations.

216 - 225 A bad wave condition will effect the dredgers involved for 8 hours. Large wave conditions will effect all dredgers, medium waves will effect the medium and small size dredgers and small waves will only prevent small size dredgers from working.

227 - 230 This routine is a safety net in case the previous two routines have been missed. This hardly ever occurs.
Module Boundary

This module activates the boundary conditions to the dredging process.

g: Initialize bad weather process

g: 

start:

simday < 0  # First simulation day
weather_down < FALSE  # All dredgers can work
large_wave_down < FALSE  # No restricting waves
medium_wave_down < FALSE
small_wave_down < FALSE
sed_ready < TRUE
year_ready < TRUE

start:

THIS typhoon < FIRST typhoon IN typhoonlist IF typhoonlist IS NOT EMPTY
nexttyphoonday < typhoon_day OF THIS typhoon
REMOVE THIS typhoon FROM typhoonlist IF typhoonlist IS NOT EMPTY
THIS gale < FIRST gale IN galelist IF galelist IS NOT EMPTY
nextgaleday < gale_day OF THIS gale
REMOVE THIS gale FROM galelist IF galelist IS NOT EMPTY
THIS fog < FIRST fog IN foglist IF foglist IS NOT EMPTY
nextfogday < fog_day OF THIS fog
REMOVE THIS fog FROM foglist IF foglist IS NOT EMPTY
THIS wave < FIRST wave IN badwaveslist IF badwaveslist IS NOT EMPTY
nextbadweatherday < wave_day OF THIS wave
REMOVE THIS wave FROM badwaveslist IF badwaveslist IS NOT EMPTY

badweathers:  # Start of generating bad weathers

WAIT UNTIL (sed_ready = TRUE) & (year_ready = TRUE)
MOVE fday TO VALUE simday IF animation = TRUE

IF project_ready = TRUE  # Stop if project is finished
PASSIVATE
GOTO finish IN projectmanager
END
DISPLAY "DAY: ";simday AT LINE 9 POSITION 20 COLOUR 14 ON 1 WITH IMAGE a:****** IF animation = FALSE

nexttyphoonday < 10000 IF typhoonlist IS EMPTY
nextgaleday < 10000 IF galelist IS EMPTY
nextfogday < 10000 IF foglist IS EMPTY
nextbadweatherday < 10000 IF badwaveslist IS EMPTY

IF (simday MODULO(7) = 0)
sed_ready < FALSE  # Distributing weekly
WAIT UNTIL activedredgers IS EMPTY
WAIT UNTIL activesections IS EMPTY
CALL newweek  # siltation
END

IF (simday = 106) & (fish = TRUE)  # A small joke during simulation
ACTIVATE fgen FROM start IN SGEN IF animation = TRUE
fish < FALSE

WAIT UNTIL sed_ready = TRUE  # Wait until week process is finished
IF (simday = 365)
year_ready < FALSE  # A new starts
CANCEL ships IF shipgen IS ACTIVE
CANCEL tidegen IF tidegen IS ACTIVE
GOTO start IN newyear
END

WAIT UNTIL sed_ready = TRUE  # Wait until week process is finished
IF (simday = 365)
year_ready < FALSE  # A new starts
CANCEL ships IF shipgen IS ACTIVE
CANCEL tidegen IF tidegen IS ACTIVE
GOTO start IN newyear
END

start2:  # Select first badweather
nextbadweatherday < MIN(nexttyphoonday, nextgaleday, nextfogday)

IF animation = FALSE
DISPLAY "next down day:";MIN(nextbadweatherday, nextbadweatherday, nextbadweatherday) AT LINE 9 POSITION 50 COLOUR 14 ON 1 WITH IMAGE a:****
DISPLAY "next typhoon ";nexttyphoonday AT LINE 5 POSITION 50 COLOUR 14 ON 1 WITH IMAGE a:**
***
DISPLAY "next gale ";nextgaleday AT LINE 6 POSITION 50 COLOUR 14 ON 1 WITH IMAGE a:***
***
DISPLAY "next fog ";nextfogday AT LINE 7 POSITION 50 COLOUR 14 ON 1 WITH IMAGE a:***
DISPLAY "next wave ":";nextbadweaveday AT LINE 8 POSITION 50 COLOUR 14 ON 1 WITH IMAGE a
1сте
80 END
81
82 a====================g
83 @ No badweather
84 a====================g
85
86 IF (MIN(nextbadweatherday, nextbadweaveday) > simday)
87   @WRITE "simday, nbad, nwd, typhoon, gale, fog ";simday; nextbadweatherday;nextbadweaveday;
88     nexttyphoonday;nextgaleday;nextfogday WITH IMAGE A:=============:
89     anotherday:
90     WAIT 1 DAY @ No badweather or waves
91     simday < simday + 1 @ Increase daynumber
92     REPEAT FROM badweathers
93 END
94 a====================g
95 @ Checking weather
96 a====================g
97
98 IF (nextbadweatherday = simday) @ Bad weather occurs
99     weather_down < TRUE @ Cancel dredging
100   @WRITE "weather_down < true at simday = ";simday WITH IMAGE A:==
101   @WRITE "simday, nbad, typhoon, gale, fog ";simday; nextbadweatherday; nexttyphoonday;next
galeday;nextfogday WITH IMAGE A:=============:
102 END
103
104 IF (nextbadweatherday = nexttyphoonday) @ A typhoon occurs
105     starttyphoon:
106     MOVE fstatus[1] TO 1 IF animation = TRUE
107     nexttyphoonday < 10000 IF typhoonlist IS EMPTY
108     IF typhoonlist IS NOT EMPTY @ Select a new typhoon
109         THIS typhoon < FIRST typhoon IN typhoonlist
110         nexttyphoonday < typhoon_day OF THIS typhoon
111         WHILE (nexttyphoonday = simday) @ Select a new typhoon if
112         REMOVE THIS typhoon FROM typhoonlist
113         REPEAT FROM starttyphoon @ two typhoons at the same
day occur
114     END
115     REMOVE THIS typhoon FROM typhoonlist
116 END
117 END
118
119 IF (nextbadweatherday = nextgaleday) @ A gale occurs
120     startgale:
121     MOVE fstatus[2] TO 1 IF animation = TRUE
122     nextgaleday < 10000 IF galelist IS EMPTY
123     IF galelist IS NOT EMPTY @ Select a new gale
124         THIS gale < FIRST gale IN galelist
125         nextgaleday < gale_day OF THIS gale
126         WHILE (nextgaleday = simday) @ Select a new fog if two
127         REMOVE THIS gale FROM galelist
128         REPEAT FROM startgale @ fogs at the same day occur
129     END
130     REMOVE THIS gale FROM galelist
131 END
132 END
133
134 IF (nextbadweatherday = nextfogday) @ A fog occurs
135     startfog:
136     MOVE fstatus[3] TO 1 IF animation = TRUE
137     nextfogday < 10000 IF foglist IS EMPTY
138     IF foglist IS NOT EMPTY @ Select a new fog
139         THIS fog < FIRST fog IN foglist
140         nextfogday < fog_day OF THIS fog
141         WHILE (nextfogday = simday) @ Select a new fog if two
142         REMOVE THIS fog FROM foglist
143         REPEAT FROM startfog
144     END
145     REMOVE THIS fog FROM foglist
146 END
147 END
148 END @ End of badweathers proced.
149
150 a====================g
151 @ Checking waves
152 a====================g
153
154 IF (simday = nextbadweaveday) @ Checking waves
155 startwave:
156     MOVE fstatus[4] TO 1 IF animation = TRUE
157     @WRITE "Waves down at "; simday WITH IMAGE a:==
158     IF (nextwavename != "Lwave") @ Checking large waves
159     large_wave_down < TRUE
WRITE "large waves" WITH IMAGE a

END

IF (nextwavename = "Mwave")  
  medium_wave_down < TRUE
  WRITE "medium waves" WITH IMAGE a
END

IF (nextwavename = "Swave")  
  small_wave_down < TRUE
  WRITE "small waves" WITH IMAGE a
END

startnewave:
  NO more waves
nextbadwaveday < 10000 IF badwaveslist IS EMPTY
  Select a new wave
  THIS wave < FIRST wave IN badwaveslist
  nextbadwaveday < wave_day OF THIS wave
  nextwavename < wavename OF THIS wave
  REMOVE THIS WAVE FROM badwaveslist IF badwaveslist IS NOT EMPTY
  IF (nextbadwaveday = simday )
    WRITE "**** WITH IMAGE a
    IF (nextwavename = "Mwave")
      large_wave_down < TRUE
      WRITE "large waves 2" WITH IMAGE a
    END
    IF (nextwavename = "Mwave")
      medium_wave_down < TRUE
      WRITE "medium waves 2" WITH IMAGE a
    END
    IF (nextwavename = "Swave")
      small_wave_down < TRUE
      WRITE "small waves 2" WITH IMAGE a
    END
    REPEAT FROM startnewave
  END
END

IF (weather_down = TRUE)  
  BAD weather
  WAIT 12 HOURS  
  weather_down < FALSE  
  bad weather pass
  large Wave_down < FALSE  
  bad waves pass
  medium_wave_down < FALSE
  small_wave_down < FALSE
  MOVE flavstatus[2] TO SINK  
  REMOVE typhoon FROM SINK
  MOVE flavstatus[3] TO SINK  
  REMOVE gale FROM SINK
  MOVE flavstatus[4] TO SINK  
  REMOVE fog FROM SINK
  MOVE flavstatus[4] TO SINK  
  REMOVE waves FROM SINK
  WAIT 12 HOURS  
  WAIT the remaining day
  simday < simday + 1  
  GOOD weather now
  REPEAT FROM badweathers
END

IF ((large_wave_down = TRUE) OR (medium_wave_down = TRUE) OR (small_wave_down = TRUE))  
  BAD wave conditions
  WAIT 8 HOURS  
  BAD weather pass
  large Wave_down < FALSE  
  BAD waves pass
  medium_wave_down < FALSE
  small_wave_down < FALSE
  weather_down < FALSE
  MOVE flavstatus[4] TO SINK  
  REMOVE waves FROM SINK
  move 14 HOURS  
  WAIT the remaining day
  simday < simday + 1  
  BEFORE increasing simday
  REPEAT FROM badweathers
END

IF (MIN(nextbadweatherday, nextbadwaveday) < simday)
  nextbadweatherday < nextbadweatherday + 1
GOTO start!  
  Emergency procedure in 
  case a day is missed

END
Module SHIPPING1

The module represents the process of a ship sailing to Shanghai. The ship starts at the beginning of the entrance channel in section number seven. Firstly the ship sails for ten minutes. Then, if it encounters a dredger, the parameter ship_down is changed to ship_down = TRUE. This means dredging operation are down due to a commercial ship close to the dredger. Ten minutes later, the ship has passed the dredger and ship_down is made false. Line 20 assures that no other vessels effecting the dredger. It is very well possible that two commercial vessels, both from opposite directions, effect dredging operations for maximum twenty minutes. This procedure is repeated until the ship has sailed to all of the seven section of the entrance channel to Shanghai.

Module SHIPPING2

This module is similar to SHIPPING1, but describes the process of a ship sailing from Shanghai to the open sea.

Module SHIPGENERATOR

The commercial vessels also using the entrance channel to Shanghai are generated in this module. Only large bulk carriers will effect dredging operations in the channel. There vessels are generated with interval hours. Interval is the inter arrival time of large bulk carriers, taken at an average of 16 hours between to vessels with a deviation of 2 hours. This equals some 548 large bulk carriers per year. Each bulk carrier has a direction, where direction 1 means sailing to Shanghai and direction 2 sailing from Shanghai.
MODEL SHANGHAI  
MOD SHIPPING1

1 @ Module Shipping1
2 @
3 @
4 @ This model creates large bulk carriers which effect dredging operations
5 @ when passing.
6 @
7 start: @ Ship sailing to Shanghai
8 m < 7
9 WAIT UNTIL shiplist IS NOT EMPTY
10 WHILE project_ready = FALSE
11   THIS ship1 < FIRST ship1 IN shiplist
12   REMOVE THIS ship1 FROM shiplist
13   WHILE m ≠ 0
14     ENTER shiplist(m)
15     WORK 10 MINUTES @ Sailing into section
16     ENTER sectiondown(m)
17     shiplist_down = TRUE @ No dredging in section
18     WORK 10 MINUTES @ Dredging is possible
19     LEAVE sectiondown(m)
20     WAIT UNTIL sectiondown(m) IS EMPTY @ Other vessels ?
21     ship_down = FALSE @ Sailing out of section
22     WORK 10 MINUTES
23     LEAVE shiplist(m)
24     m = m - 1
25 END
26 WAIT UNTIL shiplist IS NOT EMPTY
27 END

MODEL SHANGHAI  
MOD SHIPPING2

1 @ Module Shipping2
2 @
3 @
4 @ This model creates large bulk carriers which effect dredging operations
5 @ when passing. Vessels sailing to sea from Shanghai.
6 @
7 @
8 start: @ Ships sailing to sea
9 WAIT UNTIL ship2list IS NOT EMPTY
10 WHILE project_ready = FALSE
11   THIS ship2 < FIRST ship2 IN ship2list
12   REMOVE THIS ship2 FROM ship2list
13   FOR g < 1 TO 7
14     ENTER shiplist(g)
15     WORK 10 MINUTES @ Sailing into section
16     ENTER sectiondown(g)
17     shiplist_down = TRUE @ No dredging in section
18     WORK 10 MINUTES @ Dredging is possible
19     LEAVE sectiondown(g)
20     WAIT UNTIL sectiondown(g) IS EMPTY @ Other vessels ?
21     ship_down = FALSE @ Sailing out of section
22     WORK 10 MINUTES
23     LEAVE shiplist(g)
24 END
25 WAIT UNTIL ship2list IS NOT EMPTY
26 END
27

MODEL SHANGHAI  
MOD SHIPGENERATOR

1 @ Module Shipgenerator
2 @
3 @
4 @ This module generates ships sailing to and from Shanghai
5 @
6 start:
7 WHILE project_ready = FALSE @ Inter arrival time of ships
8   WAIT interval HOURS @ 1=Shanghai, 2=Sea
9   direction = CEIL(sample*2) @ Sailing to Shanghai
10   IF direction ≤ 1
11     THIS ship1 < NEW ship1
12     JOIN THIS ship1 TO shiplist
13 END
14 IF direction > 1 @ Sailing from Shanghai
15   THIS ship2 < NEW ship2
16   JOIN THIS ship2 TO ship2list
17 END
18 END

Date: 97/03/17  
Time: 10:36:34

Module DREDGING

This module describes the process of a single dredger. The model can deal with three kinds of dredgers: small -, medium - and large dredgers. Each dredger responds differently to limiting boundary conditions, such as wave heights. The small size dredgers have a maximum capacity of 5000 m³, the medium size dredgers of 8500 m³ and the large dredgers can carry 15000 m³.

Lines       Events

10 - 20      Before the dredgers can start, they have to wait until any current bad weather situation passes.

22           If the dredgers already carry 85% of the maximum load, they are sent to the dump site.

23           The macro Tidecheck calculates the maximum load a dredger can carry due to the available water depth at the time the dredger is finished with dredging. For each section between the working section of the dredger and the sea the maximum allowable draft of the dredger is calculated. This results into a maximum loading capacity of the dredger. This parameter is called the dredgermaxcapacity.

28 - 58      The dredger starts the maintenance dredging, if more than a 1000 m³ of in situ material is present within the section. The dredgerclass indicates the type of dredger; small (S), medium (M) or large (L). The dredging itself is represented by the integrate statement in lines 31, 39 or 47, depending on the dredger size. The integration is stopped when the dredger is full or a limiting boundary condition occurs. If the dredger is loaded less than 90% of its maximum capacity the dredging operation is repeated from the beginning.

63           If a section has less then 1000 m³ of maintenance dredging material then the dredger starts with capital dredging. This means the depth of a section increases. The dredging routine for capital dredging is equal to that of maintenance dredging.

98-121       When the dredger is ready dredging it will proceed to the dumping area. The model knows two dumpsites at different sailing distances from the end of the channel.
124 - 128 This routine calculates the sailing time of a dredger to and from a dumpsite. An empty dredger sails faster than a loaded dredger. The dredger characteristics are read from the file *dredgers* in macro *Initialize*.

130 - 184 The procedure keeps record of all the changes in section volume due to dredging operations. From lines 160 to 165 all the attributes of the dredger which executed the dredging operation are reset to their original values. Lines 167 to 182 check if a section needs be dredged any further. If a section contains less than 1000 m$^3$ of maintenance or capital dredging material, the section is removed from the list. with sections that needs to be dredged.
MODEL SHANGHAI
MOD DREDGING

1: Module dredging
2: Simulates the dredging of the channel sections
3:
4:*************************************************************************************************************************************************
5: startdredge: @ Start dredging process
6:*************************************************************************************************************************************************
7: IF dredgerclass = "GN"
8: WAIT UNTIL (weather_down = FALSE) & (ship_down = FALSE) & (large_wave_down = FALSE) & (medium_wave_down = FALSE) & (small_wave_down = FALSE)
9: END
10: IF dredgerclass = "MN"
11: WAIT UNTIL (weather_down = FALSE) & (ship_down = FALSE) & (large_wave_down = FALSE) & (medium_wave_down = FALSE)
12: END
13: IF dredgerclass = "LN"
14: WAIT UNTIL (weather_down = FALSE) & (ship_down = FALSE) & (large_wave_down = FALSE)
15: END
16: GOTO dumping IF (dredger_current_load > 0.85*dredgermaxcapacity)
17: CALL tidecheck IF (tides_check = TRUE)
18: start_maintenance_dredging: @ Start with maintenance dredging
19: @ if any material is present
20: IF (section_maint_vol OF dredger_section) > 1000
21: IF dredgerclass = "LN"
22: INTEGRATE UNTIL ((actual_production*section_bulk_fac_maint OF dredger_section) > dredgermaxcapacity) | (weather_down = TRUE) | (large_wave_down = TRUE) | (ship_down = TRUE) WITH ACCURACY 4
23: dredger_current_load < actual_production * section_bulk_fac_maint OF dredger_section
24: IF dredger_current_load < dredgermaxcapacity*0.90
25: REPEAT FROM startdredge
26: END
27: IF dredgerclass = "MN"
28: INTEGRATE UNTIL ((actual_production*section_bulk_fac_maint OF dredger_section) > dredgermaxcapacity) | (weather_down = TRUE) | (large_wave_down = TRUE) | (medium_wave_down = TRUE) | (ship_down = TRUE) WITH ACCURACY 4
29: dredger_current_load < actual_production * section_bulk_fac_maint OF dredger_section
30: IF dredger_current_load < dredgermaxcapacity*0.90
31: REPEAT FROM startdredge
32: END
33: IF dredgerclass = "GN"
34: INTEGRATE UNTIL ((actual_production*section_bulk_fac_maint OF dredger_section) > dredgermaxcapacity) | (weather_down = TRUE) | (large_wave_down = TRUE) | (medium_wave_down = TRUE) | (small_wave_down = TRUE) | (ship_down = TRUE) WITH ACCURACY 4
35: dredger_current_load < actual_production * section_bulk_fac_maint OF dredger_section
36: IF dredger_current_load < dredgermaxcapacity*0.90
37: REPEAT FROM startdredge
38: END
39: END
40: END
41: IF dredgerclass = "LN"
42: INTEGRATE UNTIL ((actual_production*section_bulk_fac_maint OF dredger_section) > dredgermaxcapacity) | (weather_down = TRUE) | (large_wave_down = TRUE) | (medium_wave_down = TRUE) | (small_wave_down = TRUE) | (ship_down = TRUE) WITH ACCURACY 4
43: dredger_current_load < actual_production * section_bulk_fac_maint OF dredger_section
44: IF dredger_current_load < dredgermaxcapacity*0.90
45: REPEAT FROM startdredge
46: END
47: END
48: END
49: END
50: dredger_active < FALSE @ Dredger is ready
51: dredger_type < "main" @ Hopper is loaded with maint.
52: dredger_current_draft < dredger_draft_empty*(((dredger_draft_loaded-dredger_draft_empty)/dredger_capacity) * dredger_current_load
53: GOTO dumping @ Sailing and dumping time
54: END
55: start_capital_dredging: @ Start with capital dredging
56: IF (section_cap_vol OF dredger_section) > 1000
57: IF dredgerclass = "LN"
58: INTEGRATE UNTIL ((actual_production*section_bulk_fac_cap OF dredger_section) > dredgermaxcapacity) | (weather_down = TRUE) | (large_wave_down = TRUE) | (ship_down = TRUE) WITH ACCURACY 4
59: dredger_current_load < actual_production * section_bulk_fac_cap OF dredger_section
60: IF dredger_current_load < dredgermaxcapacity * 0.90
61: REPEAT FROM startdredge
62: END
63: END
64: END
65: END
66: END
67: END
68: END
69: END
70: END
71: END
IF dredgerclass = "W"

INTEGRATE UNTIL ((actual_production*section_bulk_fac_cap OF dredger_section) > dredge
maxcapcity) | (weather_down = TRUE) | (large_wave_down = TRUE) | (medium_wave_down = TRUE) |
(ship_down = TRUE) WITH ACCURACY 4

IF dredger_current_load < actual_production * section_bulk_fac_cap OF dredger_section

REPEAT FROM startdredge

END

IF dredgerclass = "S"

INTEGRATE UNTIL ((actual_production*section_bulk_fac_cap OF dredger_section) > dredge
maxcapcity) | (weather_down = TRUE) | (large_wave_down = TRUE) | (medium_wave_down = TRUE) |
(small_wave_down = TRUE) | (ship_down = TRUE) WITH ACCURACY 4

IF dredger_current_load < actual_production * section_bulk_fac_cap OF dredger_section

REPEAT FROM startdredge

END

dredger_active < FALSE  // Dredger is ready

dredgertype < "capital"  // Dredger did capital dredging

dredger_current_draft < dredger_draft_empty>((dredger_draft_loaded-dredger_draft_empty)/dredgercapacity)*dredger_current_load

GOTO dumping  // Sailing and dumping time

END  // End of dredging routine

REPEAT FROM startdredge  // Repeat dredging procedure

dumping:  // This is the dumping procedure

GOTO firstdumper  // Fill the first dumping site

THIS dumper site < FIRST dumper site IN dumper site list

dredger.dumper < THIS dumper site

IF (dump_current_load OF dredger_dumper + actual_production) < dumpcapacity OF dredger_dumper

MOVE fvdump[1] TO dump_current_load OF dredger_dumper IF animation = TRUE

WAIT 0.1 HOUR

GOTO sailing

END

THIS dumper site < SUCC OF THIS dumper site IN dumper site list

dredger.dumper < THIS dumper site

IF (dump_current_load OF dredger_dumper + actual_production) < dumpcapacity OF dredger_dumper

MOVE fvdump[2] TO dump_current_load OF dredger_dumper IF animation = TRUE

WAIT 0.1 HOUR

GOTO sailing

END

SAVE "Dumping sites are almost full. Create new dumping sites." WITH IMAGE a

dump_current_load OF dredger_dumper < dump_current_load OF dredger_dumper + actual_production * dump_bulkfac OF dredger_dumper

MOVE fvdump[2] TO dump_current_load OF dredger_dumper

sailing:  // Sailing to and from dumper site

GOTO firstdumper  // Fill the first dumping site

dredger.sailing_time < ((totsections - dredging section) * 10 + (dump_sailing_distance OF dredger_ 
dump/1000) */ (1/dredger.speed_loaded) + (1/dredger.speed_empty))

WAIT (dredger.sailing_time) HOURS  // Wait dredger sailing time

boarding:  // Bookkeeping of section changes

IF dredgertype = "maint"  // In case of maintenance dredging

jobdredgedequant OF dredger_job < actual_production

section_current_depth OF dredger_section < section_current_depth OF dredger_section + (12 
.50 - section_current_depth OF dredger_section)*((actual_production)/(section_maint_vol OF dredger_ 
section + section_cap_vol OF dredger_section))

section_maint_vol OF dredger_section < section_maint_vol OF dredger_section - actual_produ 
ction  // Updating section maint volume

section_depth[section_number OF dredger_section] < (section_current_depth OF dredger_ 
section * 10)

MOVE fdepthsection[section_number OF dredger_section] TO (13-section_current_depth OF dredger_ 
section) IF animation = TRUE

END

IF dredgertype = "capital"
jobdredgerquant OF dredger_job < actual_production
144  section_current_depth OF dredger_section < section_current_depth OF dredger_section + (12 .5) * section_current_depth OF dredger_section)"/(section_maint_vol OF dredger_section + section_cap_vol OF dredger_section))
145  section_cap_vol OF dredger_section < section_cap_vol OF dredger_section - actual_production
146  depth[section_number OF dredger_section] < (section_current_depth OF dredger_section * 10)
147  MOVE fdepthsection[section_number OF dredger_section] TO (13-section_current_depth OF dredger_section) IF animation = TRUE
148 END
149
150  a Final bookkeeping of dredged quantities
151 a
152  total_project_quantity < total_project_quantity - actual_production
153  STORE total_project_quantity AS "dredging"
154  totalMoved < total Moved + actual_production
155  STORE totalMoved AS "totalmoved"
156  MOVE ftotalquant TO total_project_quantity IF animation = TRUE
157  MOVE fquant TO VALUE total_project_quantity IF animation = TRUE
158  DISPLAY "REMAINING VOLUME: ";total_project_quantity AT LINE 5 POSITION 20 COLOUR 14 ON 1 WITH IMAGE a********
159
160  actual_production < 0  a Resetting dredger production
161  dredger_current_load < 0  a Resetting dredger's load
162  dredger_sailing_time < 0  a Resetting dredger's capacity
163  dredger_maxcapacity < dredger_capacity  a Resetting dredger's capacity
164  dredger_current_draft < dredger_draft_empty
165  dredger_active < FALSE
166
167  IF (section_maint_vol OF dredger_section > 1000) || (section_cap_vol OF dredger_section > 1000)
168    REMOVE dredger_section FROM active_sections  a Section is removed from
169    JOIN dredger_section TO freesectionlist  a Section isn't empty
170    LEAVE activatedredgers  a Dredger no longer active
171    ENTER free dredgerlist
172    PASSIVATE
173 END
174
175  IF (section_maint_vol OF dredger_section < 1000) && (section_cap_vol OF dredger_section < 1000)
176    REMOVE dredger_section FROM active_sections  a Dredger is ready
177    LEAVE activatedredgers  a Dredger no longer available new job
178    ENTER freedredgerlist
179    IF (freesectionlist IS EMPTY) && (total_project_quantity < 1000)
180    WRITE "project klaar" WITH IMAGE a
181    project_ready < TRUE
182  END
183  PASSIVATE
184  END
185  PASSIVATE
186
Macro NEWWEEK

This macro takes care of all the project parameter needing a weekly update. This include the weekly siltation quantity, the project costs and the average channel depth.

Macro NEWYEAR

After one year of simulating, new boundary conditions have to be generated. This macro causes dredging operation to be halted. Line 13 - 23 make sure all old boundary conditions are removed before new one's are created. The simulation year number, simyear, is raised with one and the simulation starts again from module MAINMOD where the boundary condition generator is activated again.

Macro DREDGERASSIGN

This macro is called from the module PROJECTMANAGER. He assigns a dredger to a section. Normally this is done on a First In First Out (FIFO) bases. In case of a special dredger assignment scenario (special = 1), the smallest available dredger is allocated at the shallowest available section. So this dredger, having the smallest draft, will be less restricted by low water tidal levels.
MODEL SHANGHAI
MOD NEWYEAR

1 @ Module Newyear
2 @
3 @
4 @ This module resets old boundary conditions and creates new one's
5 @ when a one year passes
6 7 start:
8 DISPLAY "$YEAR: ";simyear+1 AT LINE 7 POSITION 20 COLOUR 14 ON 1 WITH IMAGE a:****** IF animation = FALSE
9 10 WAIT UNTIL activedredgers IS EMPTY
11 WAIT UNTIL activesections IS EMPTY
12 13 REMOVE EACH typhoon IN typhoonlist IF typhoonlist IS NOT EMPTY
14 REMOVE EACH gale IN galelist IF galelist IS NOT EMPTY
15 REMOVE EACH fog IN foglist IF foglist IS NOT EMPTY
16 REMOVE EACH sediment IN sedimentlist IF sedimentlist IS NOT EMPTY
17 REMOVE EACH wave IN badwaveslist WITH wavename="Swave" FROM badwaveslist IF badwaveslist IS NOT EMPTY
18 REMOVE EACH wave IN badwaveslist WITH wavename="Mwave" FROM badwaveslist IF badwaveslist IS NOT EMPTY
19 REMOVE EACH wave IN badwaveslist WITH wavename="Lwave" FROM badwaveslist IF badwaveslist IS NOT EMPTY
20 REMOVE EACH wave IN S_wavelist FROM S_wavelist IF S_wavelist IS NOT EMPTY
21 REMOVE EACH wave IN M_wavelist FROM M_wavelist IF M_wavelist IS NOT EMPTY
22 REMOVE EACH wave IN L_wavelist FROM L_wavelist IF L_wavelist IS NOT EMPTY
23 CANCEL manager
24 simyear < simyear + 1
25 MOVE fyear TO VALUE simyear IF animation = TRUE
26 simday < 0
27 GOTO start IN MAINMOD
28

MODEL SHANGHAI
MAC DREDGERASSIGN

1 @ Macro Dredger assign
2 @
3 @ This macro assigns the dredger to the most suitable section
4 5
6 IF special = 0 @ FIFO assignment
7 THIS dredger < FIRST dredger IN freedredgerlist
8 THIS section < FIRST section IN freesessionlist
9 END
10 11 IF special = 1 @ Small dredger to shallow sections
12 THIS dredger < FIRST dredger IN freedredgerlist
13 IF (dredgerclass ="S")
14 THIS section < FIRST section IN freesessionlist WITH SMALLEST section_current_depth
15 END
16 IF (dredgerclass ="M")
17 THIS section < FIRST section IN freesessionlist WITH SMALLEST section_current_depth
18 END
19 IF (dredgerclass ="L") @ Large dredgers to deeper sections
20 THIS section < FIRST section IN freesessionlist WITH GREATEST section_current_depth
21 END
22 END
23 24
25
MODEL SHANGHAI
MAC NEWWEEK

1 @ Macro Newweek
2 @
3 @ This module generates the weekly siltation for each channel section
4 @ and also calculates the total project costs (weekly update).
5 @ This module is also used for updating weekly values, e.g. costs
6 @ Current is badweather
7
8
9 @***************************
10 @ Siltation
11 @***************************
12
13 start:
14 IF sedimentlist IS NOT EMPTY
15    THIS_sediment < FIRST_sediment IN sedimentlist
16    bad_sediment < THIS_sediment
17    REMOVE EACH section IN freesectionlist FROM freesectionlist
18    THIS_section < FIRST_section IN sectionlist
19    bad_section < THIS_section
20    total_project_quantity < total_project_quantity + sedimentfraction OF bad_sediment
        @ Total project quantity increases
21    FOR sed < 1 TO totsections
22        section_current_depth OF bad_section < section_current_depth OF bad_section - (12.50
        - section_current_depth OF bad_section)*(sedimentfraction OF Bad_sediment/totsections)/(sect
        ion_cap_vol OF bad_section+section Maint_vol OF bad_section))
        @ Section on depth reduces
23        section Maint_vol OF bad_section < section Maint_vol OF bad_section + (sedimentfracti
        on OF bad_sediment/totsections)
        @ Assigning siltation quant.
24    END
25    JOIN bad_section TO freesectionlist
26    THIS_section < SUCC OF THIS_section IN sectionlist
27    bad_section < THIS_section
28    END
29    REMOVE bad_sediment FROM sedimentlist
30    END
31
32
33 @***************************
34 @ Project costs
35 @***************************
36 @***************************
37 IF (n_small_dredgers < 0)
38    THIS_dredger < FIRST_dredger IN dredgerlist WITH dredgerclass = "S"
39    bad_dredger < THIS_dredger
40    total_costs < total_costs + n_small_dredgers * dredger_weekly_costs OF bad_dredger
41    END
42
43 IF (n_medium_dredgers < 0)
44    THIS_dredger < FIRST_dredger IN dredgerlist WITH dredgerclass = "M"
45    bad_dredger < THIS_dredger
46    total_costs < total_costs + n_medium_dredgers * dredger_weekly_costs OF bad_dredger
47    END
48
49 IF (n_large_dredgers < 0)
50    THIS_dredger < FIRST_dredger IN dredgerlist WITH dredgerclass = "L"
51    bad_dredger < THIS_dredger
52    total_costs < total_costs + n_large_dredgers * dredger_weekly_costs OF bad_dredger
53    END
54
55 DISPLAY "TOTAL COSTS: "; total_costs AT LINE 3 POSITION 20 COLOUR 14 ON 1 WITH IMAGE a:*****
      ***
56 MOVE tfootcosts TO VALUE total_costs IF animation = TRUE
57
58 @***************************
59 @ Average channel depth
60 @***************************
61 THIS_section < FIRST_section IN sectionlist WITH SMALLEST section_current_depth
62 bad_section < THIS_section
63 DISPLAY "Depth of shallowest section: ";section_current_depth OF bad_section AT LINE 12 POSI
       TION 20 COLOUR 14 ON 1 WITH IMAGE a:***.
64
65 IF tides_check = TRUE
66    THIS_dredger < FIRST_dredger IN dredgerlist WITH GREATEST dredger_draft_loaded
67    bad_dredger < THIS_dredger
68    IF section_current_depth OF bad_section > dredger_draft Loaded OF bad_dredger
69       WRITE "tide check passivated" WITH IMAGE a
70       tides_check < FALSE
71       @ All sections have sufficient
72       @ depth
73    END
74
75 sed Ready < TRUE
76        @ Siltation process is ready
Macro READTIDES

All the relevant tidal data is read from the file Tidefile. Each section of the channel has its own tidal curve. The entrance channel to Shanghai is 70 kilometres long. When at the sea side of the channel the maximum high water level is reached, this same level will occur at the Shanghai side of the channel some 1 hour and 45 minutes later. This phase difference must be accounted for in the dredging simulation model.

Macro TIDES

This macro calculates the tidal water level height at a given time. The levtime is the actual time for which the water level height is calculated.
MODEL SHANGHAI
MAC READTIDES

1 @ Marco Readtides
2 @
3 @
4 @ This macro reads tidal information
5
6 totsections < READ FROM tidefile
7 FOR j < 1 TO totsections
8   depth[j] < READ FROM tidefile
9 END
10
11 T1 < READ FROM tidefile
12 T2 < READ FROM tidefile
13 S_CU < READ FROM tidefile
14 DT < READ FROM tidefile
15 DT_LAST < READ FROM tidefile
16 TPCURVE < READ FROM tidefile
17 TCURVE < READ FROM tidefile
18
19 FOR j < 1 TO TOTSECTIONS
20 FOR k < 1 TO TPCURVE
21    WNT[j,k] < READ FROM tidefile
22 END
23
24 WST[j,k] < READ FROM tidefile
25 END
26
27
28
29

MODEL SHANGHAI
MAC TIDES

1 @ Marco Tides
2 @
3 @
4 @ Computes tidal water levels
5
6 starttide:
7 A < (LEVTIME) - T1*FLOOR((LEVTIME)/T1)
8 B < FLOOR(A/T2)
9 T_AF_LW < A - B*T2
10 R_CU < B + S_CU
11 R_CU < R_CU - TCURVES IF R_CU > TCURVES-1
12 T < FLOOR(T_AF_LW/DT)
13 T_AF_N < T_AF_LW - T*DT
14 H1 < WNT[k,T+1] + (WST[k,T+1] - WNT[k,T+1])/2
15 H1 < H1 + (WST[k,T+1] - WNT[k,T+1])*ACOS(-1)*R_CU/TCURVES)/2
16 H2 < WNT[k,T+2] + (WST[k,T+2] - WNT[k,T+2])/2
17 H2 < H2 + (WST[k,T+2] - WNT[k,T+2])*ACOS(-1)*R_CU/TCURVES)/2
18 IF T=TPCURVE-2
19 LEVBAR[k] < DEPTH[k] +H1*(T_AF_N/DT_LAST)*(H2-H1)
20 TIDESEC[k] < (H1*(T_AF_N/DT_LAST)*(H2-H1))/10
21 END
22
23 IF X=TPCURVE-2
24 LEVBAR[k] < DEPTH[k] +H1*(T_AF_N/DT)*(H2-H1)
25 TIDESEC[k] < (H1*(T_AF_N/DT)*(H2-H1))/10
26 END
27
28 IF tides_check = TRUE
29 THIS level < NEW level
30 levelsection < k
31 levelheight < levbar[k]/10
32
33 gp:DISPLAY "Section: ";k:" Level: ";levelheight AT LINE k+12 POSITION 20 COLOUR 14 ON 1 WIT
34 H IMAGE a***a:***
35 JOIN THIS level TO levellist
36 END
37
38
Macro TIDESCOCCHEK

The number of the section in which the dredger is currently working is called the *dredging section*. Each section between the current section of the dredger and the sea has a length of ten kilometres. For each section the dwell time of the dredging in that section is calculated and called the *dredger_sailing_time*. As first the estimated loading time of the dredger is taken at one hour. The estimated time of departure (*ETD*) of the dredger from the section becomes the current time (*NOW*) plus one hour. For this point in time, called *leftime*, the water level height is calculated. This process is repeated for each section between the current section of the dredger and the sea. The limiting section is the section with the smallest available water depth. If the draft of the loaded dredger exceeds the available water depth, then the maximum loading capacity of the dredger is reduced. This reduction factor is called *draftreduction*. If the channel is deep enough the *draftreduction* will become one, meaning no draft reduction and the dredger can be loaded to its maximum capacity.

Module TIDEGENERATOR

Each hour a water level height is generated for each section. This module has no direct function within the simulation model. It only serves a graphical purpose when an animation is displayed. If the user is only interested in numerical output, then this module can be turned off. This also benefits calculation times.
MODEL SHANGHAI

MAC TIDECHECK

1 @ Macro Tidecheck
2 @
3 @ This macro checks the maximum load of a dredger which already started
4 @ dredging
5 @ Current component is dredger!
6 @
7 @
8 REMOVE EACH level IN levellist FROM levellist IF levellist IS NOT EMPTY
9 dredger_sailsec_time < (sectionlength OF dredger_section/1000)/dredger_speed_loaded
10 ETD < NOW + 1 HOUR
11 levtime < ETD
12 @ Time dredger sail through section
13 start:
14 FOR k < dredgingsection TO totsections
15 CALL tides
16 ETD < levtime + dredger_sailsec_time
17 levtime
18 @ Checking the waterdepths
19 @ Increase sailing time
20 END
21 checking_dredger:
22 @ Select the smallest section depth
23 THIS level < FIRST level IN levellist WITH SMALLEST levelheight
24 dredger_level < THIS level
25 @ Link dredger to level
26 IF (dredger_draft_loaded) > (levelheight OF dredger_level)
27 draftreduction < ((levelheight OF dredger_level)*0.95)/dredger_draft_loaded
28 dredgermaxcapacity < draftreduction * dredgercapacity
29 END
30 store draftreduction AS "draftred" @ Storing draft reduction factor
31 END
32 IF (dredger_draft_loaded) < (levelheight OF dredger_level)
33 dredgermaxcapacity < dredgercapacity
34 @ No reduction
35 END
36 END
37

MODEL SHANGHAI

MOD TIDEGENERATOR

1 @ Module Tidegenerator
2 @
3 @
4 @ This module generates tides levels for each section
5 @
6 @
7 WHILE project_ready = FALSE
8 levtime < NOW
9 FOR k < 1 TO totsections
10 CALL tides
11 MOVE ftdepthsection[k] TO tidesec[k] @ animation = TRUE
12 END
13 WAIT 1 HOUR
14 REPEAT FROM start
15 END
16 PASSIVATIVE
17 18
<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DREDGERS</td>
<td>Contains all the characteristics of the dredgers.</td>
</tr>
<tr>
<td>LIMITS</td>
<td>Contains the cumulative annual distributions of the boundary conditions.</td>
</tr>
<tr>
<td>SECTIONS</td>
<td>Contains all section data.</td>
</tr>
<tr>
<td>TIDEFILE</td>
<td>Constrains tidal data of each section.</td>
</tr>
</tbody>
</table>
FILE DREDGERS

1  @ DREDGERS, data file containing characteristics of dredgers
2  @
3  @
4  @
5  0  @ Number of small dredgers being used @
6  0  @ Number of medium dredgers being used @
7  5  @ Number of large dredgers being used @
8  @
9  @"Small 1"  @
10  @Dredger name @
11  @M5000  @Hopper capacity of small dredger (m3) @
12  @M0000  @Dredger production rate (m3/hour) @
13  @A0  @Dredger current load (m3) @
14  @A5.5  @Dredger draft loaded (m) @
15  @A2.0  @Dredger draft empty @
16  @A2.7  @Dredger speed empty (km/h) @
17  @A2.2  @Dredger speed laden (km/h) @
18  @A2.3000  @Dredger weekly costs @
19  @
20  @"Medium 1"  @
21  @Dredger name @
22  @M5000  @Hopper capacity of medium dredger (m3) @
23  @M2000  @Dredger production rate (m3/hour) @
24  @A5  @Dredger current load (m3) @
25  @A5.0  @Dredger draft loaded (m) @
26  @A3.7  @Dredger draft empty @
27  @A3.0  @Dredger speed empty (km/h) @
28  @A2.5  @Dredger speed laden (km/h) @
29  @A875000  @Dredger weekly costs @
30  @
31  @
32  @"Medium 2"  @
33  @Dredger name @
34  @M5000  @Hopper capacity of medium dredger (m3) @
35  @M2000  @Dredger production rate (m3/hour) @
36  @A5  @Dredger current load (m3) @
37  @A5.0  @Dredger draft loaded (m) @
38  @A3.7  @Dredger draft empty @
39  @A3.0  @Dredger speed empty (km/h) @
40  @A2.5  @Dredger speed laden (km/h) @
41  @A875000  @Dredger weekly costs @
42  @
43  @"Large 1"  @
44  @Dredger name @
45  @M5000  @Hopper capacity of small dredger (m3) @
46  @M6000  @Dredger production rate (m3/hour) @
47  @A0  @Dredger current load (m3) @
48  @A10.5  @Dredger draft loaded (m) @
49  @A5.0  @Dredger draft empty @
50  @A3.2  @Dredger speed empty (km/h) @
51  @A2.7  @Dredger speed laden (km/h) @
52  @A1300000  @Dredger weekly costs @
53  @
54  @"Large 2"  @
55  @Dredger name @
56  @M5000  @Hopper capacity of small dredger (m3) @
57  @M6000  @Dredger production rate (m3/hour) @
58  @A0  @Dredger current load (m3) @
59  @A10.5  @Dredger draft loaded (m) @
60  @A5.0  @Dredger draft empty @
61  @A3.2  @Dredger speed empty (km/h) @
62  @A2.7  @Dredger speed laden (km/h) @
63  @A1300000  @Dredger weekly costs @
64  @
65  @"Large 3"  @
66  @Dredger name @
67  @M5000  @Hopper capacity of small dredger (m3) @
68  @M6000  @Dredger production rate (m3/hour) @
69  @A0  @Dredger current load (m3) @
70  @A10.5  @Dredger draft loaded (m) @
71  @A5.0  @Dredger draft empty @
72  @A3.2  @Dredger speed empty (km/h) @
73  @A2.7  @Dredger speed laden (km/h) @
74  @A1300000  @Dredger weekly costs @
75  @
76  @"Large 4"  @
77  @Dredger name @
78  @M5000  @Hopper capacity of small dredger (m3) @
79  @M6000  @Dredger production rate (m3/hour) @
80  @A0  @Dredger current load (m3) @
81  @A10.5  @Dredger draft loaded (m) @
82  @A5.0  @Dredger draft empty @
83  @
84  Date: 97/03/17
85  Time: 10:38:15
<table>
<thead>
<tr>
<th>Page</th>
<th>Number</th>
<th>Description</th>
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<tr>
<td>83</td>
<td>32</td>
<td>Dredger speed empty (km/h)</td>
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<tr>
<td>84</td>
<td>27</td>
<td>Dredger speed laden (km/h)</td>
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<tr>
<td>85</td>
<td>1300000</td>
<td>Dredger weekly costs</td>
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<td></td>
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<td>87</td>
<td>&quot;L&quot;</td>
<td>Name of large dredger</td>
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<td>Dredger class (large)</td>
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<td>15000</td>
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<td>Dredger production rate (m³/hour)</td>
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<td>10.5</td>
<td>Dredger draft loaded (m)</td>
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<td>94</td>
<td>32</td>
<td>Dredger speed empty (km/h)</td>
</tr>
<tr>
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<td>27</td>
<td>Dredger speed laden (km/h)</td>
</tr>
<tr>
<td>96</td>
<td>1300000</td>
<td>Dredger weekly costs</td>
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<tr>
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<td>FILE LIMITS</td>
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<tr>
<td>2</td>
<td>File containing boundary conditions generator data</td>
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<td>3</td>
<td>Typhoon generator</td>
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</tr>
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<td>151 273 365</td>
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</tr>
<tr>
<td>6</td>
<td>0.1 0.9 1</td>
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<td>7</td>
<td>Gale generator</td>
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</tr>
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<td>8</td>
<td>Number of points</td>
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<td>151 273 365</td>
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<td>151 273 365</td>
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<td>0.5 0.55 1</td>
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<td>91 273 365</td>
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</tr>
<tr>
<td>18</td>
<td>0.1 0.9 1</td>
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</tr>
<tr>
<td>19</td>
<td>Annual siltation data versus channel depth</td>
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</tr>
<tr>
<td>20</td>
<td>Number of points</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>10000000.0 7.00</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Annual quantity (m3) versus channel depth (m)</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>End of siltation table</td>
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<td>24</td>
<td>Wave generator</td>
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<tr>
<td>26</td>
<td>181 365</td>
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</tr>
<tr>
<td>27</td>
<td>0.4 1</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Dump site data</td>
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<tr>
<td>29</td>
<td>Number of dump sites</td>
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<tr>
<td>30</td>
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<tr>
<td>31</td>
<td>Dump site capacity (m3)</td>
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</tr>
<tr>
<td>32</td>
<td>Dump bulking factor</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Dump sailing distance to KP70 (m)</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Dump site number</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Dump site capacity (m3)</td>
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</tr>
<tr>
<td>36</td>
<td>Dump bulking factor</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>Dump sailing distance to KP70 (m)</td>
<td></td>
</tr>
</tbody>
</table>
FILE TIDEFILE

1 @ File Tidetable
2 @
3 @
4 @ This file contains the tidal data of Shanghai
5 @
6 7 @ Number of bars @
7 80 70 70 85 80 90 105 @ Initial depth of sections in DM @
8 347.76 12.42 0 0.5 0.42 @ Neap-Spring-Neap, LW-LW, Start curve, DT, DT last @
9 26 28 @ TPCURVE (points tidal curve), TCURVES @
10 @
11 12 @ Waterlevels neap tide section 1 @
13 17.5 16.5 16 16 16.5 17.5 19 21 24 26 28 29 30.5 31.5 32 31.8 31.5 30.5 29 28 26 24 22 20 19
14 17.5 @
15 16 @ Waterlevels spring tide bar 1 @
16 9 8.5 7.5 6 6 7.5 9 12 18 24 28.5 32 35.5 38.5 41 42 42 41 38.5 35.5 32 28.5 24 19.5 15 9
17 @
18 @ Waterlevels neap tide section 2 @
19 16.5 16 16 16.5 17.5 19 21 24 26 28 29 30.5 31.5 32 31.8 31.5 30.5 29 28 26 24 22 20 19 17.5
20 16.5 @
21 @ Waterlevels spring tide bar 2 @
22 8.5 7.5 6 6 7.5 9 12 18 24 28.5 32 35.5 38.5 41 42 42 41 38.5 35.5 32 28.5 24 19.5 15 11.7 8.5
23 @
24 @ Waterlevels neap tide section 3 @
25 16.5 16 16 16.5 17.5 19 21 24 26 28 29 30.5 31.5 32 31.8 31.5 30.5 29 28 26 24 22 20 19 18 16
26 @
27 @ Waterlevels spring tide bar 3 @
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