Study on the navigation capacity of the approach channel of Tianjin Port: Part 1

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Introduction

Tianjin Port is situated at a central position on the west coast of Bohai Bay. It is 66 km away from the downtown of Tianjin city and roughly a distance of 170 km to the city of Beijing. The port owns a total quay line length of about 14,464 m and about 76 berths of various types which are operated by 11 terminal companies. In recent years, Tianjin Port has seen continuous rapid growth of cargo throughput. In the period from 2000 to 2005, the total throughput of the port has been growing at an average annual rate of 20.3 per cent. In 2005, the total cargo throughput of the port reached 240 million tonnes, including 4.80 million TEUs of containerized cargoes. Tianjin Port is ranked in top 10 in the world's largest ports according to throughput capacity and is the largest man-made port in China, with its approach channel (40 km in length, 234 m in bottom width and –17.4m in water depth) formed entirely by dredging.

It is planned that between 2006 and 2010, a fund of 27.68 billion yuan will be invested in the construction of port facilities, including a number of bulk cargo berths in the South Harbour Zone accommodating ships such as oil tankers up to 250,000 dwt, as well as more than ten container berths of 100,000 dwt class in the North and East Harbour Zone. Meanwhile Tianjin Port is planning to upgrade the approach channel to allow access by ships up to 250,000 dwt. It is wondered, with the exception of satisfying the requirements of creating access for ships of 250,000 dwt, how effective the new channel conditions will be in cutting short the average time ships wait for channel availability? Will the channel still be able to meet the demand from the fleet of ships accessing the port when the port is further developed with increased throughput? If the answer is negative, when should the second channel be dredged? To answer the question, a joined theme study group was set up by Tianjin Port Group Ltd and the First Design Institute of Navigation Engineering (FDINE) to specifically study the navigation capacity of the approach channel of Tianjin Port against three phases of port development by using a mathematic modeling method.

Computing method

A port system that consists of factors such as ship, channel, berths and handling operation is a random service system with multiple random factors and complex dynamic relations. Within this system, affected by the random factors such as ship arriving time and duration at berth, the operation of the channel is rendered into a status of an unbalanced busy-idle pattern that has certain impacts on the normal utilisation of the navigability of the channel. On the other hand, the constrains of channel conditions and natural conditions will also prolong the non-production waiting time of ships (at berth or anchorage), generating a 'bottle neck' phenomenon, which, at serious status, will affect the throughput capacity of the wharves and cause a great waste of the transportation capacity of the ships. For such a complex system with multiple factors interacting with each other, the conventional system analytic method would fail to make quantitive analysis. Therefore, the theme study was performed by using the computer simulation method.

The study was performed in the following process: The port system was first analysed. By means of theoretical analysis, data statistics and field investigation, mathematic models were established for the subsystems and components that constitute the complete system. Then the math models of the subsystems were converted into a simulation model of the complete integral system. The model was then used on a computer to dynamically simulate the port system operation for a certain period of time, so as to calculate out the technical indexes that reflect the status of the system operation. Finally, the navigability of the channel was evaluated by analysis of the affects of the factors of the channel on the system operation.

System analysis

The process of analysis on the system is the effort to describe, from viewpoint of mathematical regularity, each element that constitutes the integral system, and to quantify the system regulations.

The components of the Tianjin Port system are described as follows:

1. Navigation Channel

In the math model, the Main Channel and the Northern Branch Channel are chosen as the object of study. The configuration of the channel system is shown in Figure 1.

(I) Major Dimensions of the Main Channel

Channel class:	250,000 dwt
Length:	44 km
Bottom width:	315m
Water depth:	-19.7m

The Northern Branch Channel is about 8.9 km long, capable of allowing two fully loaded container carriers up to 100,000 dwt to access the port and leave the port at the same time. The North Branch Channel joins the Main Channel axis at the location of mileage of 9.8 km of the Main Channel.

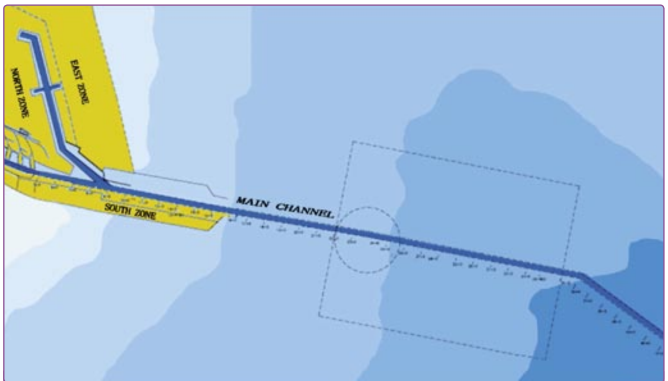

Figure 1. Tianjin Port Layout.

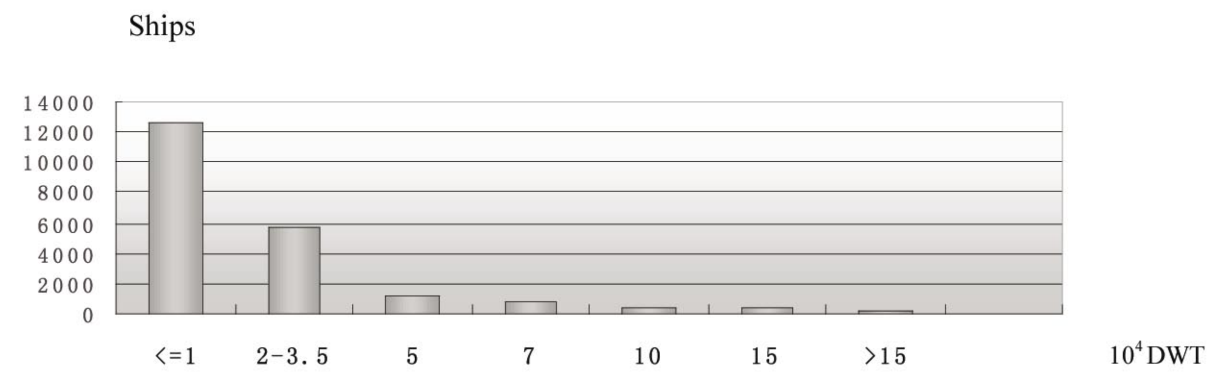

Figure 2. The number and sizes of arrival ships in 2004.

(II) Navigation Principle

According to the Chinese Standard, the width of the channel for two-way navigation will be:

$$W = 2A + b + 2c \quad (1)$$

Where: A: Width of manoeuvring lane

$A = n\,(L\sin\gamma + b)$

n: Factor of ship float shift

L: Ship length

γ: Offset angle due to wind and current pressures

b: Width of ship

c: Bank clearance

In formula (1), if the two ships are of different dimensions, the width of ship wake A will be calculated respectively for the two ships.

Navigation speed: Strictly speaking, the time used by every ship for turning and acceleration will be different due to the different manoeuvre performance of each ship. To facilitate the calculation, the mean value of the time was used in the model in accordance with the comments of some experts. Meanwhile reference was made to the 'Tianjin Port Ship Traffic Management System – Safety Monitoring and Management Regulations', which specifies that a ship navigating in the inner channel within mileage of 9.0 km shall not exceed a speed of 10 knots, and shall not exceed 12 knots in the outer channel beyond 9.0 km.

Safety distance: In accordance with 'Tianjin Port Ship Traffic Management System – Safety Monitoring and Management Regulations', the minimum distance to be kept between two ships navigating in the same direction shall be six times the ship length.

The relation between the speed of the ship navigating in the channel and the mileage can be summarised as a curve equation with argument of time t. As in the same time domain there may be a number of ships navigating in the channel, the restraint between the ships can be simplified as the problem of calculation of the numeric values between the mass points of the curve family that move along different curves.

(III) Hydrological and meteorological factors

The hydrological and meteorological factors that would affect the navigation in the channel, such as wind, wave and fog etc. are externalised in random patterns.

(IV) Tidal conditions

The tide in Tianjin Port area is of irregular semi-diurnal type. The regularity of variation of tidal levels with time t is:

$$A(t) = M_s + \Sigma\, h_i \cos\,(q_i\, t + g_i\, t) \qquad i = 1, 2, 3\ldots \quad (2)$$

Where: M_s – Mean Sea Level

h_i – the amplitude of tidal component number i

q_i – the angle speed of tidal component number i

g_i – the initial phase angle of tidal component number i

In the calculation, eight major tidal components were used: Q_1, O_1, P_1, K_1, N_2, M_2, S_2, K_2.

2. Berth conditions

Tianjin Port has 76 berths in operation. Between 2005 and 2010, 25 large scaled deep water berths will be constructed in Tianjin Port. By the year of 2020, an additional 21 large berths will be put into operation. Beyond 2020, a further 19 large berths will be added. The model simulates the navigation capacity of Tianjin port channel with 101 berths in 2010, 122 berths in 2020 and 141 berths in future beyond 2020.

Some berths are close to the navigation channel; to access these berths the ships will use part of the main channel for turning manoeuvres. Ships navigating across the converging point between the North Branch Channel and the Main Channel will interfere with the normal navigation of other ships in the channel. Therefore, the locations of the berths are also considered in the model. In accordance with the geographical locations, the berths are classified into 25 groups.

3. Ship conditions

(I) Number of arrival ships

For existing berths, the number and sizes of ships are determined according to 2004 statistics, see Figure 2. For berths planned to be constructed, the number and sizes of ships are determined according to the design documents.

It is expected that in 2010 the throughput capacity of the port will be 310 million tonnes per annum (mtpa), with the number of vessels arriving exceeding 26,060; in 2020, the port throughput capacity will be 500 mtpa, with the number of vessels arriving exceeding 32,033; in the future beyond 2020, the throughput of the port will be 590 mtpa with the number of vessels arriving exceeding 38,297.

The above figures are used as the basis in the model for the number of vessels navigating through the main channel (each ship will pass twice through the channel for entering and leaving the port).

(II) Statistical analysis of ship arriving regularity

Based on the statistics, the number of ships arriving each day is analysed as a random variable, see Figure 3.

By checking with χ^2, the number of ship arrivals can be considered to follow Poisson distribution, with the function being:

$$P_n(t) = \frac{(\lambda t)^n\, e^{-\lambda t}}{n!} \qquad n = 0, 1, 2\ldots \quad (3)$$

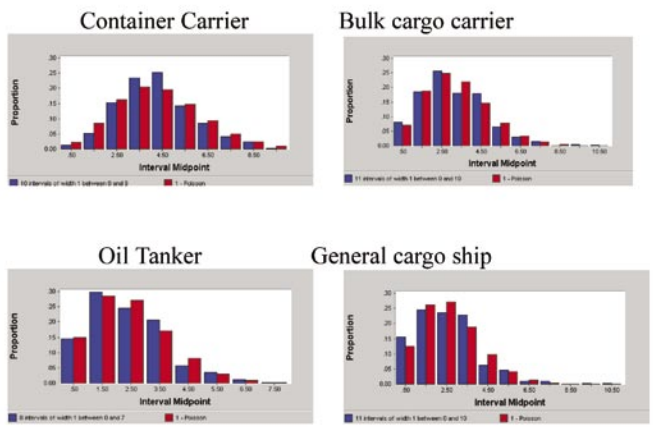

Figure 3. Distribution of ship arriving at Tianjin Port.

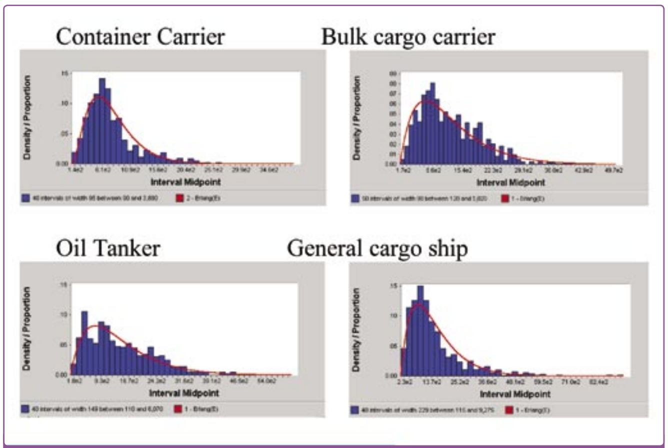

Figure 4. Time distribution of ship at berth.

Where λ is the mean number of arrival ships in given time t.

It can be theoretically proven that, if the daily number of arrival ships as a random variable follows Poisson distribution, then the time intervals of arrival ships as a random variable should follow the exponential distribution, with the distribution function being:

$$F(t) = 1 - e^{-\mu t} \quad t \geq 0 \tag{4}$$

Where μ is the mean time interval between ship arrivals.

As passenger liners arrive in a more planned pattern, they follow uniform distribution. LNG carriers are also assumed to follow uniform distribution in arrival patterns. The density function therefore will be:

$$f(t) = \frac{1}{2h} \quad a - h \leq t \leq a + h \tag{5}$$

Where: a – Mean value of interval times
h – Value of tolerance

(III) Statistical analysis of time of ship at berth

The time a ship is at berth for handling operations is also a random variable, which follows Erlang distribution according to extensive references. The statistics results of ship time at berth according to cargo categories are shown in Figure 4.

Erlang distribution density function:

$$f(x) = \frac{k\mu(k\mu x)^{k-1}}{(k-1)!} e^{-k\mu x} \tag{6}$$

Where: k – exponent number of Erlang distribution
μ – time parameter

Statistical analysis shows that the time a ship is at berth for a container carrier follows the third order of Erlang distribution and the time a ship is at berth for general cargo ships, oil tankers, and bulk cargo ships follows the second order of Erlang distribution. The time a ship is at berth for passenger ships does not follow any theoretic distribution, therefore an empirical distribution of statistics is used in the model.

4. Dispatching principle

In order to simulate the operation process of the port system, the model shall not only correctly reflect the value relation and logic relation between the relevant objects such as ship, channel, berth etc., but also, more importantly, simulate the human's function in the control of the system in the operation activities, such as the basic regulations of 'Tianjin Port Ship Traffic Management System – Safety Monitoring and Management Regulations.' In addition to satisfying the conditions described in previous sections, the model shall schedule the navigation plans in accordance with a time preference principle i.e. the first come first served principle. Meanwhile, a berth location preference principle shall be practiced as far as possible, i.e. the ship that goes to a berth in the inner part of the port should enter the port first, and the ship that goes to a berth in the outer part of the port should enter the port last, and the ship that leaves the berth in the outer part of the port should go out first and the ship that leaves the berth in the inner part of the port should go out last. As the approach channel of Tianjin Port is the 'Condition-Dependent Two-Way Channel', W will be calculated with formula (1) according to the dimensions of the two ships navigating in opposite directions to meet in the channel. Whether the width of channel at the ship draft depth is wider than W will be the condition to determine two-way or one-way navigation.

End of part 1. Part 2 of this article will discuss the establishment of the simulation model, including a simulation of three case studies on Tianjin Port to establish whether the channel will still be able to meet demand in the future. The article will go on to discuss the results, complete with results analysis and conclusions.

References available upon request.

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