Study on the impact of LNG carrier entering and leaving port on the passing capacity of narrow channel

Tai-kun Huang*, Ran Pang, Yuan-zhan Wang, Xing-yan Yang and Han Jia

1Civil Engineering School, Tianjin University, China
2CCCC First Harbor Consultants Co., Ltd, Tianjin, China

*Email: huangtaikun@fdine.net

Abstract. As a clean energy source, LNG has been widely used. LNG ships need to enter and leave the port area through the channel. With the development of the port, the ship traffic will gradually increase. As a manual excavation of narrow and long channel, its passing capacity will become a constraint factor for LNG receiving stations and port development. In this paper, the system simulation method is used to study the impact of LNG ship entry and exit on the passage capacity of the channel, which can provide basis and reference for the planning, site selection and channel construction of the LNG receiving station.

1. Introduction
As a clean energy source, LNG has been widely used. LNG ships need to enter and leave the port area through the channel. With the development of the port, the ship traffic will gradually increase. As a manual excavation of narrow and long channel, its passing capacity will become a constraint factor for LNG receiving stations and port development. The impact of LNG ships on port channel throughput always becomes a bottleneck restricting the development of large ports. An objective and reasonable estimation of the channel's ability to pass can provide important theoretical and technical support for port planning, design and decision-making. Because the factors affecting the passage ability of the channel are more complicated, the estimation formulas are mostly empirical formulas, and mainly for the river channel, the most famous formula is the West German formula proposed at the 1969 International Shipping Conference [1]. The port and shipping system, which consists of ships, waterways, berths and loading and unloading operations, is a stochastic service system with many random factors and complex dynamic connections.

Zhang Baohua [2] based on the theory of FujiiMiping, combined with the theory of maritime traffic engineering, analyzed the ability of the Laotieshan waterway in Dalian; Liu Jingxian[3] redefines the passage ability of the channel and proposes to enter through a section of the port channel per unit time. The maximum number of ships in the port and the outbound vessel is used as the channel passing capacity, and the channel saturation is used as an evaluation index of the channel service level to study the degree of patency of the inbound channel. Li Yunbin[4] studied the model of the passing ability of the channel under static and dynamic conditions based on the ship domain model and the queuing theory model. Huang Taikun et al. [5] established a simulation model of channel passing capacity. The model considers the ship random arrival, tide conditions, hydrometeorology and other factors, and calculates the ship density, service level, loading and unloading efficiency, waterway waiting,
anchorages waiting. The influence of various factors on the ability to pass the two-way channel and the complex channel.

The port navigation operation system is a complex discrete event system with high internal correlation. It is difficult to reflect the random dynamic changes of various elements in the port operation process by traditional statistical methods. It is a new method to calculate the port channel passing ability by computer system simulation[6-8]. In this paper, using computer system simulation technology, considering the factors such as ship density, service level, loading and unloading efficiency, and channel waiting, LNG ships have influence on the passage capacity of large ports, and provide basis for channel construction and site selection of LNG receiving stations.

2. Project overview
Dagang Port Area is selected as an analysis object, shown in figure 1. According to forecasts, its development is divided into three stages: near, medium and far. Recently, some berths in the port area were completed and put into operation, with a cargo throughput of 136 million tons. In the medium term, the cargo throughput was 216 million tons. In the long run, all berths in the port area were fully developed and the cargo throughput was 316 million. At present, a 100,000-ton waterway has been opened, with a length of about 46km and a width of 300m. The design has a bottom elevation of -14.6m, which is a manual excavation type long and narrow channel.

3. Simulation model establishment
In this section, the model assumptions, model constraints were explained, and model building was performed.

3.1. Model assumptions and simplifications
To simplify the problem and facilitate modeling, the following assumptions are made.

(1)The storage capacity of the terminal yard is not limited to the berthing of the ship. The ship is loaded with cargo and unloaded.

(2)Regardless of the two-way navigation of the ship in the channel.

(3)The impact of non-cargo ships such as social ships and working ships and passenger ships is not considered.

3.2. Model constraints
To simplify the problem and facilitate modeling, the following assumptions are made.

3.2.1. Model boundary

(1)LNG ships have the first priority, followed by large ships with tidal requirements and other ships.

(2)After the ship arrives at the port, it will be parked at the corresponding anchorage. When there is a free berth, it will enter the channel from the anchorage location.

(3)From the anchorage center into the waterway, ships above 100,000 tons enter the navigation channel from the starting point of the channel 46+000. Ships under 50,000 tons can be driven into the
channel from 38+000 by anchorage.

(4) LNG does not sail at night, other ships can sail at night.

(5) The LNG ship mobile safety zone is 1 nautical mile before and after.

3.2.2. Ship

Count the number of cargo ships (excluding social ships and work ships) arriving at the port and obtain a histogram of frequency distribution (Figure 2).

In probability theory and statistics, the Poisson distribution, named after French mathematician Siméon Denis Poisson, is a discrete probability distribution that expresses the probability of a given number of events occurring in a fixed interval of time and/or space if these events occur with a known average rate and independently of the time since the last event.

The number of ships arriving in port is subject to the Poisson distribution. For the statistics of ships arriving in port, the number of ships arriving in port per day is tested as a random variable.

![Figure 2. Distribution of ships arriving at the port.](image)

4. Simulation experiment design and results analysis

In this section, three different simulation experiments were designed and the experimental results were analyzed.

4.1. Experimental design

Three sets of simulation experiments were performed (Table 1). In the first experiment, the port has recently developed 136 million tons, three LNG berths, and unloaded 5 million tons of LNG annually. In the second experiment, the LNG ship mobile safety zone is 1 nautical mile. The port has recently developed 216 million tons, three LNG berths, and 15 million tons of LNG. In the third experiment, the LNG ship mobile safety zone is 1 nautical mile. The port has recently developed 316 million tons, 3 LNG berths, and 15 million tons of LNG.

4.2. Simulation experiment results and analysis

In the first experiment, the number of ships entering and leaving the channel was relatively small, so the impact of the LNG ship entering and leaving the port was relatively light. The average channel time of the ship was only 2.13 hours/ship.

In the second experiment, with the development of the port area, the density of the ship entering and leaving the port increased by 3.94 hours per boat. The impact (including direct and indirect effects) of LNG ships entering and leaving the port has become larger.

In the third experiment, due to the high density of the ship, the average waiting time of the ship was as high as 7.31 hours per boat, and the impact became more significant(Figure 3).

Since many of the systems are random factors, people tend to pay special attention to the random distribution of some statistical indicators. In the second experiment, the average daily voyage of channel was 83.7 ships. Under weather conditions permitting navigation, The ratio of free time to navigable time of channel is only 5.19(Figure 4), that is an average of 8.93 vessels sailing in the
fairway, and reached up to 27. The average waiting time for the vessel to enter and exit the port is 3.94 h/ship, which is acceptable.

![Figure 3. Ship waiting time with throughput curve.](image)

![Figure 4. The ratio of free time to navigable time with ships curve.](image)

| Conditions                        | Experiment 1 | Experiment 2 | Experiment 3 |
|-----------------------------------|--------------|--------------|--------------|
| Other cargo types                 |              |              |              |
| Transportation volume (100 million tons) | 1.36         | 2.16         | 3.16         |
| Arrival ship (ship)               | 8512         | 14068        | 19731        |
| Average waiting time for the ship (h/ship) | 2.13         | 3.94         | 7.31         |
| Directly affected by LNG ships    |              |              |              |
| Proportion of ship directly affected by LNG ship (%) | 33.4         | 47.6         | 54.3         |
| The average time to influence each ship (h/ship) | 3.77         | 5.12         | 7.53         |

5. Conclusions and recommendations

(1) Actual statistics show that the applied port-to-port ships meet the Poisson distribution.

(2) When setting up the mobile safety zone and opening other ships at night, it is feasible to reach 200 million tons of port area and handle 15 million tons of LNG.

(3) As the port throughput increases, the ship waiting for the channel time also increases. When it reaches about 300 million tons, because the ship waits for a channel time of nearly 7.31 hours per boat, the impact is greater, and it is considered to open a special channel for LNG.
In order to improve the passage capacity of the channel, it is recommended to open the night navigation function of the LNG ship under the condition of meeting the navigation rules.

References
[1] D.Y Yu, J.L Zhao, Y Deng, et al (2010). Qingdao Port main channel passage ability research. China Water Transport, 10 (3), 35-37.
[2] B.H Zhang (2009). Research on fairway capacity of Lao-Tie Hill based on ship field, Dalian University of Technology, Dalian, China.
[3] Y.Q Wen, J.X Liu (2010). Computing Model of Traffic Capacity of Harbor Public Channel. Navigation of China, 33(2), 35-39.
[4] Y.B Li (2008). Evaluation and Prediction of the Passing Capacity (Saturation) of the Main Channel of Tianjin Port, Wuhan University of Technology, Wuhan, China.
[5] T.K Huang, Y.Z Wang, S.W Li, et al (2015). Dynamic system simulation on throughput capacity of compound channel of seaport. Journal of Dalian Maritime University, 41(1), 20-26.
[6] D Jagerman, T Altiok (2003). Vessel Arrival Process and Queuing in Marine Ports Handling Bulk Materials. Queuing Systems, 45(3), 223-243.
[7] M Kia, E Shayan, F Ghotb (2002). Investigation of Port Capacity under a new approach by computer simulation. Computer & Industrial Engineering, (42), 533-540.
[8] P Legato, R.M Mazza (2001). Berth planning and resources optimization at a container terminal via discrete event simulation. European Journal of Operational Research, 133(3), 537-547.