Comprehensive evaluation method for site selection of LNG bunkering stations in Bohai Rim ports

Xinzhe Zhao1a, Wentao Ding2b, Mengchao Su2c, Yun Peng1d*, Xiangqun Song1e

1State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology, Dalian 116024, China
2Transport Planning and Research Institute, Ministry of Transport, Beijing 100028, China
a1792454394@qq.com, bdwt0404@126.com, csumc@tpri.org.cn, d*yun_peng@dlut.edu.cn, esxqun@dlut.edu.cn

Abstract—With the introduction of emission peak and carbon neutrality strategy, green shipping has already become an urgent need for the development of water transportation industry. Using liquified natural gas (LNG)-powered ships is an effective way to deal with carbon emission, and more and more shipping companies are willing to choose it as the main ship type in the future. As the open cooperation portal to the Asia-Pacific region, the Bohai Rim region occupies an important position in China national shipping system. Focusing on the bunkering needs of LNG-powered ships in the future, ports in the Bohai Rim region should add LNG bunkering stations with reasonable layout and complete facilities. This paper constructs a comprehensive evaluation system for the site selection of LNG bunkering stations in coastal ports from five aspects: natural factors, infrastructure factors, economic factors, safety factors and policy factors, and conducts the evaluation on the alternative port areas. After comprehensive analysis, the Caofeidian Port Area of Tangshan Port is recommended as the location of LNG bunkering station.

1. Introduction
In the past ten years, the development of liquefied natural gas (LNG)-powered ships has become more and more stable. The LNG-powered ship has gradually demonstrated the ability of ocean-going navigation, and the number of ships is increasing rapidly year by year. According to the Clarkson’s statistics, there are nearly 700 LNG-powered ships in the world. Meanwhile, the proportion of LNG-powered ships in newbuilding orders has exceeded 10%. Focusing on the rapid development trend of LNG-powered ships in the future, ports around the world are striving to build a global LNG bunkering network. The ports of Singapore, Antwerp, Rotterdam and Zeebrugge jointly formed the “LNG Bunkering Port Alliance” in 2014, which was committed to promoting the use of marine LNG fuel and building a global LNG bunkering port network. There are already more than ten members joining in the alliance [1].

The coastal port LNG bunkering station is still an emerging field, and relevant scholars have carried out exploration and research on the layout of the LNG bunkering station. Liu et al. [2] discussed the limiting factors for the site selection of inland river LNG bunkering stations in China, and has summed up five types of sites that are conducive to the layout of inland river LNG bunkering stations. Considering factors such as the LNG bunkering time, the number of ships to be bunkerred, and the voyage distance of the LNG bunkering ships, Lu et al. [3] used the continuous fuzzy preference relation
method to analyze, and recommended the Port of Busan, South Korea as the location of LNG bunkering station. Yang\cite{4} constructed the gravity center method function to solve the position of the LNG bunkering anchor point on the water with the goal of minimizing the economic cost, and evaluated the location of LNG bunkering station from the four aspects of economy, investment, safety and other properties. From the perspective of liner, Aymelek et al.\cite{5} established a transportation network model, aiming at minimizing the bunkering time and cost, and finally determined the LNG bunkering network. It can be seen that there are few studies on the comprehensive evaluation of site selection of LNG bunkering stations in coastal ports, and there is still a lack of a comprehensive evaluation system.

Therefore, in order to further deepen the research on the site selection of LNG bunkering stations in coastal ports, and provide a reference for the planning and construction of LNG bunkering stations in ports around the Bohai Sea in China, this paper fully forms a set of evaluation methods for the location of bunkering stations with the fully consideration of natural factors, infrastructure factors, economic factors, safety factors and policy factors.

2. **Bohai Rim regional advantages**

The port cluster around the Bohai Sea composed of the port group of Liaoning, Tianjin-Hebei and Shandong coast, which serves the economic development in Northern coastal and inland region. At present, the port cluster around Bohai Sea possesses seven of the top ten in coastal handling capacity, and four of the top ten in container handling volume. It plays a key role among the five port clusters in China\cite{6}. Simultaneously, the area around the Bohai Sea is an important implementation region where the project of turning coal into gas is promoted where the regional gas expense has increased sharply in recent years\cite{7}. In 2018, Ministry of Transport issued a key layout scheme of LNG terminal around the Bohai Sea (2022), which explicitly shows that 16 LNG berths in seven places will be expanded and constructed. Consequently, the port around the Bohai Sea is equipped with more perfect facilities of receiving and storing LNG and is suitable for planning and constructing LNG bunkering stations to meet the demands of LNG-powered ships.

3. **Comprehensive evaluation method of site selection**

3.1. **Evaluation indicator system**

To evaluate the site of LNG bunkering station objectively and comprehensively, the standard guide at domestic and foreign, such as Rules for LNG Bunkering Pontoons and Studies on the feasibility and use of LNG as a fuel for shipping has been studied and referred to\cite{8,9}. Meanwhile, concerned experts from domestic design institutes and colleges have been consulted online. After analyzing the information, multiple factors affecting sites of LNG bunkering stations have been concluded, including natural conditions, infrastructure, safety, economics and government support policies. Ultimately, this article sets up the indicator system from natural factor, infrastructure factor, economic factor, safety factor and policy factor.
3.2 Data processing

All indicators in the evaluation system for the site selection of LNG bunkering stations in coastal ports are evaluated with objective statistical data. The statistical data of each indicator are shown in Table 1. According to the original statistical data types of each indicator in the evaluation system, this paper uses three methods to standardize the data.

1) For the indicators (A1, A2, A3, A4, A5, A9, A10, A11) that are directly evaluated by statistical data, this paper uses the Z-Score standardization method to process the data. Z-Score normalization converts multiple sets of data into standard data with a mean of 0 and a standard deviation of 1 to eliminate the influence of a large difference in the magnitude of the data. The standardized indicators data can be uniformly converted into a percentile score for subsequent analysis and calculation.

2) For distance-related evaluation indicators (A6, A7, A8, A12, A13), the scoring criteria are shown in Table 1.

3) For evaluation indicators related to relevant planning and supporting policies (A14, A15), the scoring criteria are shown in Table 1.

Tab.1 Evaluation Indicator Statistics and Evaluation Criteria

| Evaluation indicators | Statistical data                        | Marking criterion                      |
|------------------------|-----------------------------------------|----------------------------------------|
| Wind conditions A1     | Maximum annual wind speed in the sea area| Directly determine the score through Z-Score normalization |
| Wave conditions A2     | Maximum annual wave height              | Directly determine the score through Z-Score normalization |
| Indicator | Calculation Method |
|-----------|--------------------|
| Water depth |
| LNG storage capacity |
| LNG terminal capacity |
| Road transport conditions |
| Railway transportation conditions |
| LNG receiving stations layout |
| LNG price to shore |
| Direct hinterland GDP |
| Total direct Hinterland imports and exports |
| Residential area distance |
| Distance to nature reserve |
| Bonded area |
| Compliance of Planning functional areas |

### 3.3 Weight determination based on entropy weight method

The entropy weight method determines the corresponding weight based on the effective information contained in the evaluation indicators [10]. The larger the entropy value is, the smaller the amount of information in the system is, and the smaller the weight of the indicator is; on the contrary, the more certain the system is, the greater the amount of information is, and the greater the weight of the indicator is [11]. The calculation process of the entropy weight method is as follows:

Assuming that there are $Z$ alternative port areas and there are $M$ evaluation indicators in the evaluation system, the information entropy of indicator $A_i$ in the evaluation system is:

$$E_i = -\frac{1}{\ln Z} \sum_{j=1}^{Z} x_{ij} \ln Z x_{ij}$$

(1)

In the formula: $x_{ij}$—the standardized score of the $j$th candidate port area of indicator $A_i$. The
A standardized method is shown in Section 1.2.

\[ \omega_j = \frac{(1 - E_j)}{(M - \sum_{i=1}^{M} E_i)} \]  \hspace{1cm} (2)

The indicator weight of the evaluation system for the location selection of the coastal port LNG bunkering station is determined after the calculation, and the distribution result is shown in Figure 2.

Fig 2 The weight calculation results of each indicator

4. Case analysis

This paper comprehensively evaluates the development status and positioning of ports around the Bohai Sea, and selects Dalian Port and Tangshan Port as the site selection range in combination with regional port density and other factors. Afterwards, further investigations are conducted on the operation of each port area and the planning orientation, and finally the Heshangdao Port Area, Nianyuwan Port Area, Dayaowan Port Area, Dagushan West Port Area, and Dagushan South Port Area which belong to Dalian Port; Caofeidian port area and Jingtang port area which belong to Tangshan Port are used as alternative stations.

Considering the impact of the new crown pneumonia epidemic on the world economy from 2020 to the present, the three indicators of A9, A10, and A11 in the comprehensive evaluation indicator system are selected from the public data in 2019 for evaluation. Except for the above indicators, the rest of the indicators are evaluated and analyzed by using the statistical data of 2021.

After combining the scores of various indicators of each port area and the weights determined by experts, the final score of each candidate port area is finally calculated according to the following formula.

\[ S = \sum_{i=1}^{n} (\omega_i s_i) \]  \hspace{1cm} (3)

In the formula: \( S \) — Final score for candidate port areas;
\[ \omega_i \] — Weight of indicator \( C_i \);

\[ S_i \] — Score of indicator \( C_i \);

The comprehensive score of each port area is shown in Figure 3.

Fig 3 The comprehensive score of each port area

The Caofeidian port area is located in the south of Tangshan City. At present, it mainly focuses on the unloading and transportation of large-scale dry bulk cargoes such as coal and ore. The port area has become the core development resource of Tangshan City by the virtue of its advantages of deep water, nearshore and vast tidal flats. In the future, the Caofeidian port area will be developed into an international and large-scale comprehensive port area focusing on port-side industrial services and bulk cargo transportation. The natural conditions and the support conditions in the hinterland of the port area are superior. At the same time, there is one LNG receiving station built in the port area, equipped with eight 160,000-square-meter LNG storage tanks and one LNG unloading berth. The LNG industry-related infrastructure is complete, which is in line with the port area development plan. Through comprehensive analysis and comparison, Tangshan Caofeidian port area is more suitable for building coastal LNG bunkering stations compared with other alternative port areas.

5. Conclusion

Combined with the current LNG bunkering guidelines and related specifications, and comprehensively analyzing the influence conditions of LNG bunkering station site selection, this paper constructs a comprehensive evaluation system for the location of LNG bunkering stations in coastal ports, which provides a reference for the location of LNG bunkering stations in coastal ports around the Bohai Sea. Through the comprehensive analysis and comparison of 15 indicators, the research recommends the construction of an LNG bunkering station in the Caofeidian port area of Tangshan Port.

Since the construction of LNG bunkering stations in coastal ports in China is still in its infancy, the comprehensive evaluation indicators constructed in this paper is not yet comprehensive. With the construction and implementation of the actual project, the impact indicators of the location of LNG bunkering stations in coastal ports can be further optimized and supplemented. At the same time, this study uses the entropy weight method to assign weights according to the amount of objective data information. In the future, the scientificity of weights can be further improved by combining the
subjective weight assignment of experts in the field.

Acknowledgements
This research was supported by National Key Research and Development Program of China (No. 2021YFB2600200).

References
[1] Peng, Y., Zhao, X., Zuo, T., et al. (2021) A systematic literature review on port LNG bunkering station. TRANSPORTATION RESEARCH PART D-TRANSPORT AND ENVIRONMENT., 91.
[2] Liu, G., Gong, J., Guo, X., et al. (2019) Layout planning method of inland river LNG fueling station. Port & Waterway Engineering., 09: 16-19+26.
[3] Lu, W., Seo J., Yeo, G. (2019) Location Selection of an LNG Bunkering Port in Korea. J. Korea. Trade., 23: 59-75.
[4] Yang, Y. (2016) Planning site selection and evaluation for coastal port LNG fuel power ship filling station., Harbin: Harbin Institute of Technology.
[5] Aymelek, M., Boulougouris, E., Turan, O., et al. (2014) Challenges and opportunities for LNG as a ship fuel source and an application to bunkering network optimisation. Proc. Int. Conf. Marit. Technol. Eng. 15–17.
[6] Cai, P. (2021) Analysis of changes in port competition pattern in the Bohai Rim region., Pearl River Water Transport., 01: 38-40.
[7] Fang, Z., Shen, C., Zhang, M., et al. (2019) Investigation on characteristics of LNG transportation and reasonable throughput capacity of LNG berth around Bohai region., Port & Waterway Engineering., 11: 36-39+53.
[8] CHINA CLASSIFICATION SOCIETY., 2017. Rules for LNG Bunkering Pontoons.
[9] International Maritime Organization., 2016. STUDIES ON THE FEASIBILITY AND USE OF LNG AS A FUEL FOR SHIPPING.
[10] Wu, W., Meng, X., Ma, Z., et al. (2013) Fuzzy comprehensive evaluation of network survivability based on combination weighting. Systems Engineering and Electronic Technology., 35(4): 786 –790.
[11] Lin, C., Yang, X. (2018) Product quality evaluation based on entropy method and order relation analysis method. Modular Machine Tool and Automatic Processing Technology., 10: 156–160.