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Location Selection of an LNG Bunkering Port in Korea

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Abstract

Purpose – The International Maritime Organization (IMO) has promulgated strict regulations on emissions in the maritime shipping industry. LNG (Liquefied Natural Gas) is, therefore, recognized as the optimal fuel alternative solution. The aim of this study is to select the most suitable location for an LNG bunkering port. This is formulated as a multiple-criteria ranking problem regarding four candidate ports in South Korea: the ports of Busan, Gwangyang, Incheon, and Ulsan.
Design/Methodology/approach - An analysis employing the Consistent Fuzzy Preference Relation (CFPR) methodology is carried out, and the multiple-criteria evaluation of various factors influencing the location selection, such as the average loading speed of LNG, the number of total ships, the distance of the bunkering shuttle, and the degree of safety is performed. Then, based on the combination of both the collected real data and experts' preferences, the final ranking of the four ports is formulated.
Findings - The port of Busan ranks first, followed by the ports of Gwangyang and Ulsan, with the port of Incheon last on the list.
Originality/value - The Korean government could proceed with a clear vision of the candidate ports' ranking in terms of the LNG bunkering terminal selection problem.

Keywords: Bunkering Port, CFPR, Crucial Factor, LNG, Location Selection, Maritime Transport
JEL Classifications: L91, L98, R41

1. Introduction

The International Maritime Organization (IMO) estimated that all emissions generated by maritime shipping count for 4.3% of the total global emissions. The ratio is expected to increase by over 10% by 2020 (Senari et al., 2016). Therefore, the IMO is strengthening regulations on the sulfur oxides (SOx) and nitrogen oxides (NOx) in the global maritime shipping industry to reduce emissions and preserve environmental sustainability (Armellini et al., 2015; Armellini et al., 2017; Feng et al., 2016; Lindstad and Eskeland, 2016; Sun et al., 2018; Zhou et al., 2017). After regulating the SOx contained in ship fuel, such as Bunker-C oil, to 4.5%, the IMO raised regulations to 3.5% in 2012. Further strengthening to 0.5% is expected by 2020 (Lindstad et al., 2015; Lindstad and Eskeland, 2016). Further, the NOx emission standard for new vessels has been strengthened by 20% over the past 11 years (from TIER I to TIER II set by the IMO) (Lindstad et al., 2015). In addition to these international regulations, the IMO has defined Emission Control Areas (ECAs) in North America, the North Sea, and the Baltic Sea (Zhen et al., 2018), applying a regulation of 0.1% on sulfur oxides (SOx) (Animah et al., 2018; Lindstad and Eskeland, 2016; Lindstad et al., 2015).

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In response to the international and domestic regulations on ship emissions, as well as suggesting an alternative to replace existing marine fuels (Bunker-C oil, 3% SOx, etc.), the following measures were proposed by experts: First, the use of low-sulfur oil for fueling marine vessels is advantageous because it can be applied without replacing or modifying existing marine equipment, but its disadvantage is that the oil's purchasing cost is about 40% higher than that of existing marine fuel (The U.S. Energy Information Administration). Second, the installation of the exhaust gas abatement device (Zhen et al., 2018), which is advantageous in that the existing fuel can be used by attaching the device to the present ship, is disadvantageous in that its installation is costly and can degenerate the engine and the output of the ship generator. Third, replacing ship fuel with environmentally friendly LNG (Zhen et al., 2018) has the advantage of a 90% reduction in sulfur oxides (SOx) (Pfoser et al., 2018). However, since the initial investment cost is excessive, LNG bunkering suffers due to lack of infrastructure. As each of the above three proposals has pros and cons, shipping companies are expected to seek optimal solutions while being affected by various factors, such as vessel type, operating area, oil price trend, government subsidies, and technology development trends. The switch to environment-friendly LNG is inevitable due to the strengthening of environmental regulations. Many top-ranking container shipping companies in the world plan to adopt LNG-fueled ships or LNG-ready shipping options. The Maersk line plans to use 0.5% sulfur fuels after 2020, MSC plans to install SOx scrubbers on their next ultra-large container vessel (ULCV). CMA-CGM plans to install SOx scrubbers or prepare ships and engines for LNG fuel (The CMA CGM).

Aiming to reduce emissions, experts have come up with many cleaner alternative ship fuels to prevent pollution from vessels. Liquefied Natural Gas (LNG) has been recognized as the most developed fuel alternative solution, essential for the sustainability of maritime transportation systems (Acciaro, 2014; Calderon et al., 2016; Fasihi et al., 2017; Koza et al., 2017; Lin et al., 2010; Peng et al., 2017; Sharafian et al., 2016; Shi, 2016; Tejada et al., 2017). Globally, major hubs are preparing bunkering infrastructure to attract LNG carriers and create added value through market preemption. Currently, in Europe, LNG bunkering is possible in 13 ports, including Rotterdam Port (during regulation development, bunkering ship construction) and Ghibli Port (bunkering company establishment). In Asia, the Port of Singapore was chosen as the operator by the LNG Bunkering International Cooperation Network. Meanwhile, Japan was the first country in Asia to establish the bunkering guidelines. Moreover, in response to vessel emission regulations, the introduction of LNG-propelled vessels and the LNG bunkering environment in Europe, the US, and Singapore is in full swing (Pfoser et al., 2018).

The Korean government plans to provide LNG bunkering services in response to domestic and overseas demands to secure port competitiveness for international attractions and support domestic vessel operation. It is possible to develop a Korean port as an LNG bunkering base in Northeast Asia, considering that Korean sea ports have advantages, such as being located on the world's main trunk route, the starting and ending calling ports for Asian-to-US sea routes. After all, LNG carriers require lubrication in Northeast Asia before crossing the Pacific. On the other hand, the basis for providing LNG bunkering services, such as regulations related to LNG bunkering and LNG terminals in major hub ports, is insufficient. Hence, it is meaningful to build an LNG bunkering port to provide LNG for vessels. Moreover, promoting the introduction of domestic LNG-powered vessels in Korea raises the international competitiveness of Korea's shipping industry.

This paper is aimed at ranking the four major ports in South Korea (the top three ports, Busan, Gwangyang, Incheon, and the largest oil handling port, Ulsan) as a target location to build an LNG receiving port, where vessels can refuel in the middle or at the beginning of long-distance navigation. Before construction starts, multiple criteria regarding strategic infrastructure and tactical planning, such as investment decisions, safety problems, and incentives from the local government, need to be considered thoroughly (Koza et al., 2017). Most importantly, the port's evaluation via an expert panel must be considered. Most previous research focused on LNG bunkering ports in Korea and worldwide, as well as factors affecting the performance of LNG ports, however, few studies conducted research on selecting an appropriate port for LNG bunkering based on those factors. This article bridges the gap by introducing the Consistent Fuzzy Preference Relations (CFPR) methodology to evaluate the priority of the four-targeted ports based on the multiple-criteria decision-making (MCDM) process to select the optimal option. According to the previous articles, the port selection problem has MCDM characteristics under uncertainty that involve multiple selection criteria (Animah et al., 2018; Awasthi et al., 2011; Lee et al., 2017; Singh et al., 2018; Zak and Weglinski, 2014). And the MCDM approaches are suitable to deal with such a complicated issue (Lu et al., 2018; Serrai et al., 2017; Stirbanovic et al., 2019; Yang et al., 2018). One of the advanced techniques, CFPR method (Chen and Chao, 2012; Chao and Chen, 2009; Chang and Wang, 2009; Kim et al., 2017), is selected in to analyze the LNG port selection problem in this study. Actually, there are other approaches that are able to solve MCDM problem. AHP is a popular method to deal with MCDM problem, however, the consistency of the questionnaires cannot be guaranteed with the increase of criteria (Chen, 2015). Likewise, the consistent pairwise comparison cannot be ensured in fuzzy analytic hierarchy process (Fuzzy AHP) approach (Wang and Chen, 2008). The CFPR method, on the other hand, laid important emphasis on the consistency of decision matrices (Chen and Chao, 2012; Herrera-Viedma et al., 2004). It conducts a pairwise comparison matrix with additive reciprocal property and consistency (Wang and Chen, 2008). There are also other advantages of applying the CFPR method: it is computationally efficient and simple to use (Chen and Chao, 2012; Wang and Chen, 2008). In addition, by employing the CFPR method, the decision matrices can be deducted from n (n-1) /2 to (n-1) for a group of n-criteria (Herrera-Viedma et al., 2004; Deng, Lu, Chan, Sadiq, Mahadevan, & Deng 2015). Therefore, the CFPR methodology is suitable for the purpose of solving this research problem (Pham and Yeo, 2018).

Section 2 provides a review of the overall LNG bunkering status in Korea, as well as the current situation of the four major Korean ports, followed by Section 3, which explains the definition and computational process of the CFPR methodology. Section 4 proposes a case study of the LNG bunkering port selection problem in South Korea by applying the CFPR method. In Section 5, a series of conclusions is discussed, as well as a set of implications, both from academic and practical perspectives.

2. Current Situation of LNG Bunkering in South Korea

Most of the natural gas in Korea is imported from other countries. The import volume of natural gas reached 33.45 million tons by 2016: 35.5% (11.88 million tons) is imported from Qatar, 13.0% (4.36 million tons) from Indonesia, 12.1% (4.08 million tons) from Oman, 11.4% (3.81 million tons) from Malaysia, and the rest (11.31 million tons) are imported from other countries (Park, 2017).

In Korea, natural gas is supplied to the nationwide pipeline through various processes, such as storage, re-emigration, and discharge at the production base. Korea Gas Corporation (KOGAS) has four production bases in Incheon, Gwangyang, Tongyoung, and Samcheok as the basis for a smooth supply of natural gas in Korea. The conditions for bunkering LNG in Korea are insufficient in terms of shipping and bunkering ports. In terms of shipping, Korea is ranked the fifth largest shipping nation in the world. If LNG bunkering conditions are established, it is estimated that there will be a large potential replacement demand for international and coastal cargo ships, Chinese car ferries, and coastal passenger ships using

LNG as fuel. However, among the 9,274 registered domestic vessels in Korea, there are only two LNG carriers, the “Eco-Nouri” vessel introduced by the Incheon Port Authority in 2013 and the newly launched “GasLog Gladstone,” due to high ship prices and the lack of relevant service infrastructure. In terms of shipbuilding, engine technology and key equipment are limited.

The Korean government is pursuing various policies in the marine, shipbuilding, and port sectors to utilize the international environmental regulations on ship emissions as an opportunity to foster new industries. As a specific policy target, the government plans to expand the number of domestic LNG-powered vessels to 100 and the ports where LNG bunkering is possible to five by 2025. To achieve these policy goals, the Korean government intends to introduce a public sector, an LNG pilot in the shipping sector, and expand the scale considering future performance. This is due to the fact that it is difficult to order private-sector LNG carriers in the project’s initial stages because of the burden of LNG carrier construction, high risk, and lack of infrastructure. Furthermore, the Korean government prepares to respond to the initial LNG bunkering demand by providing lubrication services using bunkering lines based on the KOGAS terminals in Incheon, Gwangyang, Tongyoung, and Samcheok in the short term. In the long term, the government plans to build an LNG bunkering infrastructure at major ports in preparation for the expansion of LNG-powered vessels.

Four ports can be considered candidate ports for building the LNG infrastructure. They are the top three ports in Korea: Busan, Gwangyang, and Incheon, plus the primary liquid port, Ulsan. In the case of Busan Port, through attracting private investors to the new LNG port, Ulsan Port is discussing ways to expand the LNG bunkering infrastructure as part of its strategy to become a liquid logistics hub port. In terms of the LNG transfer solution, the current solutions in the ports of Busan, Gwangyang, and Ulsan are to use STS (ship-to-ship transfer), while the port of Incheon is using TTS (truck-to-ship transfer), which has a much slower bunkering speed. The best scenario is to adopt PTS (land pipeline-to-ship transfer), which uses tanks or pipes in the berth. Therefore, constructing a new LNG bunkering terminal is needed. In addition, the government is studying the size and infrastructure of LNG bunkering operations for each port, considering the operational conditions and the characteristics of ports of entry and departure for major ports.

Table 1 below represents the real data of several quantitative factors of the ports of Busan (A1), Gwangyang (A2), Incheon (A3), and Ulsan (A4). As we can see in the table, the “Average loading speed of LNG (ton/hour)” of the ports of Busan (A1), Gwangyang (A2), and Ulsan (A4) are all 365 ton/hour. This is due to their STS capability, which requires LNG-fueled ships. However, the port of Incheon offers the much slower TTS function to LNG ships, which is the reason why the average loading speed of the port of Incheon is only 14 ton/hour. In the case of “Distance of bunkering shuttle (miles),” the ports of Gwangyang and Incheon have the shortest distance to the bunkering shuttle, while the port of Ulsan has the longest distance. With reference to the “Estimated effect on production and add value inducement (Billion KRW, Year 2026-2055),” the port of Busan is estimated at 456,768 billion KRW (Korea Won). In addition, in terms of “LNG bunkering demands of targeted port (ton),” the largest demand of LNG (1,480,000 tons) comes from the port of Busan and is 40 times greater than the smallest demand of 37,000 tons generated from the port of Incheon. The last row indicates the “Total number of ships.” The port of Busan has the largest number, while the port of Ulsan has the smallest number of ships.

As we can conclude from the table, each port has its own advantages and disadvantages in terms of different factors. It is difficult to compare and rank the ports over several dimensions. In addition to these quantitative factors, there are also qualitative factors, such as degree of safety and incentives from local government, to take into consideration to prioritize the ranking of the four alternative ports. Therefore, it makes sense to apply the CFPR methodology to solve the ranking problem.

Moreover, Fig. 1 below represents the geographical locations of the four candidate ports, as well as the distance (in miles) between the candidate port and its corresponding LNG supply bases.

Table 1. Data for the Quantitative Factors

	Busan (A1)	Gwangyang (A2)	Incheon (A3)	Ulsan (A4)
Average Loading Speed of LNG (ton/hour)	365	365	14	365
Distance of Bunkering Shuttle (miles)	23	4.86	5.40	76
Estimated Effect on Production and Add Value Inducement (Billion KRW, Year 2026–2055)	456,768	118,637	54,029	90,006
LNG Bunkering Demands of Targeted Port (ton, until Year 2020)	1,480,000	370,000	180,000	37,000
The Total Number of Ships	97,887.33	49,079.33	36,776.67	51,195

Source: All data were collected from the MOF (Ministry of Oceans and Fisheries) and by the authors during expert interviews

Fig. 1. The Geographical Locations of the Four Alternative Ports and Corresponding LNG Supply Bases.

3. Methodology

In the decision-making process, it is essential to use a method that avoids inconsistent solutions when measuring preferences among many alternatives (Chang and Wang, 2009). Therefore, Herrera-Viedma et al. (2004) presented the CFPR to construct the decision matrices' pairwise comparisons based on the addictive transitivity property. This method guarantees consistency in the decision-making process, as it avoids double-checking the inconsistency. Meanwhile, it enables decision-makers to express their preferences over a set of alternatives with the minimal judgments (n−1) by giving linguistic values to the comparison of criteria (Chao and Chen, 2009). Applying the CFPR in this paper allows us to establish a pairwise comparison of the preference decision matrices to determine the prioritization of the four alternative ports. A large number of previous researchers who utilized CFPR to analyze their research topic found meaningful results (Chang and Wang, 2009; Wang and Chang, 2007; Wang and Chen, 2007).

Basically, there are two types of preference relations utilized in the decision-making process: the multiplicative preference relation and the fuzzy preference relation (Chao and Chen, 2009).

Given $X = \{x_1, x_2, \dots, x_n, n \geq 2\}$, a finite set of alternatives to be pairwise assessed by a finite set of experts ($E = \{e_1, e_2, \dots, e_m, m \geq 2\}$) (Chao and Chen, 2009), in the multiplicative preference relation, experts will express their preferences for a set of alternatives X in two ways (Wang and Chang, 2007):

(1) The multiplicative preference relation. The set of alternatives, X, expressed by an expert can be denoted by the preference relation matrix, $A \subset X \times X, A = (a_{ij}), a_{ij} \in \left[\frac{1}{5}, 5\right]$, in which a_{ij} denotes the ratio of the preference degree of alternative x_i over x_j. As $a_{ij} = 1$ indicates an indifference between x_i and x_j, $a_{ij} = 5$ denotes that x_i is extremely preferable to x_j. A is a multiplicative reciprocal, hence, we get:

$$a_{ij} * a_{ji} = 1 \quad \forall i.j \in \{1, \dots, n\} \tag{1}$$

(2) The fuzzy preference relation. The ratio of the preference intensity of alternative x_i to that of x_j is indicated by expert preferences for a set of alternatives where X is denoted by a positive preference relation matrix, $P \subset X \times X$, with membership function, $\mu_p(x_i, x_j) = p_{ij}$. Moreover, $p_{ij} = \frac{1}{2}$ implies an indifference between x_i and $x_j (x_i \sim x_j)$, $p_{ij} = 1$ indicates that x_i is absolutely preferred to x_j, $p_{ij} = 0$ indicates that x_j is absolutely preferred to x_i, and $p_{ij} > \frac{1}{2}$ indicates that x_i is preferred to $x_j (x_i > x_j)$. P is an additive reciprocal. Thus, we have:

$$p_{ij} + p_{ji} = 1 \quad \forall i.j \in \{1, \dots, n\} \tag{2}$$

Proposition 1. Suppose the existence of a set of alternatives, $X = \{x_1, x_2, \dots, x_n\}$, which is associated with a multiplicative preference relation, $A = (a_{ij})$, with $a_{ij} \in \left[\frac{1}{5}, 5\right]$, therefore, the corresponding reciprocal additive preference relation, $P = p_{ij}$, with $p_{ij} \in [0,1]$ to $A = (a_{ij})$ is defined as follows (Chang and Wang, 2009):

$$p_{ij} = g(a_{ij}) = \frac{1}{2}(1 + \log_5 a_{ij}) \tag{3}$$

A multiplicative preference relation matrix can be transformed into various preference relations using (3).

Proposition 2. For a reciprocal additive fuzzy preference relation, P = g(A), in which P = (pij), the following statements are equivalent:

$$p_{ij} + p_{jk} + p_{ki} = \frac{3}{2} \quad \forall i, j, k \tag{4}$$

$$p_{ij} + p_{jk} + p_{ki} = \frac{3}{2} \quad \forall i < j < k \tag{5}$$

Proposition 3. For a reciprocal additive fuzzy preference relation, P = (pij), the following statements are equivalent:

$$p_{ij} + p_{jk} + p_{ki} = \frac{3}{2} \quad \forall i < j < k \tag{6}$$

$$p_{i(i+1)} + p_{(i+1)(i+2)} + \cdots + p_{j(j-1)} + p_{ji} = \frac{j-i+1}{2} \quad \forall i < j \tag{7}$$

Normally, each questionnaire is filled out in a way that represents a consistent preferences matrix. If the preference matrix contains values that are not in the interval $[0,1]$ but in interval $[-a, 1+a]$, a linear transformation is required to preserve the reciprocity and additive transitivity (Wang and Lin, 2009), that is $f: [-a, 1+a] \rightarrow [0,1]$. The transformation function is then denoted as follows (Viedma et al., 2004):

$$f\left(p_{ij}^k\right) = (p_{ij}^k + a)/(1 + 2a), \tag{8}$$

where a indicates the absolute value of the minimum negative value in this preference matrix.

In terms of quantitative factors, Herrera-Viedma et al. (2004) proposed that a multiplicative preference relation (X) on a set of alternatives (A) could be derived based on the ranking of alternatives according to certain knowledge:

$$X = \begin{bmatrix} 1 & A_{12} & A_{13} \\ A_{21} & 1 & A_{23} \\ A_{31} & A_{32} & 1 \end{bmatrix} \tag{9}$$

Then, transform the ratio of comparison to the scale of [1/5, 5] to preserve reciprocity and consistency by applying the function

$$f(x) = x^{1/\log_5^b,} \tag{10}$$

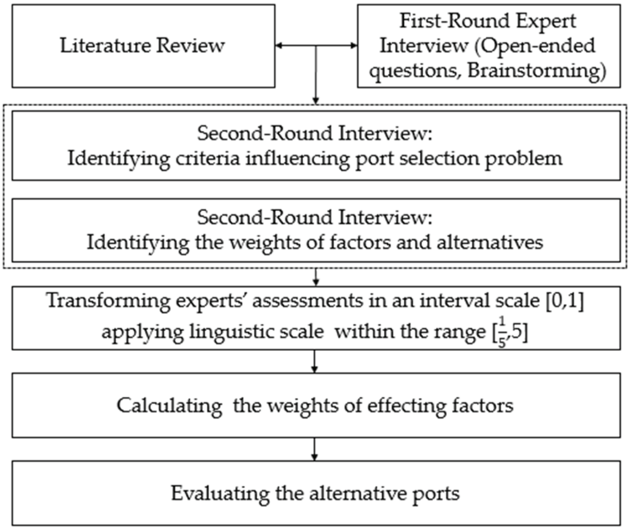
where “b” denotes the absolute value of the maximum value in the multiplicative preference relation.

4. Empirical Analysis

4.1. Identifying the LNG Port Selection Factors

The research flow chart of applying the CFPR methodology is represented in the Figure below.

Fig. 2. The Research Flow Chart based on the CFPR Methodology



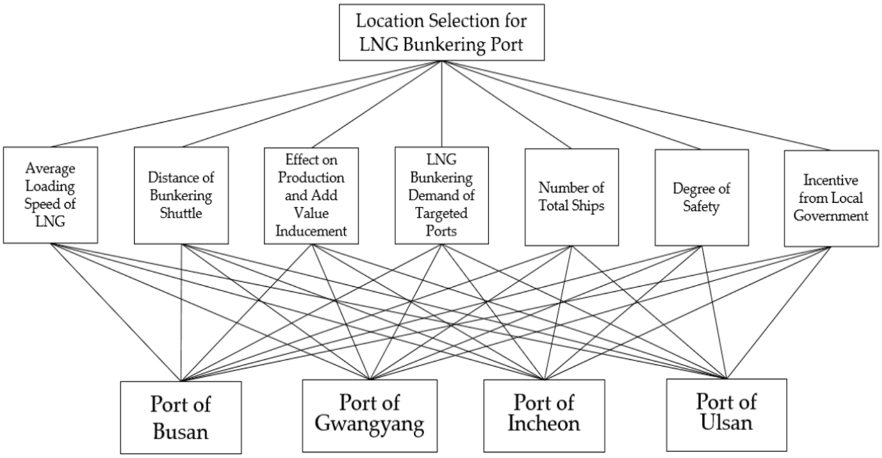
To identify suitable factors for our study, the first round of surveys was conducted with employees from the Ministry of Oceans and Fisheries (MOF), a division of the South Korean government. The major responsibilities of the MOF are insuring maritime safety and security, protecting the ocean environment, and developing ports and fishing ports. Seven experts with 15–22 years of professional working experience from different departments in the MOF—the Marine Policy Department, the Technical Processing Department, the Port Policy Department, the Trade and Commerce Department, the Coastal Planning Department, and the Port Logistics Planning Department—were invited. We selected MOF experts because the MOF is in charge of various policies, such as promoting eco-friendly, LNG-fueled ships, providing LNG bunkering terminals, and coping with international environmental regulations (SOx regulations) and safety issues. Meanwhile, the MOF has collaborated with the Ministry of Trade, Industry and Energy (MOTIE) to develop the LNG shipping and bunkering infrastructure. The survey questionnaires were conducted by face-to-face interview within a period of 57 days (from Nov. 27, 2017 to Jan. 22, 2018). After in-depth interviews with the experts, the overlapping factors were omitted, and the experts added some new factors, shown in Table 2. In the end, seven factors were identified as the most influential for the selection of the new LNG bunkering port.

Table 2. The Seven Evaluation Factors

	Factors	**Factor Type**	**Description**
1	Average Loading Speed of LNG (C1)	Quantitative Factors	The speed of loading LNG onto LNG vessels, depending on the three transfer methods: PTS (land pipeline-to-ship transfer), STS (ship-to-ship transfer), and TTS (truck-to-ship transfer).
2	Distance of Bunkering Shuttle (C2)		The distance from the production bases of the Korea Gas Corporation (KOGAS) to the targeted ports. KOGAS's production bases are Incheon, Gwangyang, Tongyoung, and the targeted ports are Busan, Gwangyang, Incheon, and Ulsan.
3	Effect on Production and Add Value Inducement (C3)		The total effects measured by Korean Won (KRW) from 2026–2055. After the LNG bunkering port, each port will be expecting effects on production and added value inducement.
4	LNG Bunkering Demands of Targeted Ports (C4)		The demand of LNG bunkering from targeted ports until 2020.
5	Number of Total Ships (C5)		The number of total ships handled in each targeted port: Busan, Gwangyang, Incheon, and Ulsan.
6	Degree of Safety (C6)	Qualitative Factors	Effectively managing the safety issues of handling LNG is essential. This factor refers to how safe it is to handle the LNG infrastructure.
7	Incentive from Local Government (C7)		The financial support and policy from the local government. Targeted ports located in different provinces in Korea. Province has different incentive system for the port's construction.

Fig. 3 below shows the analytical framework.

Fig. 3. The Analytical Framework



4.2. Identifying the Weightings to Select Factors

Seven important factors that can affect the selection of the new LNG bunkering port are finalized. These are not only qualitative factors but also quantitative factors, which makes it difficult for decision-makers to compare and put these factors in a logical order according to their preference. The CFPR methodology is, therefore, applied to tackle this problem since it can reduce the difficulties and simplify the computational procedures, as well as ensure the consistency of the decision matrices (Lee et al., 2017). Factors are divided into different groups with corresponding scales, such as “equal importance (EQ)” and “absolute importance (AB),” represented in Table 3.

Table 3. Linguistic Variables of the Importance Weights for Factors and Alternatives

Definition	Intensity of Importance
Absolute Importance (AI)	5
Very Important (VI)	4
Strong Importance (SI)	3
Weak Importance (WI)	2
Equal Importance (EQ)	1

To provide weights to these seven factors, the second-round survey was sent to 20 respondents, including those who contributed to the first-round survey. It took 52 days (from Feb. 1, 2018 to Mar. 24, 2018) for them to respond, using face-to-face interviews, telephone calls, and emails. Questionnaires were sent to 20 experts, and 16 responsible results were collected and employed for analysis. Regarding the sample size of the research employing fuzzy methodologies, 20 respondents were selected to evaluate the vendor selection process (Tam and Tummala, 2001), 19 male respondents and 20 female respondents were invited to assess the effectiveness of distance e-learning (Chao and Chen, 2009), 21 respondents participated in identifying and ranking the barriers hampering effective compliance in the Gulf of Guinea (Animah et al., 2018). Three experts were chosen to score the filling system (Yazdi, 2018); similarly, the supplier selection was calculated based on an assessment conducted by three decision-makers (Wood, 2016). In this respect, 16 experts’ responses were adequate to obtain reliability of the research results.

After sorting the data, CFPR was employed to calculate the weightings that represent the importance order of each factor in terms of influencing the LNG bunkering port selection. After completing the computational process, a normalized aggregated pairwise comparison matrix for all the factors assessed by the 16 evaluators was finalized, as represented in Table 4. The ranking of these seven decision criteria are then evaluated as follows:

Number of total ships (C5) > Degree of safety (C6) > LNG bunkering demands of targeted ports (C4) > Distance of bunkering shuttle (C2) > Average loading speed of LNG (C1) > Estimated effect on production and add value inducement (C3) > Incentive from local government (C7).

Table 4. Normalized Matrix for the Weights and Ranks of Determining Factors

E1-16	C1	C2	C3	C4	C5	C6	C7	Sum	Weight	Rank
C1	0.126	0.114	0.130	0.131	0.129	0.150	0.132	0.913	0.130	5
C2	0.137	0.122	0.139	0.139	0.138	0.159	0.139	0.972	0.139	4
C3	0.146	0.128	0.146	0.145	0.146	0.017	0.145	0.874	0.125	6
C4	0.139	0.243	0.140	0.140	0.140	0.161	0.140	1.102	0.157	3
C5	0.185	0.155	0.175	0.173	0.179	0.201	0.170	1.239	0.177	1
C6	0.161	0.139	0.157	0.156	0.159	0.180	0.155	1.106	0.158	2
C7	0.104	0.099	0.114	0.116	0.110	0.131	0.118	0.793	0.113	7

The number of total ships (C5), meaning the number of ships that enter and leave a port, which represents that port's throughput, is ranked first. This is regarded as the most important factor for evaluating a port's function (Cullinace et al., 2006; Talley and Ng, 2016), as it reflects the port's capacity and capability of handling vessels entering or leaving. For instance, the port of Busan, which is the largest port in Korea, has the biggest cargo throughput in the country (Seo et al., 2015; Song and Lee, 2017), reflecting its great big potential to handle a large number of LNG vessels in the future.

Degree of safety (C6), including navigation safety, facilities' safety, and terminal operation safety, is the second most influential of the seven evaluation factors. LNG is a very dangerous resource due to its explicability (Aneziris et al., 2014; Bubbico et al., 2009; Cleaver et al., 2006; Kim and Kim, 2018; Vanem et al., 2007). The safety issue is vital in port management because the consequences of an accident would be unbearable. For instance, in 2004, an explosion in Ghislenghien, Belgium, resulted from the rupture of a pipeline carrying natural gas from the Belgian port of Zeebrugge to northern France and caused 23 known fatalities, when a contractor accidentally damaged the pipe (The California Energy Comission). Therefore, effectively managing the safety issue of handling LNG is essential.

The third most important criterion is the LNG bunkering demands of the targeted ports (C4), which refers to the demands of LNG bunkering in the local market. If the local LNG demands are low, then there is a weak demand to build LNG bunkering infrastructures and facilities for constructing a new LNG bunkering terminal. Thus, this factor is comparatively important to this site selection problem. However, incentive from the local government (C7) falls at the bottom of the list.

4.3. Measuring Alternative LNG Bunkering Ports

4.3.1. Evaluating Alternatives based on "Qualitative Factors"

To examine the priority-weight matrix for the LNG bunkering selection by considering the influential selection criteria, the same linguistic variables for the priority weights of the selection factors represented in Table 3 are employed. It is worth mentioning that there are not only qualitative factors but also quantitative factors among the seven influential factors.

The quantitative factors including "average loading speed of LNG (C1)," "distance of bunkering shuttle (C2)," "effect on production and add value inducement (C3)," "LNG bunkering demands of targeted port (C4)," and "the total number of ships (C5)," which are required to evaluate the actual data while the qualitative criteria, such as "degree of safety (C6)" and "incentive from local government (C7)" are assessed by experts in the second-round questionnaire. The respondents were asked to state their preference for each alternative port based on linguistics terms. After computing the calculation process using the CFPR method, the normalized priority-weight matrix of the two qualitative factors are represented in Table 5.

Table 5. Normalized Priority-weight Matrix for the Four Qualitative Factors

	A1	A2	A3	A4
C6	0.246	0.213	0.313	0.229
C7	0.237	0.225	0.299	0.240

4.3.2. *Evaluating Alternatives based on "Quantitative Factors"*

In terms of quantitative factors, including "average loading speed of LNG (C1)," "distance of bunkering shuttle (C2)," "effect on production and add value inducement (C3)," "LNG bunkering demands of targeted port (C4)," and "the total number of ships (C5)," another calculation method created by Herrera-Viedma et al. (2004) was employed. Real data were collected to calculate the normalized priority-weight matrix for the quantitative factors using equations (8) and (9). The normalized priority-weight matrix is shown in Table 6 below:

Table 6. Normalized Priority-weight Matrix of the Five Quantitative Factors

	A1	A2	A3	A4
C1	0.321	0.321	0.321	0.036
C2	0.368	0.073	0.201	0.357
C3	0.239	0.199	0.438	0.124
C4	0.282	0.101	0.392	0.225
C5	0.215	0.228	0.435	0.123

4.3.3. *Evaluating Alternatives based on the Combination of "Qualitative Factors" and "Quantitative Factors"*

After conducting the analysis of priority weights for both the quantitative and quantitative factors, the next step is to combine both preference weights regarding the four alternative ports based on seven criteria and their priority weights. The matrix of the priority weights of all the criteria and the preference weights of the alternatives is represented in Table 7.

One last step is to calculate the weighted rates of each alternative port with the priority weights of each factor, as well as the preference weights of each alternative in the previous table.

Therefore, the ranking of these four alternatives based on the weighted rates is: Busan Port (0.347) > Gwangyang Port (0.271) > Ulsan Port (0.192) > Incheon Port (0.190). Thus, the conclusion can be made that Busan Port is the most suitable choice for the LNG bunkering port selection, followed by the ports of Gwangyang, Ulsan, and Incheon. The results showing Busan Port at the top of the list are reasonable, since it is the biggest port in Korea with the largest throughput and has the potential and ability to handle LNG vessels in the future. The port of Gwangyang is the second largest port, and the port of Incheon ranks third in South Korea in terms of cargo volumes handled (Song and Lee, 2017). However, in terms of the LNG transfer solution, three other ports are equipped with LNG fueling ships, so they can provide STS transfers. In contrast, at the port of Incheon, LNG ships are refueled by TTS, which is over than 20 times slower than STS. This drawback is the main reason the port of Incheon ranks last.

Table 7. The Priority-weight Matrices for All Criteria and the Preference Weight of the Alternatives

	Priority Weights	**Preference Weights**			
		A1	A2	A3	A4
C1	0.130	0.321	0.321	0.036	0.321
C2	0.139	0.201	0.368	0.357	0.073
C3	0.125	0.438	0.239	0.124	0.199
C4	0.157	0.392	0.282	0.225	0.101
C5	0.177	0.435	0.215	0.123	0.228
C6	0.158	0.313	0.246	0.229	0.213
C7	0.113	0.299	0.237	0.240	0.225

Table 8. Normalized Matrix of Weighted Rates

	Priority Weights	**Preference Weights**				**Weighted Rates**			
		A1	A2	A3	A4	A1	A2	A3	A4
C1	0.130	0.321	0.321	0.036	0.321	0.042	0.042	0.005	0.042
C2	0.139	0.201	0.368	0.357	0.073	0.028	0.051	0.050	0.010
C3	0.125	0.438	0.239	0.124	0.199	0.055	0.030	0.015	0.025
C4	0.157	0.392	0.282	0.225	0.101	0.062	0.044	0.036	0.016
C5	0.177	0.435	0.215	0.123	0.228	0.077	0.038	0.022	0.040
C6	0.158	0.313	0.246	0.229	0.213	0.049	0.039	0.036	0.034
C7	0.113	0.299	0.237	0.240	0.225	0.034	0.027	0.027	0.025
Alternative Value						0.347	0.271	0.190	0.192
Rank						1	2	4	3

4.4. Sensitivity Analysis

The aim of the sensitivity analysis is to determine how sensitive the output of a model is with respect to the model elements that are subject to uncertainty. The weights assigned to each DM (Decision Maker) are influential in the MCDM results, therefore, applying a sensitivity analysis becomes essential in observing the impact each weight has on the final rankings (Animah et al., 2018). Notably, the data adopted in MCDM problems are normally uncertain and imprecise. As a result, performing a sensitivity analysis on the decision criteria data (input data) is a preferred application of MCDM for most of the previous researchers. This paper presents a methodology for performing a sensitivity analysis on the decision criteria weights and the performance values of the alternatives expressed in terms of the decision criteria (Triantaphyllou and Sanchez, 1997). In this research, the sensitivity analysis is conducted by raising and lowering the weights of each port by 10% (small change) and 50% (big change), respectively (Maliene et al, 2018), in the five most influential factors, including (C5) "total number of ships," (C2) "distance of bunkering shuttle," (C1) "average loading speed of LNG," (C6) "degree of safety," and (C4) "LNG bunkering demands of targeted ports," then observing the final ranking of all the alternatives. The results are shown in the two tables below:

As concluded from the two tables, there is no change in the final ranking of all the alternatives when increasing or decreasing the weights of the top five factors by 10% or by decreasing by 50%. Only when increasing the determinant factors by 50% did a slight change occur in the final ranking of alternatives, such that the ports of Ulsan and Incheon traded places with each other. However, the alternative values of the ports of Incheon and Ulsan are 0.264 and 0.263, respectively, which is only a 0.01 difference. This indicates that, only if a big change (or big error) occurred in these factors, there is a small possibility the results would change slightly, which supports the stability and reliability of these research findings. Moreover, when a 10% increase is applied to the weights of the top five factors, the alternative values of the ports of Incheon and Ulsan show a 0.01 difference, only, this time, the value of the port of Ulsan is higher. These two observations indicate that a fierce competition exists between these two ports. Also, when adding on the weights of the influential factors, the port of Incheon performs better than the port of Ulsan. As a result of the sensitivity analysis, we can conclude that the proposed research results are insensitive to possible errors, and in turn, provide reliable results.

Table 9. Weighted Score Differences when Increasing/Decreasing the Weights of the Top Five Factors by 10%

	Increase 10%				Decease 10%			
	A1	**A2**	**A3**	**A4**	**A1**	**A2**	**A3**	**A4**
C5	0.085	0.042	0.024	0.044	0.069	0.034	0.020	0.036
C2	0.031	0.056	0.055	0.011	0.025	0.046	0.045	0.009
C1	0.046	0.046	0.005	0.046	0.038	0.038	0.004	0.038
C6	0.054	0.043	0.040	0.037	0.045	0.035	0.033	0.030
C4	0.068	0.049	0.039	0.017	0.056	0.040	0.032	0.014
Alternative value	0.372	0.292	0.205	0.206	0.321	0.250	0.175	0.178
Rank	1	2	4	3	1	2	4	3

Table 10. Weighted Score Differences when Increasing/Decreasing the Weights of the Top Five Factors by 50%

	Increase 50%				Decease 50%			
	A1	**A2**	**A3**	**A4**	**A1**	**A2**	**A3**	**A4**
C5	0.115	0.057	0.033	0.061	0.038	0.019	0.011	0.020
C2	0.042	0.077	0.074	0.015	0.014	0.026	0.025	0.005
C1	0.063	0.063	0.007	0.063	0.021	0.021	0.002	0.021
C6	0.074	0.058	0.054	0.050	0.025	0.019	0.018	0.017
C4	0.093	0.067	0.053	0.024	0.031	0.022	0.018	0.008
Alternative value	0.476	0.378	0.264	0.263	0.218	0.164	0.116	0.121
Rank	1	2	3	4	1	2	4	3

5. Conclusions

The transport sector takes responsibility for the climate change as well as the global warming that contributed to the substantial greenhouse gas emissions produced by transportation activities (Pfoser et al., 2018). The polluting emissions generated from large ships are under more strict regulations by the IMO. In addition, even more strict requirements are applied to specific ECA (Armellini et al., 2017). With the purpose of increasing the sustainability of the transport sector, it is vital to introduce LNG as an alternative fuel for heavy-duty long-distance transportation (Pfoser et al., 2018). The Korean government showed an inclination to develop countrywide LNG and has released a construction plan for a new LNG bunkering port since no such infrastructure exists. This research takes South Korea as a case study to evaluate the top three ports, as well as the primary liquid port, all of which are selected as candidate ports. The CFPR methodology was employed to evaluate the ranking of the four alternatives based on not only quantitative factors but also qualitative factors. Seven evaluating factors were identified by experts who work in the MOF and have over 15 years' working experience. This reflects one of the advantages of the CFPR approach that knowledge and preference of well-experienced experts are taking into account which brings more sound and reliable results (Chang and Wang, 2009). According to the experts' preferences, (C5) "total number of ships," (C6) "degree of safety," and (C4) "LNG bunkering demands of targeted ports" were defined as the most important factors. Among which, the (C5) "total number of ships" is regarded as the most essential criteria on evaluating a port's performance by previous literatures (Cullinace et al., 2006; Talley and Ng, 2016). While (C6) "degree of safety" is considered as second important criteria on the LNG bunkering selection problem since LNG is a very dangerous resource to handle. Hence, how to manage the safety issue in order to avoid any accident is a quite vital issue. Meanwhile, the candidate ports were also evaluated by experts, and the port of Busan was regarded as the most suitable location in terms of the research topic, in contrast, the port of Incheon ranked last.

There are both academic and practical implications of this study. In terms of the academic implications, the influential factors identified by the experts in selecting the optimal location are useful when considering research themes for similar location selection. In addition, both quantitative factors, which refer to the collected real data, and qualitative factors, which refer to the experts' knowledge, are involved in the decision-making process. The combination of both quantitative and qualitative factors helps derive better results when using MCDM strategies. Decision-makers may use this study as a reference when making similar decisions about location selection problems. In light of the practical applications, most importantly, the Korean government could proceed with a clear vision of the candidate ports' ranking in terms of the LNG bunkering terminal selection problem. This would also aid in better decision-making when considering the construction plan. Additionally, according to the weights of each evaluation factor, the government would know which aspects of the targeted port need more attention. For instance, safety issue ranked second on the list. When constructing the LNG bunkering terminal, the infrastructures regarding safety and security need to be recognized as key construction projects. Eventually, this study will become fundamental for future research on selecting an optimal location from several alternatives.

However, there are also limitations to this study. The experts who participated in the research survey work for the government. In the future research, the results may be more objective when inviting more experts from other fields, such as those who work for shipping companies or shippers. Moreover, the evaluation process was conducted based on one specific case in South Korea, it maybe not feasible when considering similar research problems in different geographic locations.

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