LNG Transportation Routes Risk Assessment Based on Group Decision Making

Youran Dong, Shanghai Maritime University, China
Shiqun Ma, Shanghai Lixin University of Accounting and Finance, China*
Jiu Gao, Qingyi (Shanghai) Intelligent Technology Co., Ltd., China

ABSTRACT

The risk assessment of liquefied natural gas (LNG) transportation routes has raised researchers' concerns in recent years, which is a group multi-criteria decision-making (GMCDM) problems that involves experts' opinions from different fields. To improve the effectiveness in evaluating process, this paper proposes a risk assessment method to recognize the potential risks and selects the best LNG transportation route. Firstly, the authors construct the systematic risk evaluation indices, including four first-level indices (political, economic, transportation, and operation and management risks) and nine second-level indices. Then a novel risk assessment method of the LNG transportation route is developed, including opinion representation, consensus measurement and detection, personalized feedback, and selection process. Finally, a scenario analysis is provided to model the risk evaluation process and demonstrate the soundness and applicability of the presented model.

KEYWORDS

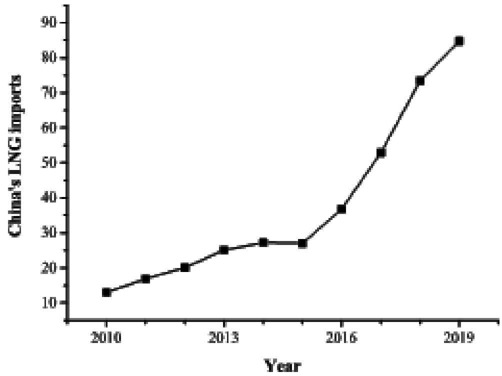
Consensus Reaching, Group Decision Making, LNG, Risk Assessment, Two-Tuple Linguistic Model

1. INTRODUCTION

Being cooled to a temperature of approximately -161 (-256) and at atmospheric pressure, natural gas condenses to a liquid (Foss & Head, 2007), known as Liquefied Natural Gas (LNG). LNG is an eco-friendly and efficient energy source because it is non-toxic and its combustion does not produce dust, particulate matter, air pollution materials, etc. Lots of advanced economics, therefore, increase the consumption of LNG to use it as fuel, fertilizers, chemical raw materials, and plastic products to mitigate environmental pollutions. China also consumes and imports more LNG in recent years. It imported 84.8 billion cubic meters of LNG in 2019, being the second largest country of LNG import, behind Japan (Looney, 2020). Fig.1 shows the rapid increase of China's LNG imports in the past decade. To meet the need for LNG consumption, China imports LNG from Australia, Qatar, Indonesia, and other LNG exporters. LNG is usually transported by ship, with being preferable for long distances and large quantities. As of April 2019, there were 21 operated LNG terminals across China with an annual receiving capacity of over 80 million tons. LNG shipping rates vary seasonally and reach their highest in winter. According to a news report on Freightwaves (Miller, 2020), spot rates for tri-fuel, diesel-electric (TFDE) propulsion LNG carriers were average $112,500 per day, and rates for M-type, electronically controlled, gas-injection (MEGI) propulsion carriers were at

DOI: 10.4018/IJFSA.309423
*Corresponding Author

Figure 1. Growth of China's LNG imports in the past decade



$125,000 per day in December 2020. If a route is blocked, ships will be forced to seek other longer and more expensive routes, thus increasing the time and costs. Since accidents and delays during LNG transportation will result in a high cost of shipping rates, risk assessment of LNG transportation routes is significant and necessary.

The safety of LNG transportation has raised much attention. Some researchers showed interest in the safety of LNG ports and terminals.

Yun et al. (Yun et al., 2009) used the Bayesian-LOPA methodology to assess the risk of LNG importation terminals. George et al. (George et al., 2019) applied fuzzy failure mode effect and criticality analysis on unloading facility of the LNG terminal. Elsayed et al. (Elsayed, 2009) proposed a fuzzy inference system for the risk assessment of liquefied natural gas carriers during loading and offloading at terminals. Zhao et al. (Zhao et al., 2015) analyzed the risks in the LNG carrier anchoring system. Perkovic et al. (Perkovic et al., 2012) proposed a collision and grounding risk assessment with Automatic Identification System (Khan et al.). Guo et al. (Guo et al., 2017) studied on the economic channel design for LNG ships using the Pedersen grounding model. Zhou et al. (Zhou et al., 2015) made a safety assessment of LNG carriers based on fault tree analysis.

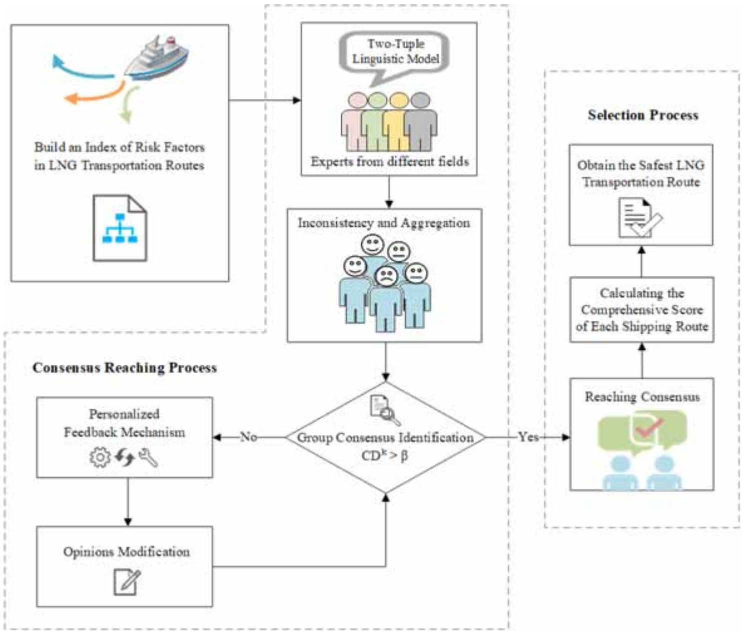
Some researchers discussed the safety of LNG storage in transportation. Wu et al. (Wu et al., 2021) used an integrated Bayesian-Catastrophe-EPE (Energy transfer theory, Preliminary hazard analysis and Evolution tree) method to quantify hazards of LNG leakage. Jeong et al. (Jeong et al., 2018) applied Integrated Quantitative Risk Assessment (IQRA) to the safety for LNG bunkering at the fuel-supplying point. Zhu et al. (Zhu et al., 2021) analyzed terrorist attacks on LNG storage tanks at ports.

Some researchers studied the risk assessment of transportation systems. Berle et al. (Berle et al., 2013) used supply chain simulation and Monte Carlo simulation to explore the optimization, risk assessment, and resilience in LNG transportation systems. Nwaoha et al. (Nwaoha et al., 2013) proposed computational techniques to hazards ranking in LNG carrier operations, using a risk matrix and a fuzzy evidential reasoning method.

As mentioned above, many scholars use various methods to assess risks in different aspects such as LNG ports, storage, and transportation system. Their studies have made outstanding contributions to various fields such as navigation, engineering, and economics.

Nevertheless, much limitation has been found on the existing risk assessment.

Figure 2. Framework of risk assessment of LNG transportation routes based on GDM



(1) Risk assessment is essentially a group multi-criteria decision making (GMCDM) problem and involves complex consensus reaching process, and only a few researchers assess the risks of LNG transportation routes in recent years considering the group interaction process.
(2) Existing studies force inconsistent experts to adopt feedback and modify their opinions without considering the extent of changes (Cao et al., 2020).

Thus, this paper proposes a novel risk assessment method for LNG shipping transportation routes. Firstly, the authors construct the evaluation indices of risk factors in LNG transportation routes. Then, the experts from different fields provide their opinions on the risks of LNG transportation routes by the two-tuple linguistic model. However, there exists inevitably inconsistency because of different viewpoints from individuals. Therefore, the elimination or lessening of inconsistency is essential in group decision making (GDM) problem. As the development of GDM improves, some feedback mechanisms emerge and are divided into three sorts (Cao et al., 2020): traditional one, unpersonalized one, and personalized one. The authors choose the personalized one as our feedback mechanism. As a result, it balances individual independence and group consistency. Finally, the best route for LNG transportation is evaluated.

2. CONSTRUCTION OF EVALUATION INDEX SYSTEM

According to extensive literature (Abdussamie et al., 2018; Antao & Soares, 2012; Balmat et al., 2009; Bubbico et al., 2009; Hightower et al., 2004; Huang, 2012; Khan et al., 2018; Lu & Wang, 2015; Nwaoha et al., 2013; Østvik et al., 2005; Paltrinieri et al., 2015; Perkovic et al., 2012; Vanem et al., 2008; Whitmore et al., 2009; Wu et al., 2021; Xu & Wu, 2019; Zhao et al., 2015; Zhu et al., 2021), the authors develop a risk evaluation indices, including four first-level indices and nine second-level indices (Table 1) .

Table 1. Risk indices of LNG transportation routes

First-level Indices	Second-level indices	Citations
Political risks	policy decisions of government	(Huang, 2012)
	intervention of foreign forces	(Lu & Wang, 2015; Nwaoha et al., 2013; Xu, 2019)
Economic Risks	fuel price	(Xu, 2019)
	vessel age	(Balmat et al., 2009; Wu et al., 2021; Xu, 2019)
Transportation Risks	natural environment	(Antao & Soares, 2012; Balmat et al., 2009; Hightower et al., 2004; Khan et al., 2018; Nwaoha et al., 2013; Østvik et al., 2005; Vanem et al., 2008; Wu et al., 2021; Xu, 2019; Zhao et al., 2015)
	shipping route distance	(Lu & Wang, 2015; Zhao et al., 2015)
	security of transit areas	(Bubbico et al., 2009; Hightower et al., 2004; Lu & Wang, 2015; Nwaoha et al., 2013; Østvik et al., 2005; Paltrinieri et al., 2015; Whitmore et al., 2009; Wu et al., 2021; Zhu et al., 2021)
Operation & Management Risks	incorrect operations	(Abdussamie et al., 2018; Antao & Soares, 2012; Østvik et al., 2005; Wu et al., 2021; Zhao et al., 2015)
	shortage of crew	(Østvik et al., 2005)

2.1 Political Risks

Political risks refer to the possibility of blockade and detour in LNG shipping routes because of political reasons, including policy decisions of government or the intervention of foreign forces. Huang (Huang, 2012) considered that the government may shut down the LNG ports, resulting in suspension of LNG production or port loading and unloading. He also mentions the compulsory requisition, takeover, detention, or confiscation of LNG transport ships and blockade of canals, waterways, and harbors. So, policy decisions of government is selected in our indices.

The intervention of foreign forces is about trade wars and diplomatic conflicts. Nwaoha et al. (Nwaoha et al., 2013) mentioned the war action and Paltrinieri et al. (Paltrinieri et al., 2015) discussed the malicious intervention. Based on these researches, the intervention of foreign forces is selected in our indices.

2.2 Economic Risks

Economic risks include two factors, fuel prices, and vessel age. Fuel price is the direct cost factor because rising costs are not conducive to the long-term operations of shipping companies. In Xu et al.'s research (Xu & Wu, 2019), they obtained the result that fuel price is an important risk factor by analysis hierarchy process (AHP) method.

Vessel age is considered in some studies (Balmat et al., 2009; Wu et al., 2021; Xu & Wu, 2019). Wu et al. argue that the material properties of tanks and ship bases deteriorate in the absence of maintenance or over vessel age. Balmat et al. (Balmat et al., 2009) analyzed the risk of the year of ship's construction. Based on these research, fuel price and vessel age are selected in our indices.

2.3 Transportation Risks

Transportation risks include three factors, i.e., natural environment, shipping route length, and security of transit areas. Most of studies (Antao & Soares, 2012; Khan et al., 2018; Nwaoha et al., 2013; Østvik et al., 2005; Vanem et al., 2008; Wu et al., 2021; Xu & Wu, 2019; Zhao et al., 2015) mentioned heavy the weather may cause accidents during the transportation of LNG. Zhao et al. (Zhao et al., 2015) further refined the natural risks and divide them into three indicators, depths of water, wind, wave and stream, visibility, and substrate of anchorage. Nwaoha et al. (Nwaoha et al., 2013) mentioned lightning and earthquake. Hightower et al. (Hightower et al., 2004) considered wind and atmospheric conditions and Balmat et al. (Balmat et al., 2009) mentioned wind speed and visibility. Based on these research, the natural environment is selected in our indices.

Shipping route length is considered in Xu et al.'s study (Xu & Wu, 2019). They thought the risk increase as the shipping route distance increase due to the growing cost. The authors also think the longer route distance will increase the possibility to meet more other unpredictable risks, such as severe weather.

Security of transit areas represents the frequency of piracy and terrorist attacks. In some studies (Bubbico et al., 2009; Lu & Wang, 2015; Østvik et al., 2005; Paltrinieri et al., 2015; Whitmore et al., 2009; Wu et al., 2021; Zhu et al., 2021), terrorist attacks were selected as a risk factor. Besides, Nwaoha et al. (Nwaoha et al., 2013) mentioned sabotage. Hightower et al. (Hightower et al., 2004) refined insider takeover or hijacking. Based on these research, security of transit areas is selected in our indices.

2.4 Operation and Management Risks

Management risks include two factors, incorrect operations, and shortage of crew. Abdussamie et al. (Abdussamie et al., 2018) discussed several pilot's mistakes and Østvik et al. (Østvik et al., 2005) mentioned crew falls or slips onboard. Nwaoha et al. (Nwaoha et al., 2013) considered operating error and Wu et al. (Wu et al., 2021) mentioned misoperation. Zhao et al. (Zhao et al., 2015) considered lack of professional training and operation negligence. Antao et al. (Antao & Soares, 2012) and Venom et al. (Vanem et al., 2008) mentioned equipment and machinery failure. Besides, Østvik (Østvik et al., 2005) also mentioned shortage of crew. According to these research, incorrect operations and shortage of crew are selected in our indices.

3.A NOVEL RISK ASSESSMENT METHOD OF LNG TRANS- PORTATION ROUTES

3.1 Opinion Representation

Data extraction is a complex problem, especially when dealing with information coming from human beings (e.g., linguistic assertions, preferences, feelings, etc.) (Truck, 2015). Many aspects of different activities in the real world can hardly be assessed in a quantitative form, but rather in a qualitative one, namely, with vague or imprecise knowledge(Yu, Li, & Fei, 2018). In that case, a better approach is to use linguistic assessments instead of numerical values (Herrera & Martínez, 2000). Also, with the develop of modern technology, fuzzy cognition has become an important problem in various fields, including economy, business, management(Li & Liu, 2020). Many research has studied the group decision problem with linguistic assessments. Yu et al.(Yu, Li, Qiu, et al., 2018) presented a method to solve multi-attribute group decision making problems with intuitionistic uncertain 2-tuple linguistic variables. They also presented an interval-valued multiplicative hesitant fuzzy preference structure to quantify the preference information and proposed information aggregation methods(Yu & Li, 2016). Zuo et al.(Zuo et al., 2019) use linear programming technique to process evaluation data of property perceived service quality, which integrates the large-scale heterogeneous data of expert preference and user evaluation. In this paper, we use the classic two-tuple linguistic model to overcome difficulties in expressing fuzzy evaluation data.

Herrera and Martinez (Herrera & Martínez, 2000) introduced the basic notations and operational laws of linguistic variables. The two-tuple fuzzy linguistic representation model represents the linguistic information with a two-tuple $\left(s_t, \alpha_t\right)$, where s_t is a linguistic label and $\alpha_t \in \left[-0.5, 0.5\right)$ is a symbolic propotion of s_t. Let $S = \left\{s_t | t = 0,1,2,\dots g\right\}$ be a linguistic term set and $\beta \in \left[0, g\right]$ a value supporting the result of a symbolic aggregation operation. For example, S with ten terms can be defined as

$$S = \begin{Bmatrix} s_0 = \text{extremely poor;} \\ s_1 = \text{very poor;} \\ s_2 = \text{poor;} \\ s_3 = \text{slightly poor;} \\ s_4 = \text{fair;} \\ s_5 = \text{slightly good;} \\ s_6 = \text{good;} \\ s_7 = \text{very good;} \\ s_8 = \text{extremely good;} \\ s_9 = \text{perfect.} \end{Bmatrix}$$

and $\left(s_{2,} 0.1\right)$ means ten percent better than 'poor' but cannot reach the level 'slightly poor'. Some researchers give out algorithms about the two-tuple linguistic model.

Definition 1. (Chen & Fan, 2004) Suppose $S = \left\{s_0, s_1, \dots, s_g\right\}$ is an ordered linguistic term set, and $s_i \in S$ represents the *i*-th linguistic term, then its corresponding subscript i can be obtained by the following function I

$$I : S \to N$$
$$I\left(s_i\right) = i, s_i \in S$$

Definition 2. (Chen & Fan, 2004) Suppose $S = \left\{s_0, s_1, \dots, s_g\right\}$ is an ordered linguistic term set, and $s_i \in S$ represents the *i*-th linguistic term, then the representation of the ordered language phrase corresponding to the ordinal i is obtained by the Equation (2).

$$I^{-1} : N \to S$$
$$I^{-1}\left(i\right) = \begin{cases} s_0, & i \le 0 \\ s_i, & 1 \le i \le r - 1 \\ s_r, & i \ge r \end{cases} \tag{2}$$

Definition 3. (Yan, 2012) Suppose $S = \left\{s_0, s_1, \dots, s_g\right\}$ is an ordered linguistic term set, and $a \in S$, $b \in S$, the 'distance' between two descriptions a and b is

$$d\left(a,b\right)=\left|I\left(a\right)-I\left(b\right)\right| \tag{3}$$

Definition 4. (Herrera & Martínez, 2000) The two-tuple that expresses the equivalent information to β is obtained with the following function

$$\begin{aligned}&\Delta:\left[0,g\right]\to S\times\left[-0.5,0.5\right)\\&\Delta\left(\beta\right)=\begin{cases}s_i & i=\text{round}\left(\beta\right)\\ \alpha=\beta-i & \alpha\in\left[-0.5,0.5\right)\end{cases}\end{aligned} \tag{4}$$

where round$\left(\cdot\right)$ is the rounding operation, s_i has the closest index label to β and α is the value of the symbolic translation.

3.2. Consensus Measurement and Detection

Consensus degrees based on distance functions can calculate the actual agreement level in GDM problems. Various research has studied measurement and detection of consensus degree and used a proper feedback mechanism to improve the agreement level of experts, which is a crucial problem in group decision making. Cao et al.(Cao et al., 2021) propose a bidirectional feedback mechanism and enable experts with conflict behavior, tolerance behavior, and rationalist behavior to align with each other. Wang et al.(Wang et al., 2022) investigate a two-stage consensus feedback mechanism based on the Louvain algorithm to make individual experts reach consensus. Xing et al.(Xing et al., 2022) studied the consensus reaching process based on the Choquet integral with interval type-2 trapezoidal fuzzy and finally get the group and individual consensus evaluation matrices. Inspired by previous research, this paper assumes that the consensus degree is divided into two sorts: (1) based on distances to the aggregated group preference; (2) based on pairwise distances between experts' preferences.

Definition 5 (Two-tuple linguistic matrix). The two-tuple linguistic matrix of expert E_k is

$$\left\{E_k=\left(v_{ij}^k\right)_{p\times q},k=1,\ldots,m\right\} \tag{5}$$

where $v_{ij}^k=\left(s_t^k,\alpha_t^k\right)$ is the decision of expert e_k on the alternative $A_i\left(i=1,\ldots,p\right)$ with the respect to the factor $C_j\left(j=1,\ldots,q\right)$.

Based on Definition 3, the authors define distance functions to describe the difference between expert e_k and e_x.

Definition 6 (Distance between opinions). v_{ij}^k and v_{ij}^x are the decisions of expert e_k and e_x on the alternative $A_i\left(i=1,\ldots,p\right)$ with the respect to the factor $C_j\left(j=1,\ldots,q\right)$, respectively, and the distance function between them is

$$d\left(v_{ij}^x,v_{ij}^k\right)=\left|I\left(v_{ij}^x\right)-I\left(v_{ij}^k\right)\right| \tag{6}$$

Definition 7.(Cao et al., 2020; Wu et al., 2020) Starting with the integrated matrix $\left\{\overline{E} = \left(\overline{v}_{ij}\right)_{p\times q}\right\}$, where $\overline{v}_{ij} = \frac{1}{p}\sum_{i=1}^{p} I\left(v_{ij}^{k}\right)$. The element of the intergrated matrix is defined as $I^{-1}\left(\overline{v}_{ij}\right) = \left(\overline{s_t}, \overline{\pm_t}\right)$. After that, the consensus degree of an expert can be evaluated at three hierarchical levels.

Level 1. Element of Alternative Level. The consensus level between expert e_k and the whole group at the element of alternative level is

$$CE_{ij}^{k} = 1 - \left|I\left(v_{ij}^{k}\right) - I\left(\overline{v}_{ij}\right)\right| \tag{7}$$

Level 2. Alternative Level. The consensus level of experts e_k on alternatives A_i is

$$CA_{i}^{k} = \sum_{j=1}^{q} w_j \cdot CE_{ij}^{k} \tag{8}$$

where w_j is the weight of each factor, and it will be calculated in the following paragraph.

Level 3. Decision Matrix Level. The consensus level of experts e_k is

$$CD^{k} = \frac{1}{p}\sum_{i=1}^{p} CA_{i}^{k} \tag{9}$$

Now the authors need to obtain a way to calculate the weight of each risk index in Table 1. Zhou et al. (Zhou & Wei, 2010) invented a method based on maximized deviation in group decision-making, and based on his research, the method of determining the weight of factor is given.

Firstly, the authors need to calculate the deviation of the whole group on a factor C_j. To reach a higher consensus level, the higher the deviation, the lower the weight of that factor.

Definition 8. The difference level between expert e_k and the whole group on C_j is

$$\Delta_{j}^{k} = \sum_{k=1,k\neq p}^{m} d\left(v_{ij}^{k}, \overline{v}_{ij}\right); i = 1,2,\ldots,p; j = 1,2,\ldots,q \tag{10}$$

The deviation of whole group on factor C_j is

$$\Delta_{j} = \frac{1}{p}\sum_{k=1}^{p} \Delta_{j}^{k} \tag{11}$$

Finally, the weight $w_j^{'}$ of each factor C_j is

$$w_j^{'} = 1 - \frac{\Delta_j}{\sum_{j=1}^{q} \Delta_j} \tag{12}$$

The weight w_j is obtained after normalization

$$w_j = \frac{w_j^{'}}{\sum_{j=1}^{q} w_j^{'}} \tag{13}$$

3.3. Personalized Feedback

If the consensus level CD^k of experts e_k is smaller than the predefined threshold value β, which should be between 0.5 and 1, they should modify their opinions through a personalized mechanism. The discordant experts, alternatives, and elements whose consensus degree is below the threshold value are identified with the following rules. (Cao et al., 2020)
The experts with consensus degree at decision matrix level below the threshold β are identified as

$$ECH = \left\{ h \middle| CD^h < \beta \right\} \tag{14}$$

The inconsistent experts' alternatives with consensus degree below β are identified as

$$ACH = \left\{ \left(h, i\right) | h \in ECH \wedge CA_i^h < \beta \right\} \tag{15}$$

Step 3. Finally, the elements of alternatives where consensus degree is below the threshold β are identified as

$$APS = \left\{ \left(h, i, j\right) | \left(h, i\right) \in ACH \wedge CE_{ij}^h < \beta \right\} \tag{16}$$

Given $h \in ECH$, then $APS_{ij}^h = \left\{ \left(i, j\right) | \left(h, i, j\right) \in APS$ is the set of inconsistent elements in the decision matrix of E_h by the inconsistent expert e_h.

Definition 9 (Individual Harmony Degree). The individual harmony degree of each element in the decision matrix E_h is

$$IHD_{ij} = \left| v_{ij}^{h'} - v_{ij}^{h} \right| \tag{17}$$

where the modified opinion $v_{ij}^{h'}$ will be calculated in Equation (20).

Definition 10 (Harmony Degree). The harmony degree of expert e_h is

$$HD_h = 1 - \frac{1}{pq}\sum_{i=1}^{p}\sum_{j=1}^{q} IHD_{ij} \tag{18}$$

Definition 11 (Group Harmony Degree). The group harmony degree in personalized feedback mechanism, and

$$GHD = \frac{1}{n}\sum_{h=1}^{n} HD_h \tag{19}$$

Definition 12 (Personalized feedback). For $(h,i,j) \in APS$, the original value v_{ij}^{k} is advised to be modified according to the following moderator's feedback

$$v_{ij}^{h'} = \left(1-\delta_h\right)\cdot v_{ij}^{h} + \delta_h \cdot v_{ij}^{-h} \tag{20}$$

where $v_{ij}^{-h} = \left(1/n-1\right)\sum_{q=1,q\neq h}^{n} v_{ij}^{q}$. Also, $I^{-1}\left(v_{ij}^{h'}\right) = \left(s_t^{h'}, \alpha_t^{h'}\right)$.

According to Cao et al. (Cao et al., 2020), a personalized feedback model is proposed to find out the feedback parameter δ_h, which are subsequently used by the moderator to give feedback to inconsistent experts and make the group consensus go above the threshold β.

Construction of Personalized Feedback Model: Based on Definition 11, the following optimal model to generate personalized feedback advice to reach maximum harmony degree is constructed.

$$\begin{cases} \text{Max} : GHD \\ \quad \text{s.t.} \begin{cases} \text{CD}^{h} \geq \beta\left(h = 1,\ldots,n\right) \\ 0 \leq \delta_h \leq 1 \\ \delta_h \leq \delta_{h+1} \end{cases} \end{cases} \tag{21}$$

3.4. Selection Process

After reaching a suitable consensus degree, the authors proposed a selection process by fusing the preferences of individual experts and obtain the final ordering of the considered alternatives (Cao et al., 2020). The element v_{ij} of the integrated decision matrix $E = \left\{\left(v_{ij}\right)_{p\times q}\right\}$ is

$$v_{ij} = \frac{1}{p}\sum_{i=1}^{p} I\left(v_{ij}^{h'}\right) \tag{22}$$

Then, the score of A_i, will be calculated as

$$SC_i = \sum_{j=1}^{q} w_j v_{ij} \tag{23}$$

Finally, the A_i of the highest score is selected as the best route.

4. NUMERICAL EXAMPLE

4.1. Consensus Degree

To testify the advantages of the proposed method, a numerical case is presented in this section. To get the risk assessment of four LNG transportation shipping routes under nine criteria, the experts' opinions are shown in the matrices below. Table 2 shows the difference between experts and groups on factor C_j.

$$E_1 = \begin{pmatrix} & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 & C_9 \\ A_1 & (s_7,0) & (s_8,-0.3) & (s_7,-0.5) & (s_7,0) & (s_7,0.2) & (s_3,-0.2) & (s_7,0.2) & (s_7,0.2) & (s_7,0.5) \\ A_2 & (s_7,0.2) & (s_8,0) & (s_7,0) & (s_6,-0.4) & (s_7,0.1) & (s_4,0) & (s_7,0.5) & (s_7,0) & (s_7,0.5) \\ A_3 & (s_7,0.1) & (s_7,0.5) & (s_6,-0.5) & (s_7,0.3) & (s_7,-0.5) & (s_6,-0.5) & (s_8,0.4) & (s_7,-0.5) & (s_8,0.3) \\ A_4 & (s_7,0.4) & (s_8,-0.5) & (s_5,-0.5) & (s_7,-0.5) & (s_4,0.3) & (s_7,-0.5) & (s_7,0.4) & (s_7,0) & (s_7,0.1) \end{pmatrix}$$

$$E_2 = \begin{pmatrix} & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 & C_9 \\ A_1 & (s_7,-0.2) & (s_8,-0.5) & (s_7,0) & (s_7,0.4) & (s_8,-0.5) & (s_3,-0.3) & (s_7,0.1) & (s_8,-0.5) & (s_7,0.3) \\ A_2 & (s_7,0.4) & (s_8,0.2) & (s_7,0.1) & (s_6,-0.2) & (s_7,0.2) & (s_4,0.3) & (s_7,0.4) & (s_7,0.2) & (s_8,-0.5) \\ A_3 & (s_7,-0.1) & (s_7,0.2) & (s_6,-0.2) & (s_8,-0.5) & (s_6,0.1) & (s_6,-0.2) & (s_9,-.5) & (s_7,-0.2) & (s_9,-0.5) \\ A_4 & (s_7,0.2) & (s_8,-0.5) & (s_5,-0.4) & (s_6,0.3) & (s_6,0.2) & (s_7,0.3) & (s_7,0.3) & (s_7,-0.2) & (s_7,0.2) \end{pmatrix}$$

$$E_3 = \begin{pmatrix} & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 & C_9 \\ A_1 & (s_7,0.1) & (s_8,-0.5) & (s_7,-0.5) & (s_7,0.3) & (s_7,-0.1) & (s_3,0) & (s_8,-0.5) & (s_7,0.1) & (s_8,-0.4) \\ A_2 & (s_7,0.1) & (s_8,0.2) & (s_7,0) & (s_6,0.1) & (s_8,-0.5) & (s_4,0.2) & (s_8,0) & (s_7,0) & (s_7,0.2) \\ A_3 & (s_7,-0.2) & (s_8,-0.5) & (s_5,0.4) & (s_8,-0.4) & (s_7,-0.2) & (s_5,0.1) & (s_8,0.1) & (s_6,0.4) & (s_8,0.4) \\ A_4 & (s_8,-0.2) & (s_7,0.3) & (s_5,-0.2) & (s_7,-0.5) & (s_5,-0.2) & (s_7,-0.4) & (s_7,0) & (s_7,-0.2) & (s_7,0.4) \end{pmatrix}$$

$$E_4 = \begin{pmatrix} & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 & C_9 \\ A_1 & (s_7,0) & (s_8,-0.3) & (s_7,-0.4) & (s_7,0.1) & (s_7,0.4) & (s_3,-0.2) & (s_8,-0.5) & (s_7,0.2) & (s_8,-0.5) \\ A_2 & (s_7,0.3) & (s_8,0.1) & (s_7,0.2) & (s_6,-0.4) & (s_7,0.2) & (s_4,0.2) & (s_8,-0.2) & (s_7,-0.2) & (s_8,-0.5) \\ A_3 & (s_7,0) & (s_7,0.3) & (s_5,0.4) & (s_7,0.2) & (s_7,-0.5) & (s_6,-0.4) & (s_8,0.4) & (s_7,-0.5) & (s_9,-0.5) \\ A_4 & (s_8,-0.4) & (s_7,-0.5) & (s_5,-0.4) & (s_7,-0.5) & (s_5,-0.5) & (s_7,-0.5) & (s_7,0.1) & (s_7,0.1) & (s_7,0.2) \end{pmatrix}$$

So, the deviation of whole group on each factor is

$$\Delta_1 = 2.35, \Delta_2 = 1.6, \Delta_3 = 2.2, \Delta_4 = 2.55, \Delta_5 = 3.45, \Delta_6 = 2.6, \Delta_7 = 3.1, \Delta_8 = 2.4, \Delta_9 = 1.7$$

Table 2. Difference between experts and groups on factor

Δ_j^k	$j=1$	$j=2$	$j=3$	$j=4$	$j=5$	$j=6$	$j=7$	$j=8$	$j=9$
$k=1$	1.9	1.6	1.8	2.3	3.1	2.2	2.8	1.8	1.6
$k=2$	2.7	1.6	3.2	2.7	3.5	3.2	3.2	3.4	1.6
$k=3$	3.1	1.8	1.8	2.9	4.7	3.2	3.8	2.0	2.4
$k=4$	1.7	1.4	2.0	2.3	2.5	1.8	2.6	2.4	1.2

Then, the weight of each factor can be calculated as

$$w_1^{'} = 0.893, w_2^{'} = 0.927, w_3^{'} = 0.900,$$
$$w_4^{'} = 0.884, w_5^{'} = 0.843, w_6^{'} = 0.882,\ w_7^{'} = 0.859, w_8^{'} = 0.891, w_9^{'} = 0.923.$$

After normalization

$$w_1 = 0.112, w_2 = 0.116, w_3 = 0.112,$$
$$w_4 = 0.110, w_5 = 0.105, w_6 = 0.110,$$
$$w_7 = 0.107, w_8 = 0.111, w_9 = 0.115.$$

Figure 3. Weight of each risk factor

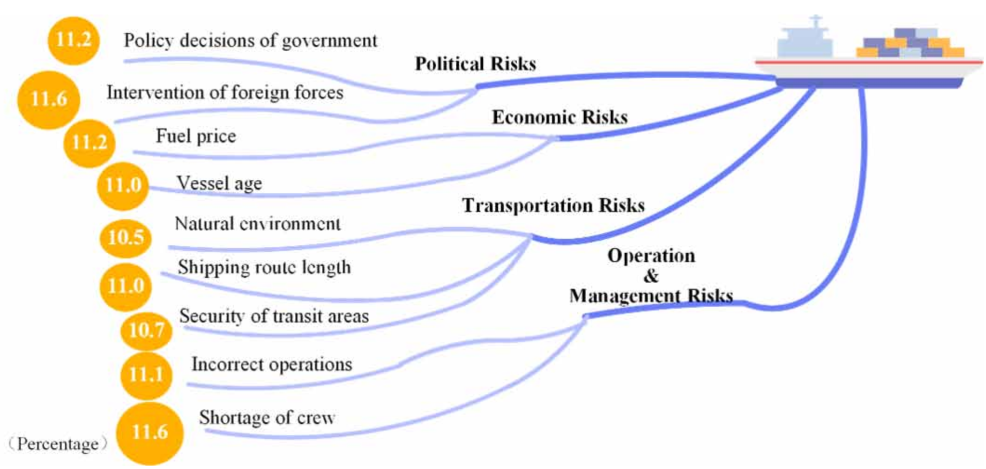


Table 3. Element of alternative level CE_{ij}^{1}

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.975	0.9	0.85	0.8	0.95	**0.975**	0.875	0.975	0.975
A_2	0.95	0.875	0.925	0.825	0.85	**0.825**	0.825	1	0.925
A_3	0.85	0.875	0.975	0.9	0.975	**1**	0.95	0.95	0.875
A_4	0.95	0.95	0.9	0.95	0.75	**0.95**	0.8	0.925	0.875

Table 4. Element of alternative level CE_{ij}^{2}

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.825	0.9	0.65	0.8	0.75	0.875	0.775	0.725	0.825
A_2	0.85	0.925	0.975	0.975	0.95	0.875	0.725	0.8	0.925
A_3	0.95	0.825	0.725	0.9	0.625	0.7	0.9	0.625	0.7
A_4	0.750	0.95	0.9	0.85	0.95	0.75	0.9	0.875	0.975

Table 5. Element of alternative level CE_{ij}^{3}

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.875	0.9	0.85	0.9	0.65	0.825	0.825	0.875	0.875
A_2	0.85	0.925	0.925	0.675	0.75	0.975	0.675	1.0	0.775
A_3	0.85	0.875	0.875	0.8	0.675	0.6	0.75	0.85	0.975
A_4	0.65	0.9	0.9	0.95	0.75	0.85	0.8	0.875	0.825

Table 6. Element of alternative level CE_{ij}^{4}

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
A_1	0.975	0.9	0.95	0.9	0.85	0.975	0.825	0.875	0.975
A_2	0.95	0.975	0.875	0.825	0.95	0.875	0.8	0.925	0.875
A_3	0.95	0.925	0.875	0.8	0.975	0.95	0.95	0.925	0.95
A_4	0.95	0.95	0.9	0.95	0.95	0.95	0.9	0.825	0.975

In the assessment of LNG transportation routes, the authors assume equal weights for all factors, then the consensus level between experts e_k and e_x is

$$CA_1^1 = 0.918,\ CA_2^1 = 0.888,\ CA_3^1 = 0.925,\ CA_4^1 = 0.894$$
$$CA_1^2 = 0.791,\ CA_2^2 = 0.888,\ CA_3^2 = 0.806,\ CA_4^2 = 0.876$$
$$CA_1^3 = 0.842,\ CA_2^3 = 0.839,\ CA_3^3 = 0.806,\ CA_4^3 = 0.827$$
$$CA_1^4 = 0.913,\ CA_2^4 = 0.904,\ CA_3^4 = 0.915,\ CA_4^4 = 0.926$$

So, the consensus level is

$$CD_1 = 0.906, CD_2 = 0.840, CD_3 = 0.828, CD_4 = 0.915.$$

The threshold β is assumed as 0.85, so expert e_2, e_3 should modify their opinions through personalized mechanism.

4.2. Personalized Feedback

According to Section 3.3, the authors get

$$ECH = \{2,3\}$$
$$ACH = \{(2,1),(2,3),(3,1),(3,2),(3,3),(3,4)\}$$
$$APS_h = \begin{Bmatrix} (2,1,1), & (2,1,3), & (2,1,4), & (2,1,5), & (2,1,7), & (2,1,8), & (2,1,9), & (2,3,2), & (2,3,3), \\ (2,3,5), & (2,3,6), & (2,3,8), & (3,1,5), & (3,1,6), & (3,1,7), & (3,2,4), & (3,2,5), & (3,2,7), \\ (3,2,9), & (3,3,4), & (3,3,5), & (3,3,6), & (3,3,7), & (3,4,1), & (3,4,5), & (3,4,7), & (3,4,9). \end{Bmatrix}$$

According to Equation (21), expert e_2 and e_3 are advised to modify their opinions. The feedback parameters and group harmony degree are $\delta_2 = 0.064, \delta_3 = 0.182$ and $GHD = 0.98$, respectively. After turning the modified opinions into two-tuple linguistic form, we get

$$E_2' = \begin{pmatrix} & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 & C_9 \\ A_1 & (s_7,-0.19) & (s_8,-0.5) & (s_7,-0.03) & (s_7,0.39) & (s_7,0.48) & (s_3,-0.3) & (s_7,0.12) & (s_7,0.48) & (s_7,0.31) \\ A_2 & (s_7,0.4) & (s_8,0.2) & (s_7,-0.1) & (s_6,-0.2) & (s_7,0.2) & (s_4,0.3) & (s_7,0.4) & (s_7,0.2) & (s_8,-0.5) \\ A_3 & (s_7,-0.1) & (s_7,0.21) & (s_6,-0.22) & (s_8,-0.5) & (s_6,0.13) & (s_6,-0.22) & (s_9,-0.5) & (s_7,-0.22) & (s_9,-0.5) \\ A_4 & (s_7,0.2) & (s_8,-0.5) & (s_5,-0.4) & (s_6,0.3) & (s_6,0.2) & (s_7,0.3) & (s_7,0.3) & (s_7,-0.2) & (s_7,0.2) \end{pmatrix}$$

$$E_3' = \begin{pmatrix} & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 & C_9 \\ A_1 & (s_7,0.1) & (s_8,-0.5) & (s_7,-0.5) & (s_7,0.3) & (s_7,-0.02) & (s_3,-0.04) & (s_7,0.46) & (s_7,0.1) & (s_8,-0.4) \\ A_2 & (s_7,0.1) & (s_8,0.2) & (s_7,0) & (s_6,0.03) & (s_7,0.44) & (s_4,0.2) & (s_8,-0.08) & (s_7,0) & (s_7,0.25) \\ A_3 & (s_7,-0.2) & (s_8,-0.5) & (s_5,0.4) & (s_8,-0.45) & (s_7,-0.28) & (s_5,0.19) & (s_8,0.16) & (s_6,0.4) & (s_8,0.4) \\ A_4 & (s_8,-0.28) & (s_7,0.3) & (s_5,-0.2) & (s_7,-0.5) & (s_5,-0.26) & (s_7,-0.4) & (s_7,0.05) & (s_7,-0.2) & (s_7,0.36) \end{pmatrix}$$

And the consensus level after modification is
$CD_1' = 0.911, CD_2' = 0.850, CD_3' = 0.850, CD_4' = 0.915.$

4.3. Selection Process

The final matrix is

$$E = \begin{pmatrix} & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 & C_9 \\ A_1 & (s_7,-0.021) & (s_8,-0.4) & (s_7,-0.357) & (s_7,0.196) & (s_7,0.266) & (s_3,-0.186) & (s_7,0.319) & (s_7,0.219) & (s_7,0.479) \\ A_2 & (s_7,0.250) & (s_8,0.125) & (s_7,0.075) & (s_6,-0.245) & (s_7,0.235) & (s_4,0.175) & (s_8,-0.345) & (s_7,0) & (s_7,0.439) \\ A_3 & (s_7,-0.050) & (s_7,0.379) & (s_6,-0.481) & (s_7,0.388) & (s_6,0.463) & (s_6,-0.482) & (s_8,0.365) & (s_7,-0.455) & (s_8,0.425) \\ A_4 & (s_7,0.429) & (s_7,0.450) & (s_5,-0.300) & (s_6,0.450) & (s_5,-0.465) & (s_6,0.450) & (s_7,0.212) & (s_7,-0.075) & (s_7,0.214) \end{pmatrix}$$

Table 7. Risk Scores

Shipping route	A_1	A_2	A_3	A_4
Risk score	(s_7 , -0.283)	(s_7 , -0.149)	(s_7 , -0.058)	(s_6 , 0.488)

So, the best LNG transportation shipping lane is A_3.

5. COMPARISON AND DISCUSSION

In order to verify the advantages of the proposed mechanism, a comparison analysis among the proposed mechanism, traditional feedback mechanism and the unpersonalized feedback mechanism is presented as Table 8. The traditional and unpersonalized feedback mechanisms both adopt the same feedback parameters for all inconsistent experts, which is not the case with the personalized feedback mechanism. More important, the main difference between the traditional and unpersonalized feedback mechanisms is that the unpersonalized one is driven by maximum GHD, which is reñected in the lower unpersonalized feedback parameters used. Thus, the unpersonalized feedback process would modify inconsistent experts' opinions less than the traditional feedback process and still achieve the main goal of the CRP. In fact, the traditional feedback mechanism only pursues the consensus in excess while neglecting group harmony.

Table 8. Main consensus decision making indicators in three feedback mechanisms

	Personalized feedback mechanism	Traditional feedback mechanism	Unpersonalized feedback mechanism
The sum of feedback mechanism	0.246	1.000	0.320
CD_1	0.911	0.923	0.913
CD_2	0.850	0.893	0.857
CD_3	0.850	0.894	0.850
CD_4	0.919	0.929	0.920
GHD	0.983	0.935	0.979

On the one hand, the main theoretical contributions are as follows. It exhibits three facets of novelty: (1) a GDM approach is introduced into the issue of LNG transportation routes, where experts provide their opinions from different perspectives according to their prior knowledge. Thus, the credibility and validity of the assessment are improved; (2) experts provide their risk evaluations by two-tuple linguistic model, which can avoid the information loss in the process of information aggregation. Furthermore, the consensus and harmony are measured more easily by defining a linguistic set consisting of nine terms; (3) besides, the personalized feedback mechanism proposed by Cao et al. enables inconsistent experts to modify their opinions to a minimum extent, which will improve the satisfaction and harmony of experts in the decision-making process.

On the other hand, this article provides signiðcant practical insights for the risk evaluation method of LNG transportation routes. It not only helps experts more easily express their opinions by linguistic terms, but also considers the consistency among experts. A novel consensus reaching process with personalized feedback mechanism is introduced to improve the credibility of the risk assessment process. However, the proposed risk evaluation is still limited, it lacks a systematic evaluation system, which is the direction to be improved in the future

6. CONCLUSION

This paper proposes a novel risk assessment method to identify the best LNG shipping transportation route. The results of scenario analysis show that the proposed method is an effective way to assess the LNG transportation risks. The main advantages of this study are as the following:

(1) The authors introduce the GDM method into the risk assessment of LNG transportation routes. The GDM procedure usually involves a process of group interaction, which promotes the integration of views from different fields' experts. Specifically, experts provide their opinions from different perspectives according to their prior knowledge. As a result, the credibility and validity of the assessment are improved.
(2) As two-tuple linguistic model effectively avoids the information loss in the fusion process of linguistic information, the authors apply it to the risks evaluation process, helping experts express their vague and uncertain opinions in a quantified form. The authors define a linguistic set consisting of ten terms and provide the concept of distance between two linguistic term sets. Furthermore, the authors measure the consensus degrees from three levels to calculate the agreement level in the GDM problem. A personalized feedback mechanism is applied to improve the consensus among experts after identifying the inconsistency.
(3) The personalized feedback mechanism enables inconsistent experts to modify their opinions to a minimum extent, without obtrusion of others' opinions. As a result, the satisfaction and harmony of experts in the decision-making process are improved. Finally, the authors choose the best LNG transportation route by a selection process.

CONFLICT OF INTEREST

The authors of this publication declare there is no conflict of interest.

FUNDING AGENCY

This research was supported by the Shanghai Municipal Education Commission [grant number ZZLX19001].

REFERENCES

Abdussamie, N., Daboos, M., Elferjani, I., Shuhong, C., & Alaktiwi, A. (2018). Risk assessment of LNG and FLNG vessels during manoeuvring in open sea. *Journal of Ocean Engineering and Science*, *3*(1), 56–66. doi:10.1016/j.joes.2017.12.002

Antao, P., & Soares, C. G. (2012). Risk assessment to the approach and berth of LNG vessels at the FLNG systems. In *Maritime engineering and technology* (p. 425). Talyor & Francis Group.

Balmat, J.-F., Lafont, F., Maifret, R., & Pessel, N. (2009). MAritime RISk Assessment (MARISA), a fuzzy approach to define an individual ship risk factor. *Ocean Engineering*, *36*(15-16), 1278–1286. doi:10.1016/j.oceaneng.2009.07.003

Berle, Ø., Norstad, I., & Asbjørnslett, B. E. (2013). Optimization, risk assessment and resilience in LNG transportation systems. *Supply Chain Management*, *18*(3), 253–264. doi:10.1108/SCM-03-2012-0109

Bubbico, R., Di Cave, S., & Mazzarotta, B. (2009). Preliminary risk analysis for LNG tankers approaching a maritime terminal. *Journal of Loss Prevention in the Process Industries*, *22*(5), 634–638. doi:10.1016/j.jlp.2009.02.007

Cao, M., Wu, J., Chiclana, F., & Herrera-Viedma, E. (2021). A bidirectional feedback mechanism for balancing group consensus and individual harmony in group decision making. *Information Fusion*, *76*, 133–144. doi:10.1016/j.inffus.2021.05.012

Cao, M., Wu, J., Chiclana, F., Ureña, R., & Herrera-Viedma, E. (2020). A personalized consensus feedback mechanism based on maximum harmony degree. *IEEE Transactions on Systems, Man, and Cybernetics. Systems*, 1–13.

Chen, Y., & Fan, Z.-P. (2004). Study on Consistency and the Related Problems for Judgment Matrix with Linguistic Assessment Information. *Systems Engineering-theory & Practice*, *4*, 136–141.

Elsayed, T. (2009). Fuzzy inference system for the risk assessment of liquefied natural gas carriers during loading/offloading at terminals. *Applied Ocean Research*, *31*(3), 179–185. doi:10.1016/j.apor.2009.08.004

Foss, M. M., & Head, C. (2007). *Introduction to LNG*. Center for Energy Economics, Bureau of Economic Geology, Jackson School of Geosciences, University of Texas.

George, J. J., Renjith, V., George, P., & George, A. S. (2019). Application of fuzzy failure mode effect and criticality analysis on unloading facility of LNG terminal. *Journal of Loss Prevention in the Process Industries*, *61*, 104–113. doi:10.1016/j.jlp.2019.06.009

Guo, W., Tong, X., & Liu, J. (2017). Study on the economic channel design for LNG ships using Pedersen grounding model. *2017 4th International Conference on Transportation Information and Safety (ICTIS),* 129-133.

Herrera, F., & Martínez, L. (2000). A 2-tuple fuzzy linguistic representation model for computing with words. *IEEE Transactions on Fuzzy Systems*, *8*(6), 746–752. doi:10.1109/91.890332

Hightower, M., Gritzo, L., Luketa-Hanlin, A., Covan, J., Tieszen, S., Wellman, G., Irwin, M., Kaneshige, M., Melof, B., & Morrow, C. (2004). *Guidance on risk analysis and safety implications of a large liquefied natural gas (LNG) spill over water*. Academic Press.

Huang, T. (2012). *Research on risk assessment and shipping arrangement of LNG transport routes* [Doctoral dissertation]. Wuhan University of Technology.

Jeong, B., Lee, B. S., Zhou, P., & Ha, S. (2018). Determination of safety exclusion zone for LNG bunkering at fuel-supplying point. *Ocean Engineering*, *152*, 113–129. doi:10.1016/j.oceaneng.2018.01.066

Khan, B., Khan, F., Veitch, B., & Yang, M. (2018). An operational risk analysis tool to analyze marine transportation in Arctic waters. *Reliability Engineering & System Safety*, *169*, 485–502. doi:10.1016/j.ress.2017.09.014

Li, D.-F., & Liu, P.-D. (2020). Big data and intelligent decision methods in economy, innovation and sustainable development. *Technological and Economic Development of Economy*, *26*(5), 970–973. doi:10.3846/tede.2020.13354

Looney, B. (2020). BP statistical review of world energy. BP Statistical Review.

Lu, J., & Wang, S. (2015). Safety evaluation of China's maritime transport key nodes. *Journal of Transportation Systems Engineering and Information Technology*, *15*(1), 30–36.

Miller, G. (2020). *LNG shipping rates just hit $125,000 per day*. Retrieved November 2 from https://www.freightwaves.com/news/lng-shipping-rates-just-hit-125000-per-day/

Nwaoha, T. C., Yang, Z., Wang, J., & Bonsall, S. (2013). Adoption of new advanced computational techniques to hazards ranking in LNG carrier operations. *Ocean Engineering*, *72*, 31–44. doi:10.1016/j.oceaneng.2013.06.010

Østvik, I., Vanem, E., & Castello, F. (2005). HAZID for LNG tankers. *SAFEDOR report D, 4*(1).

Paltrinieri, N., Tugnoli, A., & Cozzani, V. (2015). Hazard identification for innovative LNG regasification technologies. *Reliability Engineering & System Safety*, *137*, 18–28. doi:10.1016/j.ress.2014.12.006

Perkovic, M., Gucma, L., Przywarty, M., Gucma, M., Petelin, S., & Vidmar, P. (2012). Nautical risk assessment for LNG operations at the Port of Koper. *Strojniški vestnik- Jixie Gongcheng Xuebao*, *58*(10), 607–613.

Truck, I. (2015). Comparison and links between two 2-tuple linguistic models for decision making. *Knowledge-Based Systems*, *87*, 61–68. doi:10.1016/j.knosys.2015.05.030

Vanem, E., Antao, P., Østvik, I., & de Comas, F. D. C. (2008). Analysing the risk of LNG carrier operations. *Reliability Engineering & System Safety*, *93*(9), 1328–1344. doi:10.1016/j.ress.2007.07.007

Wang, S., Wu, J., Chiclana, F., Sun, Q., & Herrera-Viedma, E. (2022). Two stage feedback mechanism with different power structures for consensus in large-scale group decision-making. *IEEE Transactions on Fuzzy Systems*, 1. Advance online publication. doi:10.1109/TFUZZ.2022.3144536

Whitmore, W. D., Baxter, V. K., & Laska, S. L. (2009). A critique of offshore liquefied natural gas (LNG) terminal policy. *Ocean and Coastal Management*, *52*(1), 10–16. doi:10.1016/j.ocecoaman.2008.10.002

Wu, J., Bai, Y., Zhao, H., Hu, X., & Cozzani, V. (2021). A quantitative LNG risk assessment model based on integrated Bayesian-Catastrophe-EPE method. *Safety Science*, *137*, 105–184. doi:10.1016/j.ssci.2021.105184

Wu, J., Cao, M., Chiclana, F., Dong, Y., & Herrera-Viedma, E. (2020). An optimal feedback model to prevent manipulation behavior in consensus under social network group decision making. *IEEE Transactions on Fuzzy Systems*, *29*(7), 1750–1763. doi:10.1109/TFUZZ.2020.2985331

Xing, Y., Cao, M., Liu, Y., Zhou, M., & Wu, J. (2022). A Choquet Integral based Interval Type-2 Trapezoidal Fuzzy multiple attribute group decision making for Sustainable Supplier Selection. *Computers & Industrial Engineering*, *165*, 107935. doi:10.1016/j.cie.2022.107935

Xu, S. W., & Hongjuan. (2019). How to construct a conventional LNG shipping import risk assessment system. *China Petroleum Enterprise*, (10), 62–65.

Yan, Q. (2012). *Study on Methods for Hybrid Multiple Attribute Group Decision Making* [Doctoral dissertation]. Shanxi University.

Yu, D., & Li, D.-F. (2016). Managing interval-valued multiplicative hesitant fuzzy information in GDM problems. *Scientia Iranica*, *23*(4), 1918–1927. doi:10.24200/sci.2016.3937

Yu, G.-F., Li, D.-F., & Fei, W. (2018). A novel method for heterogeneous multi-attribute group decision making with preference deviation. *Computers & Industrial Engineering*, *124*, 58–64. doi:10.1016/j.cie.2018.07.013

Yu, G.-F., Li, D.-F., Qiu, J.-M., & Zheng, X.-X. (2018). Some operators of intuitionistic uncertain 2-tuple linguistic variables and application to multi-attribute group decision making with heterogeneous relationship among attributes. *Journal of Intelligent & Fuzzy Systems*, *34*(1), 599–611. doi:10.3233/JIFS-17821

Yun, G., Rogers, W. J., & Mannan, M. S. (2009). Risk assessment of LNG importation terminals using the Bayesian–LOPA methodology. *Journal of Loss Prevention in the Process Industries*, *22*(1), 91–96. doi:10.1016/j.jlp.2008.10.001

Zhao, S., Soares, C. G., & Zhu, H. (2015). A Bayesian network modelling and risk analysis on LNG carrier anchoring system. *2015 International Conference on Transportation Information and Safety (ICTIS)*, 432-436. doi:10.1109/ICTIS.2015.7232059

Zhou, H., & Wei, Y. (2010). Maximized Deviation-Based Group Decision-Making Fuzzy Comprehensive Evaluation. *2010 International Conference on E-Business and E-Government*, 1549-1553.

Zhou, T., Zhang, D., Fu, S., Wu, C., & Wan, C. (2015). Safety assessment of LNG carriers based on fault tree analysis. *2015 International Conference on Transportation Information and Safety (ICTIS)*, 715-719. doi:10.1109/ICTIS.2015.7232164

Zhu, R., Hu, X., Bai, Y., & Li, X. (2021). Risk analysis of terrorist attacks on LNG storage tanks at ports. *Safety Science*, *137*, 105–192. doi:10.1016/j.ssci.2021.105192

Zuo, W.-J., Li, D.-F., Yu, G.-F., & Zhang, L.-P. (2019). A large group decision-making method and its application to the evaluation of property perceived service quality. *Journal of Intelligent & Fuzzy Systems*, *37*(1), 1513–1527. doi:10.3233/JIFS-182934