Journal of Korea Port Economic Association
Vol.37, No.4, 2021, pp.13-31.
https://doi.org/10.38121/kpea.2021.12.37.4.13

한-유럽 복합운송 경로선택에 관한 연구
중국-유럽 화물열차를 중심으로*

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Multimodal Route Selection from Korea to Europe Using Fuzzy AHP-TOPSIS Approaches: The Perspective of the China-Railway Express

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Abstract

Since the signing of the Korea-Europe Free Trade Agreement, the volume of trade transactions between South Korea and Europe has increased. The traditional single-mode transport system has been transformed into an intermodal transport system using two or more modes of transport. In addition, the conventional sea and air transport routes have been restricted, leading to a decline in Korean exports to Europe, and the rail transport mode is becoming mainstream in the market due to the influence of COVID-19. This paper focuses on the China-Railway Express to explore a new intermodal transport route from Korea to Europe. First, the fuzzy analytic hierarchy process (AHP) is used to evaluate the factor weights when selecting intermodal transport routes from Korea to Europe. Then, the TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method is used to rank three alternatives. The results show that among the four factors (total cost, total time, transportation capability, and service reliability), the total cost is the most significant factor, followed by the total time, service reliability, and transportation capability. Furthermore, the alternative route 1 (Incheon-Dalian-Manchuria-Hamburg) is preferred.

Key words: Multimodal transport, China Railway Express, Fuzzy AHP-TOPSIS

▷ 논문접수: 2021. 10. 15. ▷ 심사완료: 2021. 12. 30. ▷ 게재확정: 2021. 12. 31.

* 이 논문은 해양수산부 2021년도 해운항만물류 전문인력양성사업 지원에 의해 연구되었음

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Ⅰ. Introduction

Since the signing of the Korea-Europe Free Trade Agreement in 2011, the volume of trade transactions between South Korea and Europe has been increasing yearly and the entire market continues to expand. At the same time, the traditional single-mode transport system has been transformned into an intermodal transport system where two or more modes of transport are used to meet not only cost demands but also service demands. Currently, 43.5% of the Korea-Europe intermodal routes are by combined sea-land transport (Eun-Kyung Lee et al., 2019), and much of the trade demand relies on a single corridor through the Suez Canal followed by sea-rail intermodal transport, which is connected by the Trans-Siberian Railroad (TSR), the Trans-Chinese Railroad (TCR), or the Trans-Mongolian Railroad (TMR).

Additionally, the possibility of using the Arctic Ocean route connected by the Trans-Asian Railway (TAR) is increasing due to the thawing ice in the Arctic (Dongjin Kim, 2015). However, the Arctic sea route is currently available for only three months per year, but it is expected to be able to operate year-round after 2030 due to the rapid glacial thaw (Eun-Kyung Lee et al., 2013). Moreover, the smooth use of the Trans-Korean Railway (TKR) depends on the political situation in the Korean Peninsula.

In 2019, global trade markets were hit by the impact of the coronavirus disease 2019 (COVID-19). Transportation costs rose while shortages of shipping containers occurred due to congested ports and COVID-19 restrictions. On March 23, 2021, the situation was exacerbated after Ever Given, one of the largest container ships in the world, ran aground in the Suez Canal, which blocked the corridor. Some ships were able to change their route, but their sailing time increased by one to two weeks, and their safety risks expanded.

Despite the global downturn in the freight market, the China-Railway Express is rapidly developing. The total number of its freight trains increased by 50% year-on-year to 12,406 in 2020, 7.3 times higher than in 2016. With several transport companies recently launching new rail transport routes and services from China to Europe, it has become more important for Korean companies to choose an efficient transportation route to ensure the stability of their services and to save costs.

Many studies have evaluated Korean-European intermodal routes such as those of TKR, TSR, and TAR or assessed the influencing factors, but not enough studies have comprehensively evaluated the China-Railway Express route in intermodal transport. Accordingly, we investigate the qualitative and quantitative factors in the use of the China-Railway Express services from Incheon port to Hamburg based on inputs from actual decision-makers of Korean transport companies and scholars. The fuzzy theory is used in the analytic hierarchy process (AHP) to express the judgments of the decision-makers and scholars more accurately through linguistic variables; and subsequently, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is used to choose the best route from three alternatives, thus providing a new point of reference for academia and industry.

Ⅱ. Literature Review

Multimodal freight transportation is defined as the transportation of goods through a sequence of at least two different modes of transportation (UNECE, 2009). It can combine the advantages of three kinds of transportation: by sea, land, and air. Rail and sea transport can be used for long distances and large freight quantities, and road transport can be used to collect and distribute freight over short or medium distances. At the same time, multimodal transportation provides a full range of transportation methods and route options that enable them to coordinate more departments of the supply chain to achieve effective relationships (Qu & Chen, 2008; Southworth & Peterson, 2000). In choosing from among various modes of transport, decision-makers are giving more weight to economic factors such as time, distance, and cost. Environmental issues are also being considered, since some governments have proposed new regulations and taxes to encourage companies to use more sustainable modes of transport (Steadieseifi et al., 2014).

Most previous studies on multimodal route selection can be divided into two categories. The first category includes studies that explored how to minimize time and cost using mathematical algorithms such as mixed-integer models and dynamic models. Sun (2020) used the fuzzy multi-objective routing model, which is linear and considers the constraints of the customers' preferred service levels, to analyze a hazardous materials multimodal network. This study clearly pointed out the conflicting relationships between the economic, risk, reliability, and timeliness objectives and outlined a road-rail multimodal transportation plan. Chang (2008) focused on three features of international multimodal transport and formulated a multi-objective multimodal commodity flow problem with time windows and concave costs that provided an efficient solution to the model based on a heuristic algorithm. Tian and Cao (2017) proposed a generalized-interval fuzzy mixed-integer programming model for practical situations that uses three mathematical methods of designing a heuristic algorithm based on a greedy criterion and a linear relaxation algorithm to determine the optimal mode of transportation and the optimal number of each type of goods to be transported through each path. Seo et al. (2017) introduced a multimodal transport cost model and explored seven alternative routes for laptop export from Chongqing to Rotterdam. The results can help decision-makers find a balance between transportation time and costs. Thee inventory theoretic model has also been utilized effectively in route selection. Woo et al. (2018) compared the total annual cost of four routes from Korea to the U.S. Through real transportation data collected from a Korean auto parts company, it was found that the inventory cost plays a decisive role in changing the cost competitiveness of different routes. In addition, a sensitivity analysis has shown that the cost structure plays an important role in competitiveness in different market conditions. J. Kim et al.

Table 1. MCDM method for multimodal route slection

Researcher	Transport routes	Method
Eu et al.,(2015)	6 alternative routes from Korea to Europe	TOPSIS
Gerçek et al.,(2004)	3 alternative rail transit network proposals in Istanbul	AHP
Park et al., (2019)	3 alternative routes form Korea (Donghae port) to Vietnam	CFPR
Koohathongsumrit and Meethom (2021)	16 alternative routes from Thailand to Vietnam	AHP DEA TOPSIS
Koohathongsumrit and Meethom(2021a)	4 alternative routes from Thailand to Cambodia	FRAM; DEA FAHP; ZOGP
Meethom and Kengpol (2009)	4 alternative routes from Bangkok to Danang	AHP ZOGP
Hamurcu and Eren (2018)	8 alternative monorail routes	ANP TOPSIS

(2020) compared the total logistics costs of seven multimodal transport routes from Korea to the U.S. and considered the variability of the main factors in the field of automotive parts. Multimodal transport modes were also used in case studies of long-distance transportation of hazardous materials (Xie et al., 2012) by applying a HAZMAT (hazardous materials) model to optimize the location of transfer stations and transport routes for two different network sizes, and suggestions for future research were presented.

On the other hand, multiple-criteria decision-making (MCDM) is a more flexible and transparent way to solve this complex problem. It is widely used and is becoming more and more important in multimodal route selection. The most commonly used MCDM methods are the analytic hierarchy process (AHP), analytic network process (ANP), simple additive weighting (SAW), ELimination Et Choix Traduisant la REalitm (ELECTRE), and TOPSIS) (Yannis et al., 2020).

Some scholars have already conducted studies using a single approach. Eu et al. (2015) considered the qualitative and quantitative factors simultaneously and used TOPSIS to evaluate the Korea-Europe intermodal routes to rank six links in relation to the actual situation. They indicated that some routes require national policy support to be smoothly used for commercial purposes. Park et al. (2019) used the consistent fuzzy preference relationship (CFPR) model to improve the competitiveness of small and medium-sized ports analysis and combined it with actual industry data and expert opinions. It showed that the container transport route from the east coast of Korea to Ho Chi Minh was the optimal choice of three alternative routes, and that volume commitment was the first of 19 influencing factors, followed by the incentive system risk and profitability. Gerçek et al. (2004) used AHP to evaluate three alternative transportation projects planned by the Istanbul government to help decision-makers develop a new alternative route that was a combination of two alternative routes and to start their construction.

Table 2. Factor summary of literature study

Criteria	Sub-criteria	Reference
Total Cost	Transportation costs	Ha, (2002); Kim et al.,(2005) Wang and Yeo (2018); Lee et al., (2013) Kim et al., (2019); Eu et al., (2015) Kim (2015); Sur and Kim(2020) Pham et al., (2018); Seo et al.,(2017)
	Transit cost	
	Subsidy	
Total Time	Transportation time	Kim et al.,(2005) ; Lee et al.,(2013) Eu et al.,(2015); Wang and Yeo(2018) Sur and Kim(2020) ; Seo et al.,(2017) Kim(2015) ;Kopytov and Abramov(2012)
	Transit time	
	Customs clearance time	
Transportation Capability	Load capacity	Ma et al.,(2021) Han(2011) Wang and Yeo(2018)
	Transport frequency	
	Transit capability	
Service Reliability	Security / Safety	Kopytov amd Abramov(2012) Pham et al.,(2018) Wang and Yeo(2018) Eu et al.,(2015) ; Ha(2002) Kim(2015) ; Qu and Chen(2008)
	Flexibility	
	Punctuality	

Several integrated MCDM approaches and hybrid methods have also been used because they are more powerful than single methods (Koohathongsumrit & Meethom, 2021a). Hamurcu and Eren (2018) combined ANP and TOPSIS for urban transportation planning by studying the Turkish capital, Ankara. The ANP weights were applied to TOPSIS to calculate the ideal negative and positive solutions, which were those that had the highest ranking of eight alternative routes. TPT Doan et al. (2021) discussed how to select an efficient intermodal route between China and Vietnam from the perspective of logistics service providers and shippers, considering both qualitative and quantitative data using a hybrid Delphi and CFPR approach. They identified Chongqing to Haiphong as the best of eight routes and the transportation cost as the most important route choice for 40-feet containers. Wang and Yeo (2018) proposed the use of the Fuzzy Delphi and Fuzzy ELECTRE I methods, considering the five factors of the total cost, reliability, capacity, total time, and security, to evaluate multimodal transport routes from Korea to Central Asia. Pham et al. (2018) first identified the four evaluation quasi-sides of the transport time, transport cost, accuracy set, and reliability through literature synthesis and expert interviews, and then combined the fuzzy theory and MCDM techniques to evaluate alternative routes. The results showed that the “all-water” route via the Panama Canal is preferable for the Hong Kong-New York route and that the transportation cost was the most important factor in the route selection, followed by the transportation time, reliability, and route characteristics. Also, studies on a decision support system (DSS) for multimodal route selection have been found. Meethom and Kengpol (2009) processed DSS based on a multimodal transportation cost model combined with AHP and ZOGP. Ambrasaite et al. (2011) developed a DSS for the composite modeling assessment (COSIMA), a combination of the CBA and MCDA methods that allows the introduction of risk analysis and Monte Carlo simulation into the MCDA part after the uncertainty of the weights is compensated for. An actual case study of a Baltic railway line construction scenario through the Baltic States and Poland was presented. Data envelopment analysis (DEA) is commonly used to control the risk magnitude. Thus, more than two novel combinations of MCDM methods are applied to multimodal route selection. Koohathongsumrit and Meethom (2021) invented a three-stage model, the integrated AHP–DEA-TOPSIS model, to rank multimodal freight routes. Subsequently, the fuzzy risk assessment model (FRAM) DEA-FAHP-ZOGP (zero-one goal programming model) was also developed to test the functionality and applicability using an actual intermodal route between Thailand and Cambodia.

Concerning multimodal transport route selection many scholars focus on both total cost and total transport time (Kengpol, Tuammee, and Tuominen 2014; Koohathongsumrit and Meethom 2021; Pham, Kim, and Yeo 2018; Wang and Yeo 2016, 2018). In addition, the subsidy was selected as a sub-criteria because the CRE operation currently relies on government subsidies to attract cargo volumes (Feng et al., 2020). Furthermore, intermodal transportation routes that pass through several countries with variable infrastructure, for example, different environments of infrastructure, have been a focus of intermodal difficulties, in addition to shippers' flexibility and punctuality of service demand.

Ⅲ. Methodology

3.1 Fuzzy set

The above literature analyzed only an index of the port. Actually, however, port operation is not a simple system. Thus, if only a single index is selected, only one aspect of the port efficiency can be reflected. Some scholars evaluated port performance by constructing multiple indicators such as the port throughput, port infrastructure, and port operating profits.

$$\mu(x \mid \tilde{A}) = \begin{cases} 0, & x < l \\ (x-l)/(m-l), & l \le x \le m \\ (u-x)/(u-m), & m \le x \le u \\ 0, & x > u \end{cases}$$

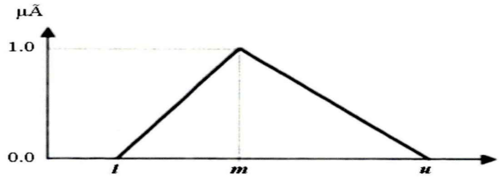

Figure 1. The membership function of the triangular fuzzy number

The fuzzy theory is used to deal with uncertain decision-making in order to solve the ambiguity of human thinking. At the same time, the fuzzy set theory provides a formal tool that is inherently imprecise when dealing with problems and realizes data grouping with unclear boundaries. Evaluators are required to make supervisory judgments by using linguistic variables to express effects such as “very good,” “good,” “equal,” “poor,” and “very poor.” In contrast, traditional calculations are very accurate to achieve the definition of "clear and crisp." Any method can perform "fuzzified" processing by generalizing the concept of a clear set as a fuzzy set with fuzzy boundaries.

Fuzzy numbers are fuzzy subsets of real numbers. Fuzzy numbers are used to deal with uncertain values, such as about 7 or close to 10 (Chen & Hwang, 1992). The triangular, Gaussian, trapezoidal, and bell-shaped curve membership functions are generally used in many membership functions. In this study, a triangular membership function is used. The membership degree and membership factor of TFN are defined by three real numbers and expressed as $(1, m, u)$. As shown in Figure 1, in the real values $(1, m, u)$ that constitute the triangular number, "1" is the smallest probable value, "m" is the most probable number, and "u" is the largest probable value.

3.2 Fuzzy AHP

The fuzzy logic is used in decision-making methodologies such as AHP and ANP. The core of AHP was originally a method of converting subjective assessments of relative importance to a set of overall scores or weights (Saaty, 1980). The fuzzy extension of AHP was developed to reflect a humanistic way of thinking more accurately because decision-makers typically provide uncertain answers rather than precise values. This is based on an explicit mathematical structure that is defined to allow the determination of feature vectors based on relatively accurate or precise weights.

The fuzzy set theory and AHP is among the MCDM methods that produce highly sensitive and right decisions. Buckley (1985) incorporated a fuzzy matrix into the AHP method to address this human condition.

The method integrated the vagueness in the response of people involved in decision-making to bring it closer to human reality and to provide decision-making analysis with greater validity (Huang & Wu, 2005). The literature shows that many studies have used fuzzy MCDM methods in different fields. The first Fuzzy AHP method using the triangular fuzzy method was proposed by van Laarhoven and Pedrycz (1983)

Table 3. Linguistic variables for the preference of each criterion

AHP Scale	Linguistic Scale	Fuzzy Number
1	Equal	1, 1, 1
2	Weak advantage	1, 2, 3
3	Not bad	2, 3, 4
4	Preferable	3, 4, 5
5	Good	4, 5, 6
6	Fairly good	5, 6, 7
7	Very good	6, 7, 8
8	Absolute	7, 8, 9
9	Perfect	9, 9, 9

through the pairwise comparison matrix. In later years, various types of fuzzy numbers such as the trapezoidal membership function and bell-shaped methods, which are less commonly used, were proposed. In this thesis, Fuzzy AHP analysis includes the following steps.

(1) Construct a pairwise comparison matrix between all elements/criteria in the dimensions of the hierarchical system. Assign language terms to pairwise comparisons by asking which of every two dimensions is more important, as in the following matrix $\widetilde{A}$. Use nine scale rankings with reference as in Table 3.

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & |1 & \dots & a\tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ 1/\tilde{a}_{21} & 1 & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{n1} & 1/\tilde{a}_{n2} & \dots & 1 \end{bmatrix}$$

(2) Define the fuzzy geometric mean and fuzzy weights for each criterion using geometric averaging techniques.

In Equation 1, $\widetilde{a_{ij}}$ is the fuzzy comparison value of dimension i to criterion j. Therefore, $\widetilde{r_i}$ is the geometric mean of the

fuzzy comparison value of criterion i to each criterion, and $\widetilde{w_i}$ is the fuzzy weight of the ith criterion.

$$where: \tilde{a}_{ij} = \hat{9}^{-1}, 8^{-1}, \hat{7}^{-1}, \hat{6}^{-1}, \hat{5}^{-1}, \hat{4}^{-1}, \hat{3}^{-1}, \quad \text{(eq.1)}$$
$$\hat{2}^{-1}, \hat{1}^{-1}, \tilde{1}, \tilde{2}, \tilde{3}, \tilde{4}, \tilde{5}, \tilde{6}, \tilde{7}, \tilde{8}, \tilde{9}$$
$$\widetilde{r_i} = (\widetilde{a_{i1}} \otimes \dots \otimes \widetilde{a_{ij}} \otimes \dots \otimes \widetilde{a_{\in}})^{1/n}$$
$$\widetilde{w_i} = \widetilde{r_i} \oplus [\widetilde{r_1} \oplus \dots \oplus \widetilde{r_i} \oplus \dots \oplus \widetilde{r_n}]^{1/n}$$

(3) The pairwise comparison matrix can be derived from the weights of the options as in Eq2. where Ã is the comparison matrix, λmax is the maximum eigenvalue of Ã, and w̃ is the eigenvector that correspond to λmax.

$$\widetilde{A_w} = \lambda_{\max} \widetilde{w}, \ \widetilde{w} = (\widetilde{w_1}, \widetilde{w_2}, \dots \widetilde{w_n})^T \quad \text{(eq.2)}$$

(4) The consistency index (CI) is also defined in AHP to measure the inconsistency in the pairwise comparison matrix Ã; CR is the consistency ratio, which is used to measure the degree of CI through the following equation.

$$C.I. = \frac{\lambda_{\max} - n}{n-1} \quad \text{(eq.3)}$$

$$CR. = \frac{CI.}{RI.} \quad \text{(eq.4)}$$

where $RI.$ is the stochastic consistency index when $CR. \langle$ 0.10 The degree of inconsistency is considered acceptable for the comparison matrix Ã, and the eigenvector w̃ is used as the normalized weighted vector. Otherwise, the comparison matrix needs to be adjusted.

3.3 Technique for Order of Preference by Similarity to Ideal Solution(TOPSIS)

The TOPSIS method is presented in Chen and Hwang (1992). It is a useful technique for dealing with real-world multiple-attribute or multiple-criteria decision-making (MADM/MCDM) problems (Hwang & Yoon, 1981). It is a multiple-criteria method of identifying solutions from a finite set of alternatives. The basic principle is that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution (Jahanshahloo et al., 2006; Shih et al., 2007).

In general, TOPSIS proceeds through the following steps to normalize the decision matrix, normalize the weights, and compute the positive ideal solution (PIS) and the negative ideal solution (NIS). The PIS proposes the optimal solution that maximizes the benefit and minimizes the cost, and conversely, the NIS proposes a negative solution that minimizes the benefit and maximizes the cost attributes.

The TOPSIS method used in this study is as follows.

Step 1. Establish the normalized decision matrix $[r_{ij}]_{m*n}$, where r_{ij}(i=1, . . ,m and j = 1, . . , n) denotes the performance score of the i th alternative for the jth criterion.

The value of r_{ij} is obtained through pairwise comparison of the benefit and cost criteria, in their best fuzzy descriptions, between each pair of decision alternatives. (using the nine-point scale of AHP)

Step 2. Calculate the weighted normalized decision matrix$[v_{ij}]_{m*n}$, where v_{ij}(i = 1, . . . ,m; and j = 1, . . . , n) are calculated as v_{ij}= $r_{ij}\times w_j$, whrer w_j is the weight of criterion m_j and $\sum_{j=1}^{n} w_j = 1$

Step 3. Determine the PIS and the NIS as follows:

$$A^+ = v_1^+, v_2^+, \ldots, v_n^+ \\ = (mLSUPjax\, v_{ij} : i \in I,)(LSUPj \min v_{ij} : i \in J)$$

$$A^- = v_1^-, v_2^-, \ldots, v_n^- \\ = (\min v_{ij} : i \in I,)(LSUPj \max v_{ij} : i \in J)$$

Step 4. Calculate the separation measures using the n dimensional Euclidean distance. The separation of each alternative from the PIS and NIS is given as:

$$d_i^{\square} = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^{\square}), \; i = 1,2,\ldots m$$

$$d_i^{\square} = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_j^{\square}), \; i = 1,2,\ldots m$$

Step 5. Calculate the relative closeness to the ideal solution. where the value of C_i is between 0 and 1. The relative closeness of alternative A_i is defined as:

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-}$$

Step 6. Ranking the alternatives based on the calculations in Step 5.

Ⅳ. Empirical Analysis and Results

4.1 Survey design

In the first stage of the survey, shown in Figure 3, the hierarchy (the main criteria and subcriteria) for the intermodal route selection were obtained based on the factors discussed in the literature review. Subsequently, 20 experts from universities, research institutes and related logistics companies were invited to participate in the questionnaire survey from May 13 to July 13 in 2021, as show in Table 4.

The experts included managers of port authorities, senior experts and professionals from research institutes, and academics and professors from China and South Korea, each with more than 13 years of experience on average in multimodal transport in Korea, China, and Europe. The results of the questionnaire were used in the calculation using the fuzzy AHP method, the weights of each factor were calculated using the fuzzy AHP method, and with the consistency test, the alternative routes were evaluated in the

Table 4. Composition of the pool of respondents

Firm	Number of respondents	Position	Average work experience (Year)
Busan Port Terminal	1	CEO	35
PyeongTaek-DangJin Logistis	1	CEO	40
Sun Kwang Newport Container Terminal	1	General manager	33
YongJin Global Logistics	1	CEO	25
Korea Transport Institute	2	General manager	25
Cainiao Network	1	General manager	9
YunExpress	1	General manager	11
JD	1	General manager	8
Scholar of Logistics Management from Korea	5	Professor	20
Scholar of Logistics Management from China	6	Professor	16

second stage using qualitative and quantitative data to determine the best route and to rank the alternative routes, as shown in Figure 2.

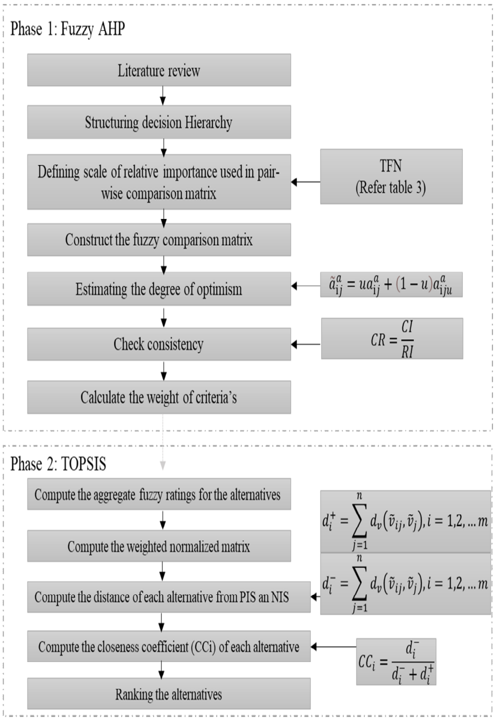

Figure 2. Research diagram for the route selection

4.2 Results of route selection factor priority

4.2.1 Results of the major criteria

The experts assessed the relative importance of the factors using the linguistic variables in Table 3 and showed that among the determinants of route selection, the total cost was given priority (0.4), followed by the total time (0.256), service reliability (0.183), and transportation capability (0.161). The results are presented in Table 5. When deciding on a transportation route, the transportation cost was given the highest priority because this factor has a significant impact on the total cost of cargo transportation and thus, on the company's profit and freight costs. Most of the freight companies offer door-to-door transportation services, but there are different forms in the quotations that are not transparent enough for different countries and ports due to multiple changes and uncertainties, which affect the total cost. The Korean-European multimodal transport routes require many transits through ports and various regions due to railway gauge width, creating different prices. In the event of the epi-

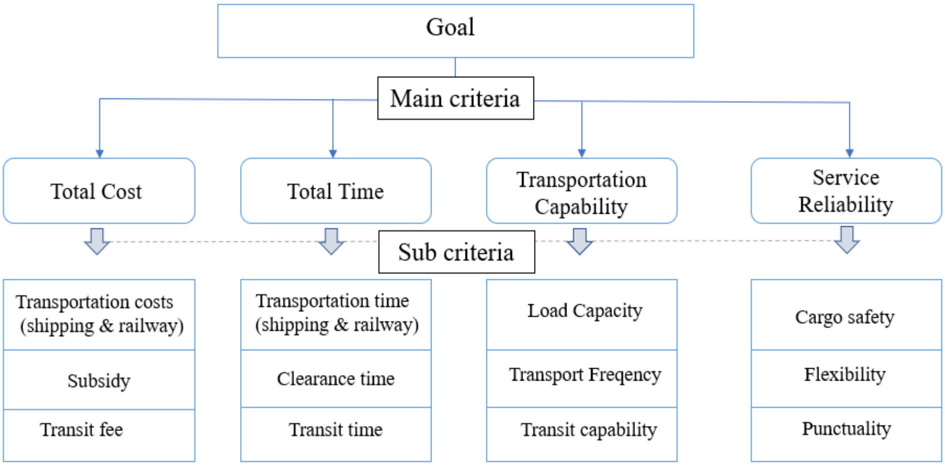

Figure 3 Hierarchy of criteria for multimodal route selection

demic, demand for containers on CRE trains has surged dramatically, and price increases are significant concerns for decision-makers. The transportation time is also a key factor in selecting routes. Generally, shorter transportation times reduce the risk of cargo in transit. International multimodal transport is often prolonged due to unpredictable reasons such as natural factors and the international situation. The multimodal route selection decision process also considers the service reliability, which is used to ensure on-time execution of the plan and to avoid uncertainty and risky situations during transport, especially in extreme weather conditions. Furthermore, to b the growing volume of freight, the constraints that may be caused by transportation capability are also important factors in providing a stable service.

4.2.2 Results of weights on sub-criteria

Transportation costs are the most important in terms of the weights of the subfactors. Generally, transportation costs account for more than 50% of the total cost of transporting goods (Jakob et al., 2006). The transportation time ranks second. The risk increases with time throughout the transport, especially in multimodal transport decisions that require the shortest time to reach the destination based on cost control. The frequency of operation (0.095) is an important limitation of multimodal transport. Although several routes of the China-European Liner have been opened, they cannot depart on time because the number of goods does not meet the operation requirements. At the same time, due to the pathway to Russian Siberia, climate may affect the smooth operation of the liner in a particular season. The opening frequency can only increase to meet growing market demand. A special sub-factor is subsidy (0.059). In the early stage of development of the China-Railway Express, subsidies enabled operators to cover

Table 5. AHP results of the main criteria

Factor	Fuzzy Score			Defuzzification	Rank
Total cost	0.397	0.402	0.401	0.400	1
Total time	0.253	0.256	0.259	0.256	2
Transportation capability	0.162	0.160	0.161	0.161	4
Service reliability	0.189	0.182	0.179	0.183	3

Table 6. AHP results of the sub-criteria

Factor	Fuzzy Score			Defuzzification	Rank
Transportation costs (shipping & railway)	0.178	0.190	0.200	0.189	1
Subsidy	0.054	0.059	0.064	0.059	8
Transit fee	0.028	0.030	0.033	0.031	12
Transportation time (shipping & railway)	0.097	0.102	0.105	0.101	3
Clearance time	0.057	0.057	0.058	0.057	9
Transit time	0.071	0.073	0.075	0.073	6
Load capacity	0.064	0.060	0.056	0.060	7
Transport frequency	0.156	0.152	0.148	0.152	2
Transit capability	0.045	0.044	0.044	0.044	10
Cargo safety	0.096	0.095	0.093	0.095	5
Flexibility	0.043	0.039	0.038	0.040	11
Punctuality	0.112	0.099	0.086	0.099	4

operating losses and maintain normal operations; but the total amount is too big for the government, whose initial intention for the subsidy is to promote the rapid and sustainable development of the China-Railway Express, not just to cover its operating losses. However, due to the higher freight costs compared to the cost of sea freight without subsidies, the China-Railway Express cannot maintain the economic viability of its operations. Therefore, further development is oriented towards reducing transport costs rather than relying on local government subsidies to compete with maritime transport on freight rates (Feng, 2020).

4.3 Assessment of alternatives

4.3.1 Alternative routes from Incheon to Hamburg

The number of China-Railway Express trains is increasing. Many cities and ports have become important nodes. To find alternative routes, it is necessary to determine the original, destination, and transit nodes in this network. China has three transit seaports (Rizhao Port, Dalian Port, and Lianyungang Port) and three inland transshipment cities (Alashankou in the Xinjiang Uygur Autonomous Region of China and Erlianhot and Manzhouli in the Inner Mongolia Autonomous Region) that can provide cargo

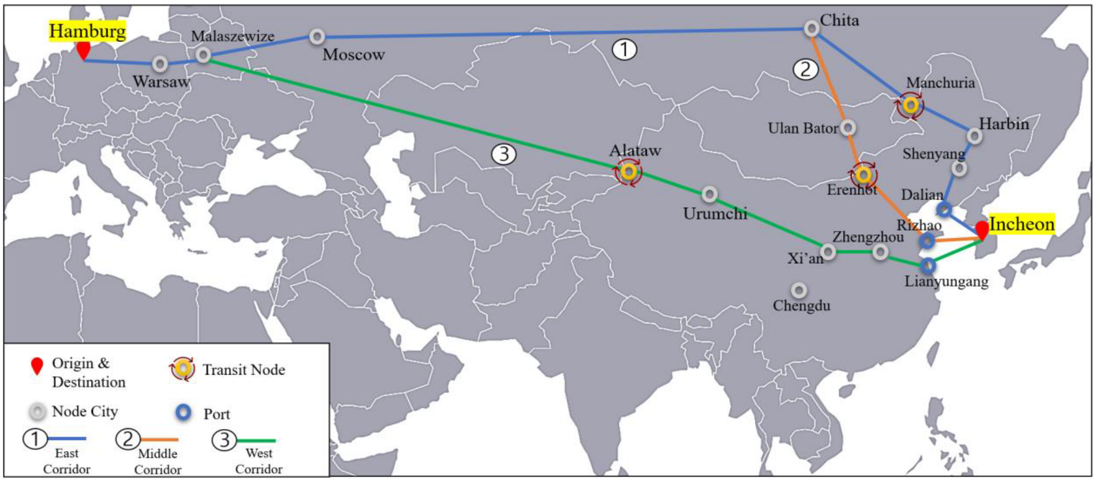

Figure 4. Alternative routes for transporting cargo from Korea to Europe.

Table 7. Evaluation results of alternative routes.

Alternatives	d*	d-	CCi	Rank
1. Incheon – Dalian – Manchuria – Hamburg	0.0916	0.0007	0.4633	1
2. Incheon – Rizhao – Erenhot – Hamburg	0.1071	0.0007	0.3892	2
3. Incheon – Lianyungang – Alataw – Hamburg	0.1315	0.0003	0.1475	3

transit and customs clearance services, which have changed train tracks. These three inland transshipment cities undertake the transshipment of the three corridors in the eastern, central, and western regions, respectively, of the China-Railway Express Construction and Development Plan 2016–2020.

4.3.2 Evaluation of alternative routes

For comparison, quantitative data are paramount but qualitative analysis is also required to achieve clarity. Therefore, a combination of qualitative analysis and quantitative analysis is used in route selection to avoid subjectivity.

The subjective factors (safety, flexibility, and punctuality) were assessed based on the judgment of each decision-maker who answered the questionnaire. Three alternative routes for cargo transportation from Incheon to Hamburg were evaluated based on the subfactors and the expert opinions.

The final ranking of the alternatives is shown in Table 7. Route 1 is the first choice, which departs from Incheon port via the port of Dalian, China; exits via Manzhouli; and arrives in Hamburg via Russia and other countries using the eastern route of the China-Railway Express.

The number of voyages from Incheon to Dalian is growing. At the same time, Shenyang, China's industrial city with perfect infrastructure in the early days and the largest cargo consolidation center in the northeast, in addition to its large number of inland hubs in Manzhouli, opened a cumulative 2,010 columns in June this year, compared with the same period last year, of which more than 2,000 columns were completed 45 days earlier. Manzhouli station is using a digital port system to strengthen the information transfer between customs and freight forwarding companies in order to provide 24-hour service for outbound China-Railway Express trains and to improve customs clearance efficiency. In addition, to compress the port dressing time, the management is fully exploiting the capacity of its resources by optimizing the scheduling. As a result, the port dressing capacity has greatly improved. A noteworthy point is that after the opening of the TKR railroad in South Korea, the transportation time can be shortened by rail transport directly to Shenyang, but this is subject to the political situation on the Korean Peninsula. The next route is No. 2, from Rizhao port in China to the central corridor Erenhot and arriving at Hamburg via the central route of the China-Railway Express through Mongolia and Russia. Although the shipping cost from Incheon to Rizhao is very low, the port of Rizhao is small and the infrastructure is weak compared to Dalian and Lianyungang.

Route No. 3 uses mainly the western corridor of the China-Railway Express, which reaches Lianyungang from Incheon and then changes to Europe via Alashankou, where most of the goods currently leaving the country go to Central Asia (Wang Ying, 2018). Due to government support, Lianyungang has superior customs clearance time and convenience. This advantage is improving the connectivity of transport nodes and is expected to attract more Korean shippers to this port in the future.

Ⅴ. Conclusion

As trade and freight volumes between Korea to Europe continue to increase, the effect of the epidemic intermodal routes on traditional sea routes from Korea to Europe is becoming a problem. Multimodal transport services to neighboring countries are expected to improve during the rapid development of the China-Railway Express. To explore cargo transport routes, this paper reviews the transit nodes in the transport network provided by China and applies two methods, fuzzy hierarchical analysis and TOPSIS, of evaluating alternative routes with integrated qualitative and quantitative analysis. The fuzzy AHP method was used to obtain the weights of the factors and subfactors for the evaluation. TOPSIS was used to evaluate three alternative routes. The results showed that of the four main factors, the total cost is the most important, followed by the total transportation time, service reliability, and transportation capacity. In terms of the overall weighting of the subfactors, the transportation cost and the transportation time and government subsidies are important. Further results showed that the (Incheon – Dalian – Manchuria - Hamburg) route 1 is the preferred route for transport from Korea to Europe.

This study pointed out some academic and practical implications. While most studies academic are limited to traditional maritime and railroad routes, this study provided a variety of intermodal routes centered on the developing China-Europe Classes.

Furthermore, this research covers not only China domestic side but also the international side. Ultimately, this paper can give ideas and concepts to alleviate the inefficient cargo supply and enhance the frequency of operations. The fuzzy set theory and real data were also used to integrate expert opinions in order to find the best alternative route for intermodal transport of goods, which is regarded as more reliable compared to the simple AHP method. For shippers and logistics companies. the relationship and structure between relevant factors and subfactors can be referred to in order to provide in-depth information for selecting routes and adjusting to market changes in a timely manner.

China introduced the CRE as part of the Belt and Road Initiative and development in the Midwest and its link to Europe, resulting in significant growth. However, increased cargo volumes are limited to cargoes, originating and ending in China, with a limitation of expanding to other countries. Southeast Asian countries such as Vietnam and Northeast Asian countries such as Korea and Japan should be connected to the CRE.

Korea's trade with China has expanded in the recent two decades. Korea's trade to Europe has been mainly through the sea, the main land bridge route of Korea export and import to Europe are through the Busan-Far East Russia route and Incheon-Northeastern ports of China. The difference between exports and imports (back-haul) and the capacity of the Chinese railway through Tianjin Port are limiting its linkage with neighboring countries. As shown in the AHP analysis of the three routes, the route through Tianjin Port still does not change the results in the sensitivity analysis with the change of time and cost; therefore, it seems that fundamental improvement of this route is required to have competitiveness. The routes to Europe using Northeast China ports will compete with Far-east Russia (Vladivostok, etc.) via Busan Port, and a maritime route through using the Arctic Ocean routes in the future. For China to succeed in the BRI and CRE project, it is essential to establish a route that includes the passing cargoes with surrounding countries. Considering the TMGR route that passes through Mongolia via Tianjin Port, a significant capacity expansion is necessary.

However, this study did not consider the actual international trade terms, environmental factors, and changes in logistics with limited flow in both directions. Therefore, in the future, the incorporation of actual international trade terms and environmental factors into the analysis and the consideration of factor differences and selection models for reverse route selection may be explored.

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Multimodal Route Selection from Korea to Europe Using Fuzzy AHP-TOPSIS Approaches: The Perspective of the China-Railway Express

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국문요약

2011년 한-유럽 FTA 체결 이후 두 지역의 거래액은 증가일로에 있으며 전체 시장은 지속적으로 확대되고 있다. 여러 운송수단을 이용하는 복합국제운송에 대한 관심이 늘어나며 기존의 해운운송 위주의 운송 방식에서 철도를 포함한 두 가지 이상의 운송수단을 사용하는 다중운송경로를 통한 운송이 확대되고 있다.

COVID-19의 영향으로 2019년 세계 화물 시장이 타격을 받았는데 특히 해상 및 항공 노선의 급격한 제한에 기인하고 한국의 대유럽 수출도 감소하였다. 이러한 영향에도 2020년 CRE(China Railway Express) 화물 열차의 총 수는 2016년 대비 7.3배 증가한 12,406개 노선으로 전년 대비 50% 증가하였다. 철도를 이용한 육상기반의 화물운송에 대한 연구는 꾸준히 있어 왔으나 한국과 유럽의 운송노선에 대한 연구는 TSR(Trans Siberian Railway), 수에즈 해운(Suez Shipping), 기존 TCR(Trans China Railway) 노선에 국한되었다.

본 논문은 중국에서의 일대일로 구상에 따라 최근 변화를 겪고있는 실크로드의 핵심에 초점을 맞추어 중국-유럽 화물열차(CRE)를 대상으로 연구를 진행하였다. Fuzzy-AHP는 한국에서 유럽으로 가는 국제 복합항로 선정 시 요인의 우선순위를 결정하는데 사용하였으며 중국과 한국의 전문가 설문조사를 통해 결과를 도출하였다. 요인 선정 후 TOPSIS 방법을 적용하여 계획된 3개의 경로를 순위화하였다. 그 결과 총비용, 총시간, 서비스 신뢰도가 CRE 기반 복합운송을 선택할 때 의사결정자가 고려하는 요소로 나타났다. 또한, 주요 3개 복합운송노선에서 Route 1(인천-대련-만주-함부르크) 노선이 최적 노선이고 Route 2(인천-리차오-얼렌하오터-함부르크)와 Route 3(인천-롄윈강-시안-함부르크) 순서로 나타났다.

주제어: 중국-유럽화물열차, 복합운송, Fuzzy AHP, TOPSIS