

# IDENTIFYING THE KEY PHYSICAL CHARACTERISTICS' FACTORS OF FREIGHT TRANSPORTATION ROUTING

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## **Abstract**

The purposes of this research were to identify and determine the relative weights of the key physical characteristics' factors for freight transportation routing. The Delphi method was employed to screen and group the possible physical characteristics' factors. Then, the key factors of the relative weights were determined by the fuzzy analytic hierarchy process based on experts' opinions. The results showed that there are 20 key factors for freight transportation routing. The key factors were comprised in 4 groups in order of their relative weights, from the most to the least: the physical characteristics of road elements, of road competency, of blackspots, and of transportation facility. In addition, the results showed that the top 3 key factors were the percentage of access points, intersections, crosswalks, railroad crossings, and U-turn points per km, the number of lanes, and the road surfaces, respectively. The contributions of this study will be helpful for the decision-makers in freight transportation routing and the government to improve the transportation infrastructure of the country.

**Keywords:** Key physical characteristics' factors, freight transportation routing, Delphi method, fuzzy analytic hierarchy process

## **Introduction**

The 2017-2021 strategic plan from Thailand's Ministry of Transport proposes policies to improve the inland highway network connected to railways, ports, and airports and to neighboring countries: construction of new roads, improvement or expansion of existing roads as required, improvement of the blackspots, installation of safety facilities, etc. (Ministry of

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Transport, 2016). Hence, the government allocated financial resources to pursue those policies. Therefore, road transportation has become the main mode of transportation in Thailand.

The appropriate freight transportation routing is a strategy for a company. The proper route can minimize logistics expenses, reveal the potential of freight transportation processes (Arunyanart *et al.*, 2016), and customer satisfaction on the delivery time, minimization of damaged freight, etc. Over the last decade and a half, there have been many studies on the appropriate freight transportation routing or multimodal transportation routing. Banomyong and Beresford (2001) considered multimodal transportation routes for suppliers in Laos People's Democratic Republic. Chang (2008) concentrated on the multimodal transportation routing with a mathematical model. Ko (2009) developed the decision support system (DSS) for multimodal transportation routing from Busan to Moscow. Kengpol *et al.* (2012a) proposed the DSS in multimodal transportation routing within the Greater Mekong subregion countries. Kengpol *et al.* (2012b, 2014) and Kengpol and Tuammee (2015) have further introduced the DSS in multimodal green logistics with consideration of the impact from transportation on the environment. Wang and Yeo (2016) investigated international multimodal transport networks from Korea to Central Asia. Arunyanart *et al.* (2016) explored the current situation along Thailand's East-West Economic Corridor from the viewpoint of regional logistics networks. As described earlier, the authors discovered that many studies have emphasized the multimodal transportation routing with the quantitative factors which are transportation cost and transportation time, and the qualitative factors which are factors that cannot be quantified. However, they have disregarded the physical characteristics of the routes. In addition, those studies also have ignored road freight transportation routing. To solve the problem, this study aims to identify the physical characteristics' factors in road freight transportation routing.

Many previous studies considered transportation and hazardous materials (HazMat) routing with the physical characteristics.

Son *et al.* (2005) presented the criteria to evaluate the physical characteristics of transportation routes in rural areas of South Korea. Polus *et al.* (2005) and Farah *et al.* (2007) studied the correlation between different infrastructure characteristics and crash rates, developed the infrastructure coefficient, and generated a crash-prediction model. Sattayaprasert *et al.* (2008) proposed a model for HazMat transportation routing in Thailand. Regmi and Hanaoka (2012) explored multimodal transportation routes from Northeast Asia to Central Asia. As mentioned previously, the authors discovered that there are few studies which concentrated on road freight transportation routing with the physical characteristics. Moreover, they have considered the different factors for similar purposes.

Consequently, the authors decided to identify the key physical characteristics' factors for appropriate road freight transportation routing. The Delphi method was employed to screen the possible factors and group the key factors. Moreover, the key factors were analyzed by the fuzzy analytic hierarchy process (FAHP) for the relative weights that can reflect the experts' opinions for improvement of the transportation infrastructure and enhancement of the freight transportation routing.

## Materials and Methods

The purposes of this study were to identify and prioritize the key physical characteristics' factors for freight transportation routing by the Delphi method and FAHP. In achieving the purposes, there are 3 main steps as follows:

### Identifying the Possible Physical Characteristics' Factors

The possible physical characteristics' factors were identified through a detailed literature review as described above and interviews with experts who have experience of at least 5 years related to transportation and logistics management. Experts had to be selected from different organizations to reduce the bias of data collection.

### Screening and Grouping the Possible Physical Characteristics Factors

The Delphi method was employed to screen and group the possible key factors. Dalkey and Helmer (1963) developed this method at the Rand Corporation (Hsu and Sandford, 2007). The Delphi method is an expert opinion survey with 3 features: anonymous response, iteration and controlled feedback, and statistical group response (Hsu *et al.*, 2010), and there are 2 sub-steps as follows:

1. First, the key factors were determined by screening the possible physical characteristics' factors. Experts with the same qualifications as in the previously mentioned but from different groups were chosen to ensure diverse viewpoints. The number of experts should not be less than 18 which is the number to decrease the error rate of results at 0.02 (Macmillan, 1971), and the details are as follows:

- Delphi first round for screening. The authors interviewed the experts who examined the possible factors with an open-ended questionnaire for enhancement. After this, these factors were verified and appended by the experts' opinions. Finally, a close-ended questionnaire relating to the interviews with 5-point agreement Likert-type scales was developed.

- Delphi second round for screening. The experts evaluated the possible factors of the Delphi first round with the close-ended questionnaire. Then, the interquartile range (IQR), the absolute difference between the median and mode ( $|Mdn-Mo|$ ), and standard deviation (S.D.) were calculated.

- Delphi third round for screening. The experts examined the close-ended questionnaire with the statistics to compare their opinions with the consensus. In this step, the authors summarized the results of the experts' opinions with 3 criteria: both the IQR and S.D. were not greater than 1.5 and the  $|Mdn-Mo|$  was not greater than 1 (Raskin, 1994; Rayens and Hahn, 2000; Christie and Barela, 2005; Anukulbut, 2013).

2. Secondly, the key physical characteristics' factors were categorized by experts who have the same qualifications as in the previous step but from a different group.

The experts could not resolve a lot of the factors effectively, because of the experimental findings of a psychologist quoted by Miller (1956), who suggested that, in general, people could deal with information simultaneously which involves only a few facts, seven plus or minus two in number (Saaty, 1990). Therefore, the Delphi method was employed to group the key factors and the details are as follows:

- Delphi first round for grouping. The experts' opinions were collected with the open-ended questionnaire and the experts considered the key factors which were categorized into groups. Finally, the close-ended questionnaire on the interviews with 5-point agreement Likert-type scales was developed.

- Delphi second round for grouping. The experts evaluated the key characteristics' factors which were categorized as to whether they were in a suitable group or not. The descriptive statistics were calculated.

- Delphi third round for grouping. The experts examined the close-ended questionnaire with statistics to compare their opinions with the consensus. Finally, the authors summarized the results of experts' opinions with the 3 criteria as mentioned above.

### Determining the Relative Weights of the Key Physical Characteristics Factors

The FAHP was developed from the analytic hierarchy process (AHP) to solve multi-criteria decision-making problems (Wu *et al.*, 2009). This approach combined the fuzzy set theory which was introduced by Zadeh (1965). The FAHP avoids the crisp values by using fuzzy numbers to compare objects. Hence, a decision-maker can overcome uncertainty and ambiguity, issues that are similar to the human thinking processes, and make more effective decisions (Chen *et al.*, 2011). The FAHP was employed to determine the relative weights of the key factors based on the logistics experts' opinions in Thailand. Chang (1996) presented the extent analysis for the FAHP which was used in this study because the procedure of this approach is easy and similar to the traditional AHP. There are 3 steps which were presented by Kumar and Singh (2012) to calculate the relative weights as follows:

**Table 1. Triangular fuzzy scale and linguistic judgment for fuzzy AHP**

| Linguistic Variable | Triangular Fuzzy Scale (TFN)                  | Inverse Triangular Fuzzy Scale (ITFN)                               |
|---------------------|-----------------------------------------------|---------------------------------------------------------------------|
| Equally strong      | (1, 1, 1)                                     | (1, 1, 1)                                                           |
| Moderately strong   | (2, 3, 4)                                     | (1/4, 1/3, 1/2)                                                     |
| Strong              | (4, 5, 6)                                     | (1/6, 1/5, 1/4)                                                     |
| Very strong         | (6, 7, 8)                                     | (1/8, 1/7, 1/6)                                                     |
| Extremely strong    | (9, 9, 9)                                     | (1/9, 1/9, 1/9)                                                     |
| Intermediate        | (1, 2, 3), (3, 4, 5),<br>(5, 6, 7), (7, 8, 9) | (1/3, 1/2, 1), (1/5, 1/4, 1/3),<br>(1/7, 1/6, 1/5), (1/9, 1/8, 1/7) |

1. The hierarchy structure of the problem was established. It consisted of the goal, the main criteria which are the group of factors, and the sub-criteria which are the factors in each group.

2. The fuzzy pairwise comparison matrices were constructed. In this step, the key factors were evaluated with triangular fuzzy scales which were illustrated by Kengpol *et al.* (2013) and Wu *et al.* (2004), as shown in Table 1. If the experts who had experience of at least 10 years related to logistics considered the horizontal factors N are more important than the vertical factors N, then the triangular fuzzy scale was chosen. On the other hand, if the vertical factors N are more important than the horizontal factors N, the inverse triangular fuzzy scale was chosen.

3. The relative weights of the key physical characteristics' factors were calculated by the extent analysis method. There are 4 main steps by Wang *et al.* (2007) as follows:

- The value of the fuzzy synthetic extent with respect to the  $i^{\text{th}}$  object is defined as:

$$S_i = \sum_{j=1}^m M_{gi}^j \odot \left[ \sum_{j=1}^n \sum_{i=1}^n M_{gi}^j \right]^{-1} \quad (1)$$

where  $g_i$  are the goals and represent the triangular fuzzy number (TFN) of the fuzzy pairwise comparison matrices with  $i = 1, 2, \dots, n$  and  $j = 1, 2, \dots, m$  and  $n$  objects and  $m$  goals.

- The degree of possibility of  $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$  is defined as:

$$V(M_2 \geq M_1) = \begin{cases} 1 & ; \text{ if } m_2 \geq m_1 \\ 0 & ; \text{ if } l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & ; \text{ otherwise} \end{cases} \quad (2)$$

- The degree of possibility for a convex fuzzy number  $M$  to be greater than convex fuzzy numbers  $M_i$  ( $i = 1, 2, \dots, n$ ) can be defined as:

$$d'(C_i) = \min V(S_i \geq S_k) \quad (3)$$

where  $k = 1, 2, \dots, n$  and  $k \neq 1$ . Then, the relative weights' vector of a factor is given by:

$$W' = \{d'(C_1), d'(C_2), \dots, d'(C_n)\}^T \quad (4)$$

where  $C_1, C_2, \dots, C_n$  are  $n$  criteria.

- On normalization, the relative weights are:

$$W = \{d(C_1), d(C_2), \dots, d(C_n)\} \quad (5)$$

where  $W$  is not a fuzzy number.

- The average of the relative weights is required if the judgement consisted of more than 1 matrix.

4. The global relative weights of the key physical characteristics' factors were calculated by multiplying the relative weights of the key factors and the relative weights of the key factors' group.

**Table 2. The results of Delphi method for screening the possible physical characteristics' factors**

| Possible physical characteristics' factor                                             | IQR   | Mdn-Mo | S.D.  | Selected / Rejected |
|---------------------------------------------------------------------------------------|-------|--------|-------|---------------------|
| Number of lanes (each direction)                                                      | 1.000 | 0.000  | 1.092 | Selected            |
| % of lane lines and center lines                                                      | 1.000 | 0.000  | 1.199 | Selected            |
| Lane widths                                                                           | 0.750 | 0.000  | 0.998 | Selected            |
| Road surfaces                                                                         | 0.000 | 0.000  | 0.323 | Selected            |
| % of road surface deterioration                                                       | 1.000 | 0.000  | 1.200 | Selected            |
| % of frontage roads                                                                   | 1.000 | 1.000  | 0.686 | Selected            |
| Shoulder widths                                                                       | 0.750 | 0.000  | 0.461 | Selected            |
| Shoulder surfaces                                                                     | 1.750 | 1.000  | 1.060 | Rejected            |
| % of pavements                                                                        | 2.000 | 0.000  | 1.425 | Rejected            |
| % of shoulder surface deterioration                                                   | 1.000 | 0.500  | 0.616 | Selected            |
| Road slopes                                                                           | 0.000 | 0.000  | 0.922 | Selected            |
| Sight distances                                                                       | 2.750 | 1.500  | 1.542 | Rejected            |
| % of horizontal and vertical curves                                                   | 1.000 | 0.000  | 1.085 | Selected            |
| % of super elevations                                                                 | 1.750 | 0.000  | 1.552 | Rejected            |
| % of highways with guardrails                                                         | 1.000 | 0.500  | 1.150 | Selected            |
| % of access points with acceleration /deceleration lanes                              | 0.750 | 0.000  | 0.840 | Selected            |
| % of highways with no-passing zones                                                   | 3.000 | 1.500  | 1.423 | Rejected            |
| % of highways with median                                                             | 1.000 | 0.500  | 0.943 | Selected            |
| Median types                                                                          | 0.750 | 0.000  | 0.461 | Selected            |
| The load capacity of bridges                                                          | 1.500 | 0.000  | 1.114 | Selected            |
| Highway types                                                                         | 1.750 | 1.000  | 1.200 | Rejected            |
| Vertical clearance of underpasses or tunnels                                          | 1.000 | 0.500  | 1.003 | Selected            |
| Topography                                                                            | 3.000 | 1.000  | 1.581 | Rejected            |
| % of bridges                                                                          | 1.000 | 0.000  | 0.922 | Selected            |
| Median widths                                                                         | 1.000 | 0.000  | 1.042 | Selected            |
| % of access points, intersections, cross-walks, railroad crossings, and U-turn points | 1.000 | 0.000  | 0.786 | Selected            |
| % of bridges with climbing lanes                                                      | 1.000 | 0.000  | 1.138 | Selected            |

## Results and Discussion

This section presents the results to identify the key physical characteristics' factors in freight transportation routing. The details are as follows:

### The Key Physical Characteristics' Factors

The possible factors were identified through a detailed literature review and interviews with the 14 experts. The authors discovered that there are 27 possible characteristics' factors. After that, all factors were considered by 21 experts with the Delphi

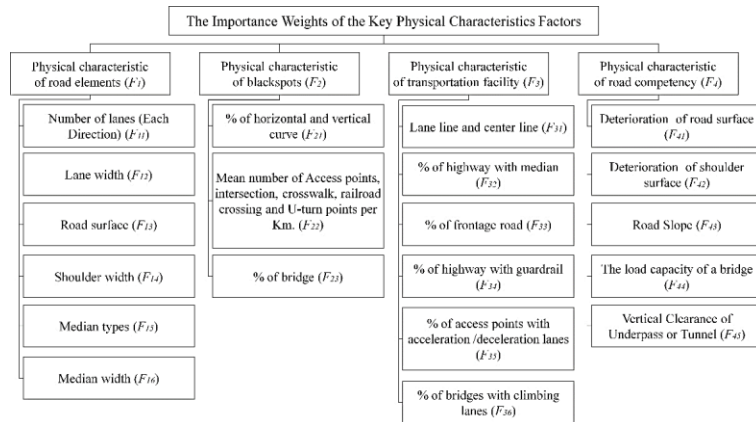
method to identify the key physical characteristics. The results showed 20 factors which were selected for analysis in the next step as shown in Table 2.

### The Group of Key Physical Characteristics' Factors

The key factors of the Delphi method in the previous step were categorized by the Delphi method because human perception is limited as previously mentioned. The results of the grouping showed that the key factors can be divided into 4 different groups as shown in Table 3.

**Table 3. The group of key physical characteristics' factors**

| Group of Factor                                              | The Key Physical Characteristics' Factor                                            |          |
|--------------------------------------------------------------|-------------------------------------------------------------------------------------|----------|
| Physical characteristic of road elements ( $F_1$ )           | Number of lanes (Each Direction)                                                    | $F_{11}$ |
|                                                              | Lane widths                                                                         | $F_{12}$ |
|                                                              | Road surfaces                                                                       | $F_{13}$ |
|                                                              | Shoulder widths                                                                     | $F_{14}$ |
|                                                              | Median types                                                                        | $F_{15}$ |
|                                                              | Median widths                                                                       | $F_{16}$ |
| Physical characteristic of blackspots ( $F_2$ )              | % of horizontal and vertical curves                                                 | $F_{21}$ |
|                                                              | % of Access points, intersections, crosswalks, railroad crossings and U-turn points | $F_{22}$ |
|                                                              | % of bridges                                                                        | $F_{23}$ |
|                                                              | % of lane line and center line                                                      | $F_{31}$ |
| Physical characteristic of transportation facility ( $F_3$ ) | % of highway with median                                                            | $F_{32}$ |
|                                                              | % of frontage road                                                                  | $F_{33}$ |
|                                                              | % of highway with guardrail                                                         | $F_{34}$ |
|                                                              | % of access points with acceleration /deceleration lanes                            | $F_{35}$ |
|                                                              | % of bridges with climbing lanes                                                    | $F_{36}$ |
|                                                              | Deterioration of road surfaces                                                      | $F_{41}$ |
| Physical characteristic of road competency ( $F_4$ )         | Deterioration of shoulder surfaces                                                  | $F_{42}$ |
|                                                              | Road Slopes                                                                         | $F_{43}$ |
|                                                              | The load capacity of bridges                                                        | $F_{44}$ |
|                                                              | Vertical clearance of underpasses or tunnels                                        | $F_{45}$ |

**Figure 1. The hierarchy structure of problems**

### The Relative weights of the Key Physical Characteristics' Factors

At this step, the authors determined the relative weights of the key factors with the FAHP and the details are as follows:

1. The authors dealt with the problem by establishing the hierarchy structure of the problems as shown in Figure 1. It consisted of 3 levels: level 1 was a goal, level 2 was a group

of key factors, and level 3 was the key factors in each group.

2. The experts evaluated both the groups and the key factors by triangular fuzzy scales. Then, the fuzzy pairwise comparison matrices were constructed by 7 experts. The pairwise comparison matrix of the group from the first expert is shown in Table 4.

**Table 4. The pairwise comparison matrix of a group from the first expert**

|       | $F_1$           | $F_2$           | $F_3$     | $F_4$           |
|-------|-----------------|-----------------|-----------|-----------------|
| $F_1$ | (1, 1, 1)       | (1, 2, 3)       | (2, 3, 4) | (1, 2, 3)       |
| $F_2$ | (1/3, 1/2, 1/1) | (1, 1, 1)       | (1, 2, 3) | (1, 1, 1)       |
| $F_3$ | (1/4, 1/3, 1/2) | (1/3, 1/2, 1/1) | (1, 1, 1) | (1/4, 1/3, 1/2) |
| $F_4$ | (1/3, 1/2, 1/1) | (1, 1, 1)       | (2, 3, 4) | (1, 1, 1)       |

3. The results of the relative weights of the key factors based on the fuzzy pairwise comparison matrices were given as follows:

- The value of the fuzzy synthetic extent with respect to the  $i^{\text{th}}$  group of factors and key physical characteristics' factors can be calculated with Equation (1) as:

$$\begin{aligned}
 S_{F1} &= (0.185, 0.397, 0.759) \\
 S_{F2} &= (0.123, 0.223, 0.414) \\
 S_{F3} &= (0.068, 0.107, 0.207) \\
 S_{F4} &= (0.160, 0.273, 0.483) \\
 S_{F11} &= (0.133, 0.218, 0.356) \\
 S_{F12} &= (0.102, 0.179, 0.313) \\
 S_{F13} &= (0.113, 0.211, 0.370) \\
 S_{F14} &= (0.062, 0.109, 0.199) \\
 S_{F15} &= (0.067, 0.120, 0.228) \\
 S_{F16} &= (0.089, 0.163, 0.294) \\
 S_{F21} &= (0.167, 0.308, 0.524) \\
 S_{F22} &= (0.296, 0.462, 0.699) \\
 S_{F23} &= (0.173, 0.231, 0.350) \\
 S_{F31} &= (0.068, 0.135, 0.260) \\
 S_{F32} &= (0.082, 0.156, 0.307) \\
 S_{F33} &= (0.105, 0.201, 0.376) \\
 S_{F34} &= (0.070, 0.139, 0.279) \\
 S_{F35} &= (0.084, 0.159, 0.307) \\
 S_{F36} &= (0.109, 0.211, 0.404) \\
 S_{F41} &= (0.143, 0.228, 0.356) \\
 S_{F42} &= (0.155, 0.249, 0.405) \\
 S_{F43} &= (0.169, 0.262, 0.405) \\
 S_{F44} &= (0.089, 0.137, 0.211) \\
 S_{F45} &= (0.076, 0.125, 0.205)
 \end{aligned}$$

- The degree of possibility for a convex fuzzy number can be calculated with Equations (2) and (3). The examples of calculating this value for the  $i^{\text{th}}$  group of factors and key physical characteristics factors are shown

below, showing only the convex fuzzy number of  $S_{F1}$  over the other groups.

$$\begin{aligned}
 V(S_{F1} \geq S_{F2}) &= 1 \\
 V(S_{F1} \geq S_{F3}) &= 1 \\
 V(S_{F1} \geq S_{F4}) &= 1 \\
 V(S_{F2} \geq S_{F1}) &= 0.564 \\
 V(S_{F2} \geq S_{F3}) &= 1 \\
 V(S_{F2} \geq S_{F4}) &= 0.827 \\
 V(S_{F3} \geq S_{F1}) &= 0.071 \\
 V(S_{F3} \geq S_{F2}) &= 0.420 \\
 V(S_{F3} \geq S_{F4}) &= 0.221 \\
 V(S_{F4} \geq S_{F1}) &= 0.706 \\
 V(S_{F4} \geq S_{F2}) &= 1 \\
 V(S_{F4} \geq S_{F3}) &= 1
 \end{aligned}$$

- The relative weights' vector of the groups and key factors in each group can be given by the minimum degree of possibility as:

$$\begin{aligned}
 W'_{Group} &= (1, 0.564, 0.071, 0.706)^T \\
 W'_{F1} &= (1, 0.822, 0.971, 0.377, 0.492, 0.745)^T \\
 W'_{F2} &= (0.600, 1, 0.190)^T \\
 W'_{F3} &= (0.665, 0.783, 0.964, 0.702, 0.792, 1)^T \\
 W'_{F4} &= (0.846, 0.948, 1, 0.252, 0.208)^T
 \end{aligned}$$

- The relative weights of the groups and key factors in each group can be given by the normalized weight vector with Equation (5) and the global relative weights for the key factors as shown in Table 5.

The results from Table 5 revealed the relative weights of the group of factors, key factors, and the global relative weights. The physical characteristics of the road elements group, of the road competency group, of the blackspots group, and of the transportation

**Table 5. The relative weights and the global relative weights of groups of factors and key physical characteristics' factors**

| Group of Factor | The Relative weight | The Key Physical Characteristics' Factor | The Relative weight | The Global Relative weight |
|-----------------|---------------------|------------------------------------------|---------------------|----------------------------|
| $F_1$           | 0.427               | $F_{11}$                                 | 0.227               | 0.097                      |
|                 |                     | $F_{12}$                                 | 0.187               | 0.080                      |
|                 |                     | $F_{13}$                                 | 0.220               | 0.094                      |
|                 |                     | $F_{14}$                                 | 0.086               | 0.037                      |
|                 |                     | $F_{15}$                                 | 0.112               | 0.048                      |
| $F_2$           | 0.241               | $F_{16}$                                 | 0.169               | 0.072                      |
|                 |                     | $F_{21}$                                 | 0.335               | 0.081                      |
|                 |                     | $F_{22}$                                 | 0.559               | 0.135                      |
|                 |                     | $F_{23}$                                 | 0.106               | 0.026                      |
|                 |                     | $F_{31}$                                 | 0.136               | 0.004                      |
| $F_3$           | 0.030               | $F_{32}$                                 | 0.160               | 0.005                      |
|                 |                     | $F_{33}$                                 | 0.196               | 0.006                      |
|                 |                     | $F_{34}$                                 | 0.143               | 0.004                      |
|                 |                     | $F_{35}$                                 | 0.161               | 0.005                      |
|                 |                     | $F_{36}$                                 | 0.204               | 0.006                      |
| $F_4$           | 0.302               | $F_{41}$                                 | 0.260               | 0.079                      |
|                 |                     | $F_{42}$                                 | 0.291               | 0.088                      |
|                 |                     | $F_{43}$                                 | 0.307               | 0.093                      |
|                 |                     | $F_{44}$                                 | 0.077               | 0.023                      |
|                 |                     | $F_{45}$                                 | 0.064               | 0.019                      |

facility group were taken as the most relative weights in their respective order as  $F_1 > F_4 > F_2 > F_3$ . Furthermore, the percentage of access points, intersections, crosswalks, railroad crossings, and U-turn points per km. ( $F_{22}$ ), the number of lanes ( $F_{11}$ ), and the road surfaces ( $F_{13}$ ) were taken as the top 3 most important key factors, respectively.

The objectives of this research were to identify and determine the relative weights of the key physical characteristics' factors for freight transportation routing. The authors discovered that 20 key physical characteristics' factors affect the freight transportation routing. The key factors can be divided into 4 groups: the physical characteristics of the road elements, of blackspots, of transportation facility, and of road competency. Moreover, the physical characteristic of the road elements was taken as the most important group in this case. In addition, the global relative weights of the key factors showed that the top 3 key factors were the percentage of access points, intersections,

crosswalks, railroad crossings, and U-turn points per km, the number of lanes, and the road surfaces, respectively. The results also showed that the FAHP is a popular and powerful tool to address the priority of the key factors. This approach can overcome the ambiguity and uncertainty in decision-making. In particular, the calculation of relative weights is given to a factor in logistics work. This evidence can be found in Kahraman *et al.* (2003); Hsu *et al.* (2010); Ganguly and Guin (2011); Lee *et al.* (2012) and Mangla *et al.* (2015). Moreover, the top 3 factors were consistent with the findings by Polus *et al.* (2005); Farah *et al.* (2007); Sattayaprasert *et al.* (2008) and Yuan *et al.* (2014). These studies were also mentioned and integrated the top 3 key factors in transportation routing. However, the results of screening, grouping, and determining relative weights for the key physical characteristics may be changed based on the experts' opinions and the results of the comparison matrix.

## Conclusions

The contribution of this research lies in the development of a new approach that is a guideline for entrepreneurs, small and medium enterprises, and logistics service provider firms for freight transportation routing with the physical characteristics' factors which are both quantitative and qualitative factors. The key factors can be divided into 4 groups. The top 3 key factors are the percentage of access points, intersections, crosswalks, railroad crossings, and U-turn points per km, the number of lanes, and the road surfaces. For future research, the key physical characteristics' factors will be enhanced in the form of the potential evaluation or risk assessment criteria. Moreover, the key factors can be considered in the DSS concept.

## References

- Anukulbut, A. P. (2013). *Qualitative Research*. 1<sup>st</sup> ed. Edbase, Bangkok, Thailand, 103p.
- Arunyanart, S., Ohmori, S., and Yoshimoto, K. (2016). Selection of export route option in GMS region: recommendation for current situation. *J. Jpn. Ind. Manage. Assoc.*, 67(2E):193-201.
- Banomyong, R. and Beresford, A.K.C. (2001). Multimodal transportation: the case of Laotian garment exports. *Int. J. Phys. Distr. Log.*, 31(9):663-685.
- Chang, D.Y. (1996). Application of the extent analysis method on fuzzy AHP. *Eur. J. Oper. Res.*, 95(3):649-655.
- Chang, T.S. (2008). Best routes selection in international intermodal networks. *Comput. Oper. Res.*, 35(9): 2,877-2,891.
- Chen, Y.C., Lien, H.P., Liu, C.H., Liou, J., Tzeng, G.W., and Yang, L.S. (2011). Fuzzy MCDM approach for selecting the best environment watershed plan. *Appl. Soft. Comput.*, 11(1):265-275.
- Christie, C.A. and Barela, E. (2005). The Delphi technique as a method for increasing inclusion in the evaluation process. *Can. J. Program. Eval.*, 20(5):105-122.
- Dalkey, N.C. and Helmer, O. (1963). An experimental application method to the use of experts. *Manage. Sci.*, 9(3):458-467.
- Farah, H., Polus, A., and Cohen, M.A. (2007). Development of an infrastructure coefficient by an analytic hierarchy process and its relationship to safety. *IATSS Res.*, 31(1):120-132.
- Ganguly, K.K. and Guin, K.K. (2013). A fuzzy AHP approach for inbound supply risk assessment. *Benchmarking Int. J.*, 20(1):129-146.
- Hsu, C.C. and Sandford, B.A. (2007). The Delphi technique: making sense of consensus. *Pract. Assess. Res. Eval.*, 12(10):1-8.
- Hsu, Y.L., Lee, C.H., and Kreng, V.B. (2010). The application of fuzzy Delphi method and fuzzy AHP in lubricant regenerative technology selection. *Expert Syst. Appl.*, 37(1):419-425.
- Kahraman, C., Cebeci, U., and Ulukan, Z. (2003). Multi-criteria supplier selection using fuzzy AHP. *Logist. Inf. Manage.*, 16(6):382-394.
- Kengpol, A., Meethom, W., and Tuominen, M. (2012a). The development of a decision support system in multimodal transportation routing within Greater Mekong sub-region countries. *Int. J. Prod. Econ.*, 140(2):691-701.
- Kengpol, A., Rontlaong, P., and Tuominen, M. (2013). A decision support system for selection of solar power plant locations by applying fuzzy AHP and TOPSIS: an empirical study. *J. Soft. Eng. Appl.*, 6(9):470-481.
- Kengpol, A., Tuammee, S., Meethom, W., and Tuominen, M. (2012b). Design of a decision support system on selection of multimodal transportation with environmental consideration between Thailand and Vietnam. *Asian Int. J. Sci. Technol. Prod. Manage. Eng.*, 5(2):55-63.
- Kengpol, A. and Tuammee, S. (2015). The development of a decision support framework for a quantitative risk assessment in multimodal green logistics: an empirical study. *Int. J. Prod. Res.*, 54(4):1,020-1,038.
- Kengpol, A., Tuominen, M., and Meethom, W. (2014). The development of a framework for route selection in multimodal transportation. *Int. J. Logis. Manage.*, 25(3):581-610.
- Ko, H.J. (2009). A DSS approach with fuzzy AHP to facilitate international multimodal transportation network. *Korea Maritime Institute Int. J. Mari. Aff. Fish.*, 1(1):51-70.
- Kumar, P. and Singh, R.K. (2012). A fuzzy AHP and TOPSIS methodology to evaluate 3PL in a supply chain. *J. Model. Manage.*, 7(3):287-303.
- Lee, T., Nha-Le, T., Genovese, A., and Koh, L. (2012). Using FAHP to determine the criteria for partner's selection within a green supply chain: The case of hand tool industry in Taiwan. *J. Manuf. Technol.*, 23(1):25-55.
- Macmillan, T. (1971). Unpublished data. The Delphi technique. The annual meeting of the California Junior Colleges Associations Committee on Research and Development, Monterey, CA, USA.
- Mangla, S.C., Kumar, P., and Burua, M.K. (2015). Risk analysis in green supply chain using fuzzy AHP approach: A case study. *Resour. Conserv. Recy.*, 104(B):375-290.
- Miller, G.A. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychol. Rev.*, 63(2):81-97.
- Ministry of Transport. (2016). Strategic Plan for 2017-2021. Bangkok, Thailand: Ministry of Transport. Available from: [www.mot.go.th](http://www.mot.go.th). Accessed date: Dec 29, 2016.
- Polus, A., Pollatschek, M., and Farah, H. (2005). Impact of infrastructure characteristics on road crashes. *Traffic Inj. Prev.*, 6(3):240-247.

- Raskin, M.S. (1994). The Delphi study in field instruction revisited: Expert consensus on issues and research priorities. *J. Soc. Work Educ.*, 30(1):75-89.
- Rayens, M.K. and Hahn, E.J. (2000). Building consensus using the policy Delphi method. *Policy Polit. Nurs. Pract.*, 1(4):308-315.
- Regmi, M.B. and Hanaoka, S. (2012). Assessment of intermodal transport corridors: cases from North-east and Central Asia. *Res. Transp. Busi. Manage.*, 5(3):27-37.
- Saaty, T.L. (1990). How to make a decision: The analytic hierarchy process. *Eur. J. Oper. Res.*, 48(1):9-26.
- Sattayaprasert, W., Hanaoka, S., Taneerananon, P., and Pradhananga, R. (2008). Creating a risk-based network for HazMat logistics by route prioritization with AHP. *IATSS Res.*, 32(1):74-87.
- Son, B., Park, M., and Lee, S. (2005). A study for hazardous road selection criteria for provincial roads. *J. East Asia Soc. Transp. Stud.*, 6:3,426-3,440.
- Wang, L., Chu, J., and Wu, J. (2007). Selection of optimum maintenance strategies based on a fuzzy analytic hierarchy process. *Int. J. Prod. Econ.*, 107(1):151-163.
- Wang, Y. and Yeo, G.T. (2016). A study on international multimodal transport networks from Korea to Central Asia: Focus on secondhand vehicles. *The Asian J. Ship. Logis.*, 32(1):41-47.
- Wu, F.G., Lee, Y.J., and Lin, M.C. (2004). Using the fuzzy analytic hierarchy process on optimum spatial allocation. *Int. J. Ind. Ergonom.*, 33(6):553-569.
- Wu, H.Y., Tzeng, G.H., and Chen, Y.H. (2009). A fuzzy MCDM approach for evaluating banking performance based on balanced scorecard. *Expert Syst. Appl.*, 36(6):10,135-10,147.
- Yuan, L., Yuan, H., Ma, Y., and Ren, Y. (2014). Development of a Safety Evaluation Model for Provincial Highway. *Discrete Dyn. Nat. Soc.*, 2014(394846):1-10.
- Zadeh, L.A. (1965). Fuzzy sets. *Inform. Control.*, 8:338-353.