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Research Article

An Integrated Potential Assessment Criteria and TOPSIS Based Decision Support System for Road Freight Transportation Routing

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Abstract
The objective of this study was to develop a Decision Support System (DSS) to select the best road freight transportation route. This DSS considers transportation cost, transportation time, and road physical route characteristic scores which are calculated by standard criteria. These criteria are composed of four groups: road elements, blackspots, transportation facilitation, and road competency. Moreover, the descriptions of each scale were constructed by the Delphi method based on suitability and facilitation of freight transportation. Each criterion has different methods to calculate the potential scores. Fuzzy Analytic Hierarchy Process (FAHP) was combined in the route selection algorithm which was a Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). This technique provides solutions to problems involving conflicting and multiple objectives. TOPSIS is applied for the final ranking of solutions used by the freight transportation routing implementation. The case of a logistic service provider company was used to evaluate the proposed DSS. The empirical study showed that the developed DSS works successfully.

Keywords: Decision support system, Road freight route's physical characteristics, TOPSIS, Proactive road freight transportation routing

1 Introduction

An appropriate freight transportation route strategy must reduce freight expenses, enhance supply chain visibility, deliver products on time, etc. [1]. Unsuccessful freight transportation or crashes usually results from a combination of three main elements: the driver, the physical route characteristic, and the vehicle [2]. According to Handerson [3], who demonstrated that drivers are not the main problem when failures of freight transportation occur, discovered they are affected by route characteristic or vehicle. One possible reason for this line of thinking is that the physical route characteristic as a whole affects freight transportation [4], [5]. Therefore, the route characteristics are considered when routing freight transportation in this study.

The freight transportation route problem has been extensively studied by researchers from several perspectives. Arunyanart *et al*. [1] contemplated the decision criteria to export route in Greater Mekong Subregion (GMS) countries using the Analytic Hierarchy Process (AHP), the criteria included engineering issues, economical issues, and environmental issues. Banomyong and Beresford [6] used a multimodal transportation cost-model to explore alternative multimodal transportation routes between Lao People's Democratic Republic (Lao PDR) to Rotterdam. Ko [7] proposed a decision-aid tool within a Decision Support System (DSS) for the facilitation of international intermodal transport routes, the Fuzzy Analytic Hierarchy

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Process (FAHP) was employed to specify the priorities of key factors for the network facilitation: cost data, traffic data, reliability data and security data. Kengpol *et al*. [8] evolved DSS which could optimize multimodal transportation routing within GMS countries, the DSS examined three criteria: transportation cost, transit time, and risk using Zero One Goal Programming (ZOGP). Kengpol *et al*. [9], Kengpol *et al*. [10], and Kengpol and Tuammee [11] further studied and combined the environmental impact in the multimodal transportation problem. Sattayaprasert *et al*. [12] proposed a method to create an effective hazardous logistics network by combining the risk assessment criteria and mathematical model, which were generated by the relative weights of risk from AHP. Yuan *et al*. [13] introduced risk assessment criteria and the relative weights from FAHP which generated a safety evaluation model for highways in the Hebei province. Seo *et al*. [14] explored the alternative routes from Chongqing to Rotterdam. The multimodal cost-model concentrated on transport cost, transit time, confidence index, etc. Beresford *et al*. [15] analyzed available multimodal transport route variations for iron ore shipments from northwest Australia to northeast China, the cost-model was applied. Kunchev [16] presented a method of truck route selection, this method consisted of multiple factors: infrastructure condition, geographic, roadside amenity, and impact of the meteorological condition. Kupytov and Abramov [17] constructed a mathematical model of the multimodal transportation system to assess and select alternatives for cargo transportation, there were four groups in the cargo transportation assessment: cost, time, reliability, and ecological impact. Effat and Hassan [18] placed emphasis on the roadway routes using least-cost path analysis and AHP in Sinai Peninsula. Kengpol [19] presented the DSS to minimize the total transportation costs with maximum satisfaction in GMS countries. One can see that there are many studies which have concentrated on the multimodal transportation problem but they have overlooked road freight transportation routing. Therefore, the road freight transport problem is explored in this study.

There are a few studies which integrated transportation cost, transportation time and physical characteristics factors of route for transportation routing. Additionally, the scrutinization of the physical characteristics have been evaluated by prioritizing the factors or risk assessment, which was a reactive transportation routing system. However, none of these studies only dealt with the potential assessment of tangible physical characteristics along the route. Furthermore, the studies considered several physical characteristic factors of similar purposes. The aim of this study is to solve this problem by establishing a standard criterion for freight routes using physical characteristics and potential assessment. The purpose of the criteria is to transform tangible route characteristics into potential scores. The descriptions of potential scale for each criterion will be conducted by the Delphi method based on suitability and facilitation of freight transportation. This technique evaluates the potential of a route by physical characteristics which makes this a proactive transportation routing system because the technique disregards historical statistical data and requires the empirical data of tangible physical characteristics.

The multi criteria decision-making approach: AHP, FAHP, ZOGP has been applied to prioritize and select the optimal freight routes, it can be found in [7]–[13]. None of these studies applied the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) which was introduced by

Hwang and Yoon [20] to select the best road freight transportation route. A few of the TOPSIS advantages are a sound logic that represents the rationale of human choice, a scalar value that accounts for both the best and worst alternatives simultaneously, and simple computation processes [21], [22].

To solve the problem as described earlier, this study aims to develop a DSS for road freight transportation routing which appraises the potential route by physical characteristics using a standard criteria assessment. The scores from route characteristics will be considered together with transportation cost and time of route. FAHP was employed to determine the relative weights for the decision criteria. The data of alternative freight routes were cogitated by TOPSIS to select the optimal road freight route. Finally, the DSS was applied to routing between Laem Chabang Port and Mukdahan Customs House to evaluate the system, this route is a part of the East West Economic Corridor (EWEC). This should prove or disprove the DSS can operate empirically and could encourage the government to deal with economic growth.

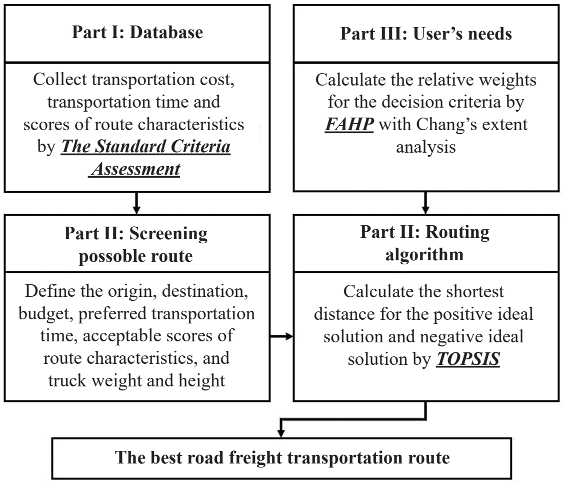


Figure 1: Systems model of DSS.

2 Methodology

This section explains the procedure to establish the DSS for road freight transportation routing. There are four parts of the DSS: part I: database, part II: screening of possible routes, part III: user's needs, and part IV: routing algorithm. The system model of DSS is shown in Figure 1.

2.1 *Part I: Database*

This part is used to store the data of all alternative routes. The data can be classified based on the quantitative and qualitative data.

2.1.1 Quantitative data

The quantitative data are transportation costs and transportation times of the freight route. The quantitative data can be specified by users. Transportation costs include fuel cost, insurance cost, tariff, etc. Costs depend on the numerous factors: vehicle types, level of goods, distance, container size, etc. Transportation times are approximated by interviewing entrepreneurs or users based on average speed of vehicle types.

2.1.2 Qualitative data

The qualitative data is the potential scores of tangible physical freight routes, which are then transformed by the standard criteria for route assessment. The standard criteria are composed of four different groups: road elements, blackspots, transportation facility, and road competency. These criteria are derived from the key factors by Koohathongsumrit and Meethom [23] who indicated that the physical characteristic factors of freight transportation routing, these factors were proven by the Delphi method based on the expert judgements. Thus, all key factors were considered in this paper. The scales of each criterion were divided into a five-point scale based on suitability and facilitation of freight transportation, the maximum potential is five and minimum is one. The description of each scale was collected and constructed with the Delphi method by interviewing experts who have experience concerning freight transportation, transportation management and reverse logistics of at least 10 years. The Delphi method first introduced by Dalkey and Helmer [24], has been widely used to obtain a consistent flow of answers through the results of questionnaires [25], [26]. This technique is an expert's opinions survey method, if the consensus among experts was not satisfactory, the analyst can survey the expert's opinions until the consensus is satisfied. The Delphi method was based on three basic characteristics: anonymous response, iteration and controlled feedback, and statistical group response [27]. The potential scores are calculated by the distance weighted summation method, it is the summation score which is weighted by the distance in their scale and total distance ratio. The score for a few criteria can be calculated by percentage comparison.

2.2 *Part II: Screening possible route*

Users defined the origin and destination; the possible road freight routes are then generated. The DSS also displays geographic information for each route. In this part, the users also define budget, preferred transportation time, acceptable route score, truck weight and height. The acceptable scores are determined from one to five. The acceptable score will be similar to one if the users desire a route with low potential score. But if the users desire an effective route, the acceptable score will be similar to five. Moreover, if the cost and time of a possible route are greater than budget and preferred time, this route is eliminated. In Addition, if the minimum load capacity of a bridge or shortest vertical clearance of an underpass, tunnel is lower or shorter than the vehicle weight and height, this route will be eliminated. Moreover, in the case that the score of each criterion is lower than the acceptable score by users, this route will also be eliminated.

2.3 *Part III: User's needs*

This part is used to define the relative weights of main decision criteria. However, human judgment always entails subjectivity and ambiguity, and in this situation, methodology of AHP is not a suitable selection. Thus, FAHP with the extent analysis method which proposed by Chang [28] was employed to determine the relative weights of decision criteria. This approach can resolve the limitation of pair-wise comparison which is the inability to handle the uncertainty and imprecision. The outlines of this approach have been explained in the following steps:

2.3.1 Judgement and comparisons

Users compare significance between two main decision criteria. All judgements are represented in a square matrix with the triangular fuzzy scales by Kengpol *et al*. [29] and Gumus [30]. These scales are similar to the traditional scales of AHP by Ganguly and Guin [31]. The vertical criteria are more important than horizontal criteria, the triangular fuzzy scale was chosen. Conversely, the reciprocal triangular fuzzy scale was chosen in case of horizontal criteria are more important than the vertical criteria. In the case of the judgement of decision criteria is operated by more than one user, the results of judgements can be aggregated by the fuzzy geometric mean method [32].

2.3.2 Calculate the relative weights

Let $X = \{x_1, x_2, \ldots, x_n\}$ be the criteria set, and $G = \{g_1, g_2, \ldots, g_n\}$ be the targets set. Degree analysis (g_i) is applied for every target by regarding each criterion. M degree analysis value related to the targets is expressed in triangular fuzzy numbers $M_{gi}^{1}, \ldots, M_{gn}^{m}$ as $i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, m$. M_{gi}^{j} shows triangular fuzzy number related to j target according to i criteria. The fuzzy synthetic values related to i criterion were then calculated. Finally, the relative weights were calculated and indicated by normalizing the lowest degree of possibility value. More details can be found in [33]–[36]. Finally, the Consistency Ratio (C.R.) should be verified.

2.4 *Part IV: Routing algorithm*

TOPSIS was employed to select the perfect freight route based on the main decision criteria: cost, time, and potential total score for each route characteristics group. This approach is based on the concept that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. TOPSIS assumes that the users have m alternatives and n criteria, users have the score of each alternative with respect to each criterion There are five steps by Parthiban *et al*. [37], Karahalios [38], and Yang *et al*. [39] as follows:

2.4.1 Construct the normalized score matrix

The transportation cost and time were converted into a five-scale score using a linear interpolation method [40]. The lowest transportation cost is five, the highest transportation cost is one. The transportation time which is the most similar from the preferred transportation time is five, the most different is one. The converted cost, time, and potential scores (x_{ij}) are transformed to normalized potential scores (r_{ij}) are defined as [Equation (1)]:

$$r_{ij} = x_{ij} / \sqrt{\sum_{i=1}^{m} x_{ij}^2} \tag{1}$$

Where $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$.

2.4.2 Construct the weighted normalized score matrix

The weighted normalized score matrix (v_{ij}) can be calculated by multiplying each row (r_{ij}) of normalized score matrix with the relative weights from FAHP (w_j). The weighted normalized score matrix is defined as [Equation (2)]:

$$v_{ij} = w_j \times r_{ij} \tag{2}$$

Where $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$.

2.4.3 Define the ideal solutions

The positive ideal solution (A^+) and negative ideal solution (A^-) were determined by finding the maximum and minimum values of weighted normalized score in each criterion. In case of positive ideal solution, if the criteria are beneficial, the highest value in each criterion will be selected. But if the criteria are non-beneficial, the lowest value will be selected. Conversely, in case of negative ideal solution, if the criteria are beneficial, the lowest value in each criterion will be selected. But if the criteria are non-beneficial, the highest value will be selected. A^+ and A^- are defined as [Equations (3) and (4)]:

$$A^+ = \{v_1^+, ..., v_j^+\} = \left\{\left(\max_j v_{ij} \middle| i \in I\right), \left(\min_j v_{ij} \middle| i \in J\right)\right\} \quad (3)$$

$$A^- = \{v_1^-, ..., v_j^-\} = \left\{\left(\min_j v_{ij} \middle| i \in J\right), \left(\max_j v_{ij} \middle| i \in I\right)\right\} \quad (4)$$

Where v_1^+ is the positive ideal solution in j^{th} criterion, v_j^- is the negative ideal solution in jth criterion; j = 1, 2, 3, …, n and i = 1, 2, 3, …, m. I is associated with benefit criteria: potential score, relative weights, etc. J is associated with non-benefit criteria: cost, risk score, etc.

2.4.4 Calculate distance of the ideal solution

The Euclidean distances of each alternative from the positive ideal solution and the negative ideal solution were calculated. The positive ideal distance (S_i^+) and the negative ideal distance (S_i^-) are given as [Equations (5) and (6)]:

$$S_i^+ = \left\{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2\right\}^{1/2} \quad (5)$$

$$S_i^- = \left\{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2\right\}^{1/2} \quad (6)$$

Where v_j^+ is the positive ideal solution in j^{th} criterion, v_j^- is the negative ideal solution in j^{th} criterion; j = 1, 2, 3, …, n and i = 1, 2, 3, …, m.

2.4.5 Rank the preference order

The best alternative transportation route is the one that has the highest relative closeness to the ideal solution (C_i), which can be defined as [Equation (7)]:

$$C_i = S_i^- / S_i^+ + S_i^- \quad (7)$$

Where 0 C_i 1 and i = 1, …, m.

3 The Standard Criteria for Physical Road Freight Transportation Route Assessment

The authors established the standard potential assessment criteria for physical characteristics in road freight transportation routing. These standard criteria consist of four physical characteristic groups: road elements, blackspots, transportation facility, and road competency. The scales for each criterion are divided into a five-point scale based on suitability and facilitation of freight transportation. In addition, the Delphi method is used to define the descriptions for each criterion. The scores in 3.1 and 3.4.3 are calculated by the distance weighted summation method. The scores in 3.2, 3.3, 3.4.1, and 3.4.2 are calculated by the percentage comparison method. Finally, the scores in 3.4.4 and 3.4.5 are calculated by the average score method. Standard criteria for road freight transportation characteristic assessment are as follows:

3.1 *Road elements assessment criteria*

3.1.1 Number of lanes

A lane is part of the roadway, it allows the vehicles to drive. The broad roadway is always separated by a lane line or separation line. Standard criterion for number of lanes is shown in Table 1. This criterion conforms to Sattayaprasert *et al.* [12] who demonstrated that the risk level is increased when the number of lanes decreases.

Table 1: Standard criterion for number of lanes

Potential	Description
5	> 6 lanes in each direction
4	5 or 6 lanes in each direction
3	4 lanes in each direction
2	3 lanes in each direction
1	≤ 2 lanes in each direction

3.1.2 Lane width

A lane width is the cross-sectional dimension of a lane, perpendicular to the direction of travel. Lane width usually impacts on vehicle speeds, transit routes, etc. Standard criterion for lane width is shown in Table 2. This criterion conforms to Sattayaprasert *et al*. [12], Yuan *et al*. [13], and Son *et al*. [41] who explained that the risk level is increased when the lane width narrows. This issue is confirmed by the findings of Zegeer and Council [42] who summarized that lane widening can reduce crash rates.

Table 2: Standard criterion for lane width

Potential	Description
5	> 4.00 meters
4	> 3.50 meters and ≤ 4.00 meters
3	> 3.25 meters and ≤ 3.50 meters
2	> 3.00 meters and ≤ 3.25 meters
1	≤ 3.00 meters

3.1.3 Road surface

The potential of road surface is considered by the material types which are used to construct the road surface or pavement. The various material types provide different driving sensations. Standard criterion for road surface is shown in Table 3.

3.1.4 Shoulder width

A road shoulder is the area which is adjacent to both sides of the roadway. This area does not include the sidewalk [43]. According to Zegeer and Council [42], shoulder widening can reduce crash rates. Standard criterion for shoulder width is shown in Table 4. This criterion conforms to Polus *et al*. [4], Farah *et al*. [5], Sattayaprasert *et al*. [12], and Yuan *et al*. [13] who demonstrated that the risk level and shoulder width increases concurrently.

Table 3: Standard criterion for road surface

Potential	Description
5	Rigid road surface with concrete slabs's length > 10.00 meters
4	Rigid road surface with concrete slabs's length > 8.00 meters and ≤ 10.00 meters
3	Flexible road surface or rigid road surface with concrete slabs's length ≤ 8.00 meters
2	Laterite or gravel road surface
1	Unpaved surface or surface materials not designed for the movement of vehicles, or other materials of lower quality than laterite or gravel road surface.

Table 4: Standard criterion for shoulder width

Potential	Description
5	> 3.00 meters
4	> 2.50 meters and ≤ 3.00 meters
3	> 2.00 meters and ≤ 2.50 meters
2	> 1.50 meters and ≤ 2.00 meters
1	≤ 1.50 meters

3.1.5 Type of median

A median is a portion of roadway separating opposing directions of the travelled way for routes with four lanes or more and roadways in an urban area [44]. There are four types of median in roadways: flush and painted, raised, barrier, and depressed [45]. Standard criterion for type of median is shown in Table 5.

Table 5: Standard criterion for type of median

Potential	Description
5	Depressed with barrier or concrete
4	Raised with barrier or concrete, barrier and depressed
3	Raised with anti-glare
2	Raised
1	Flush and painted or roadway without median

3.1.6 Median width

The purposes of median width are to allow a space for turning or U-turning vehicles, provide a recovery area for out-of-control vehicles, provide a safe area for pedestrians crossing the street, provide width for future lanes, etc. [44]. Median width can be measured by the total width between the left edge to the right edge of the median type. Standard criterion for shoulder width is shown in Table 6.

3.2 *Blackspots assessment criteria*

3.2.1 Percentage of bridge

A bridge is a structure that is built over a river, road, or railway to allow vehicles to cross from one side to the other. Bridges are an obstacle to road freight transportation: traffic regulations, the load capacity for heavy vehicles, etc. The potential score of percentage of a bridge is calculated by the number of bridges and total distance ratio. Standard criterion for percentage of bridge is shown in Table 7.

Table 6: Standard criterion for median width

Potential	Description
5	> 2.55 meters for flush and painted, > 10.00 meters for raised, > 1.00 meters for concrete, and > 21.00 meters with at least 1.00 meters of deepness for depressed
4	> 2.00 meters and ≤ 2.55 meters for flush and painted, > 6.00 meters and ≤ 10.00 meters for raised, > 0.65 meters and ≤ 1.00 meters for concrete barrier, and > 21.00 meters for depressed
3	> 1.50 meters and ≤ 2.00 meters for flush and painted, > 4.20 meters and ≤ 6.00 meters for raised, > 0.50 meters and ≤ 0.65 meters for concrete barrier, and > 18.00 meters and ≤ 21.00 meters for depressed
2	> 1.00 meters and ≤ 1.50 meters for flush and painted, > 1.60 meters and ≤ 4.20 meters for raised, > 0.25 meters and ≤ 0.50 meters for concrete barrier, and > 15.00 meters and ≤ 18.00 meters for depressed
1	≤ 1.00 meters for flush and painted, ≤ 1.60 meters for raised, ≤ 0.25 meters for concrete barrier, and ≤ 15.00 meters for depressed

Table 7: Standard criterion for percentage of bridge

Potential	Description
5	No bridge on roadway
4	≤ 3%
3	> 3% and ≤ 8%
2	> 8% and ≤ 10%
1	> 10%

3.2.2 Percentage of curve

A curve is used to change the direction of vehicles gradually. The curve section is more dangerous than a straight section [41]. The potential score of percentage of curve is calculated by the number of curves and total distance ratio. Standard criterion for percentage of curve is shown in Table 8. This criterion conforms to Sattayaprasert *et al*. [12] and Yuan *et al*. [13] who demonstrated that the risk level is increased when the number of curves increases.

Table 8: Standard criterion for percentage of curve

Potential	Description
5	≤ 10%
4	> 10% and ≤ 20%
3	> 20% and ≤ 25%
2	> 25% and ≤ 30%
1	> 30%

3.2.3 Percentage of access point

An access point is the specific or minor roadway which connects to a major roadway. The potential score of percentage of access point is calculated by the number of access points and total distance ratio. Standard criterion for percentage of access point is shown in Table 9.

Table 9: Standard criterion for percentage of access point

Potential	Description
5	≤ 10%
4	> 10% and ≤ 15%
3	> 15% and ≤ 20%
2	> 20% and ≤ 30%
1	> 30%

3.3 *Transportation facility assessment criteria*

3.3.1 Percentage of lane line

A lane line is a white broken or solid line. It is used to control traffic on the two lanes roadway in the same direction. In the case that a freight route has only one lane, the separation line is considered. This line is a yellow broken or solid line. The potential is calculated by the roadway with lane line or separation line and total distance ratio. Standard criterion for lane line is shown in Table 10.

Table 10: Standard criterion for percentage of lane line

Potential	Description
5	100%
4	> 90%
3	> 80% and ≤ 90%
2	> 70% and ≤ 80%
1	≤ 70%

3.3.2 Percentage of median

The potential of percentage of median is calculated by the roadway with median and total distance ratio. Standard criterion for percentage of median is shown in Table 11.

Table 11: Standard criterion for percentage of median

Potential	Description
5	100%
4	> 90%
3	> 85% and ≤ 90%
2	> 70% and ≤ 85%
1	≤ 70%

3.3.3 Percentage of frontage road

A frontage road is a roadway which is adjacent to the left of major roadway. The potential of percentage of frontage road is calculated by the roadway with median and total distance ratio. Standard criterion for percentage of frontage road is shown in Table 12. This criterion conforms to Sattayaprasert *et al*. [12], who demonstrated that the risk level is high in the case of non-frontage roadways.

Table 12: Standard criterion for percentage of frontage road

Potential	Description
5	100%
4	> 60%
3	> 30% and ≤ 60%
2	> 10% and ≤ 30%
1	≤ 10%

3.3.4 Percentage of roadway with guardrails

Guardrails are placed along the edge of roadways. They are used to reduce the consequence of crashes in which vehicle run off the roadway or cross the median [46]. Roadways with guardrails provide a feeling of safety to the driver. The potential of percentage of roadways with guardrails is calculated by the roadway with guardrail and total distance ratio. Standard criterion for percentage of roadways with guardrails is shown in Table 13.

Table 13: Standard criterion for percentage of roadways with guardrails

Potential	Description
5	> 80%
4	> 60% and ≤ 80%
3	> 40% and ≤ 60%
2	> 20% and ≤ 40%
1	≤ 20%

3.3.5 Percentage of access point with a speed change lane

A speed change lane is a part of the access point on a roadway. Speed change lanes consist of acceleration and deceleration lanes. This section allows the vehicle to use appropriate speed while entering or leaving a roadway. The potential of access point with speed change lane is calculated by the access point with speed change lane and total access point on a roadway ratio. Standard criterion for percentage of access point with a speed change lane is shown in Table 14.

Table 14: Standard criterion for percentage of access point with a speed change lane

Potential	Description
5	> 80%
4	> 50% and ≤ 80%
3	> 30% and ≤ 50%
2	> 10% and ≤ 30%
1	≤ 10%

3.3.6 Percentage of bridge with climbing lane

A climbing lane is used to prevent heavy vehicles obstructing the traffic on a bridge [47]. Since climbing uphill is difficult for heavy vehicles, they can travel in the climbing lane on bridges without slowing traffic. The potential of percentage of a bridge with a climbing lane is calculated by the bridge with climbing lane and total bridge on a roadway ratio. Standard criterion for percentage of bridge with climbing lanes are shown in Table 15.

Table 15: Standard criterion for percentage of bridge with climbing lane

Potential	Description
5	100%
4	> 60%
3	> 40% and ≤ 60%
2	> 20% and ≤ 40%
1	≤ 20%

3.4 *Road competency assessment criteria*

3.4.1 Percentage of deterioration of road surface

A deterioration of road surface is a defective road pavement. The deteriorations of flexible road surface are cracking, deformation, defection, miscellaneous distress, etc. The deteriorations of rigid road surface are joint seal damage, faulting, pumping, scaling, etc.

[48]. The potential of deterioration of road surface is calculated by roadway with deterioration and total distance ratio. Standard criterion for percentage of deterioration of road surface is shown in Table 16.

Table 16: Standard criterion for percentage of deterioration of road surface

Potential	Description
5	No deterioration of road surface on roadway
4	≤ 5%
3	> 5% and ≤ 10%
2	> 10% and ≤ 20%
1	> 20%

3.4.2 Percentage of deterioration of shoulder surface

A deterioration of shoulder surface is a defective shoulder pavement which has a drop-off, separation, etc. The potential of deterioration of shoulder surface is calculated by roadway with shoulder surface deterioration and total distance with shoulder ratio. Standard criterion for percentage of deterioration of road surface deterioration is shown in Table 17.

Table 17: Standard criterion for percentage of deterioration of shoulder surface

Potential	Description
5	No deterioration of shoulder surface on roadway
4	≤ 10%
3	> 10% and ≤ 20%
2	> 20% and ≤ 30%
1	> 30%

3.4.3 Percentage of road slope

A road slope is an inclined or declined roadway. The potential of road slope is considered by the slope percentage based on topography. Organization for Economic Co-operation and Development [49] discovered that accident rates and slope percentage have a positive relationship. Standard criterion for road slope is shown in Table 18. This criterion conforms to Sattayaprasert *et al*. [12], and Yuan *et al*. [13] who demonstrated that the risk level and percentage of road slope increase concurrently.

Table 18: Standard criterion for road slope

Potential	Description
5	No road slope for all topographies
4	≤ 4% for mountainous, ≤ 3% for hilly, and ≤ 2% for level
3	> 4% and ≤ 6% for mountainous, > 3% and ≤ 6% for hilly, and > 2% and ≤ 4% for level
2	> 6% and ≤ 15% for mountainous, > 6% and ≤ 15% for hilly, and > 4% and ≤ 15% for level
1	> 15% for all topographies

3.4.4 The load capacity of a bridge

The potential of load capacity of a bridge is considered by the average score of all bridges along the route. Standard criterion for the load capacity of a bridge is shown in Table 19.

Table 19: The load capacity of a bridge

Potential	Description
5	> 60 tons
4	> 55 tons and ≤ 60 tons
3	> 45 tons and ≤ 55 tons
2	> 30 tons and ≤ 45 tons
1	≤ 30 tons

3.4.5 Vertical clearance of underpass or tunnel

A vertical clearance is the height of an underpass or a tunnel. The potential of vertical clearance is considered by the average score of all underpasses or tunnels along the route. Standard criterion for vertical clearance of underpass or tunnel is shown in Table 20.

Table 20: Standard criterion for vertical clearance of underpass or tunnel

Potential	Description
5	> 6.00 meters
4	> 5.00 meters and ≤ 6.00 meters
3	> 4.50 meters and ≤ 5.00 meters
2	> 3.50 meters and ≤ 4.50 meters
1	≤ 3.50 meters

4 Results and Discussion

To point out the usability of the DSS proposed in this study, an application to the actual empirical case is presented. The application was conducted with a logistics service provider company who transported electronic integrated circuit products between Laem Chabang Port and Mukdahan Customs House. The destination is located on EWEC with neighboring countries and other economic corridors. According to the summary values of 2017's exports, products were valued at about three billion USD [50]. The details are as follows:

4.1 *Data collection*

The authors began by gathering the data from all possible routes for the decision-making. The data for each route were composed of transportation cost, transportation time, physical characteristic scores, load capacity of bridges, and vertical clearance of underpasses or tunnels. The 20ft (Twenty-Foot Equivalent Units: TEU) container transportation was selected. Then, transportation cost was collected by interviewing the senior executive directors of the company. Next, the experts approximated the transportation time based on the historical data. Finally, the route scores, load capacity, and vertical clearance were collected by fieldwork with the standard criteria for physical road freight transportation route assessment. For example, the score of road element group can be computed by the summation score of each criterion in their group, the score of number of lanes equaled 2.721, followed by lane width equaled 3.212, road surface equaled 3.451, shoulder width equaled 2.311, type of median equaled 2.426, median width equaled 1.571, respectively. The scores of the others group were also calculated by summation score method. Hence, the data of all possible routes are shown in Table 21.

Table 21: The data of possible routes

Criterion	The possible route			
	1	2	3	4
Cost (USD)	286	297	319	318
Time (Hours)	16	15	18	15
Road elements (Score)	15.692	16.616	17.834	16.296
Blackspots (Score)	7	7	7	7
Transportation facility (Score)	11	11	12	13
Road competency (Score)	12.433	12.978	13.469	10.754

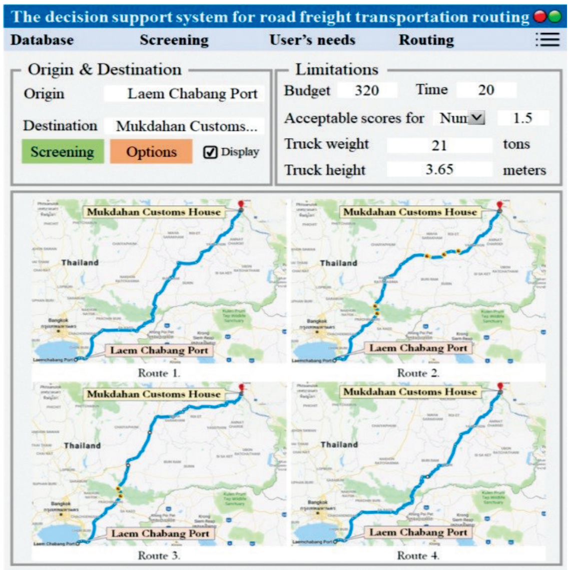


Figure 2: The result of screening.

4.2 *The result of screening possible routes*

The DSS can screen the possible freight routes for alternative freight route by comparing the user's data: budget, preferred transportation time, acceptable potential scores, truck weight and height with the freight route database. Possible freight routes were eliminated if they failed one of the five agreements as follows. The transportation cost of route exceeds the budget. The transportation time of route was longer than the preferred transportation time. The route's scores were lower than the acceptable route score. The lowest load capacity of a bridge on the route was lower than the truck weight. Finally, the shortest vertical clearance of underpass or tunnel on the route was shorter than the truck height. For this study, the senior executives defined the budget at 320 USD, the preferred transportation time at 20 h, and the acceptable potential scores for each criterion at 1.5, this score means that the users desire the score more than or equal to 1.5 in each criterion. Hence, none of the possible routes were eliminated. The result of screening for alternative routes is shown in Figure 2.

4.3 *The results of user's need*

Users can make decisions according to their needs when routing. The DSS employed FAHP to define the relative weights of main decision criteria: cost, time, road elements total score, blackspots total score, transportation facility total score, and road competency total score. As a result of the relative weight definition, three senior executive directors of the company determined the relative weights of cost at 0.231, followed by, time at 0.218, road elements at 0.088, blackspots at 0.194, transportation facility at 0.251, and road competency at 0.018, respectively. The number of users was enough and reliable because the decision-making does not require a large number of experts, but it requires those to be knowledgeable about the problem [31]. In fact, the decision-maker in a few circumstances is limited, this point conforms to the transportation routing problem of the case study, it is based on only three users. Finally, the C.R. of the user's judgements was considered, it was at 0.060. This value showed that the relative weights of main decision criteria were reliable and applicable because the user's judgements are consistent.

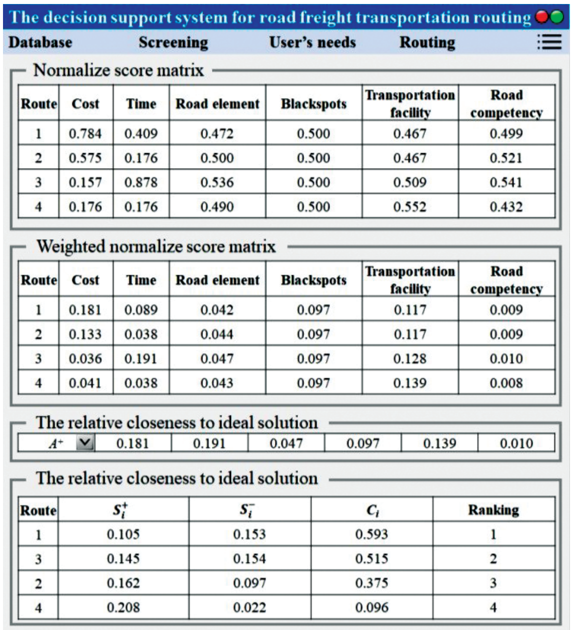
4.4 *The best road freight transportation route*

The alternative freight routes were constructed from the best road freight routes with the DSS algorithm which is the TOPSIS approach for decision-making. The data of alternative routes and the relative weights were integrated and calculated by using Equations (1) and (2), the weighted normalized matrix was constructed as shown in Figure 3. For example, v_{ij} can be computed by multiplying the normalize score in i^{th} route and the relative weight of j^{th} criterion. These variables can be computed as:

$$v_{11} = 0.784 \times 0.231 = 0.181$$
$$v_{12} = 0.409 \times 0.218 = 0.089$$
$$v_{13} = 0.472 \times 0.088 = 0.042$$
$$\vdots$$
$$v_{46} = 0.432 \times 0.018 = 0.008$$

Then, the ideal solutions are calculated as shown in Figure 3. The positive ideal solutions which are the highest value of weighted normalize score matrix in each criterion were determined. For example, the highest value in cost criterion equaled 0.181. Thus, the positive ideal solution (A^+) was defined as:

$$A^+ = \{0.181, 0.191, 0.047, 0.097, 0.139, 0.010\}$$


The decision support system for road freight transportation routing

Database Screening User's needs Routing

Normalize score matrix

Route	Cost	Time	Road element	Blackspots	Transportation facility	Road competency
1	0.784	0.409	0.472	0.500	0.467	0.499
2	0.575	0.176	0.500	0.500	0.467	0.521
3	0.157	0.878	0.536	0.500	0.509	0.541
4	0.176	0.176	0.490	0.500	0.552	0.432

Weighted normalize score matrix

Route	Cost	Time	Road element	Blackspots	Transportation facility	Road competency
1	0.181	0.089	0.042	0.097	0.117	0.009
2	0.133	0.038	0.044	0.097	0.117	0.009
3	0.036	0.191	0.047	0.097	0.128	0.010
4	0.041	0.038	0.043	0.097	0.139	0.008

The relative closeness to ideal solution

A^+	0.181	0.191	0.047	0.097	0.139	0.010

The relative closeness to ideal solution

Route	S_i^+	S_i^-	C_i	Ranking
1	0.105	0.153	0.593	1
3	0.145	0.154	0.515	2
2	0.162	0.097	0.375	3
4	0.208	0.022	0.096	4

Figure 3: The result of the best transportation route.

The negative ideal solutions which are the lowest value of weighted normalize score matrix in each criterion were determined. For example, the lowest value in cost criterion equaled 0.036. Thus, the negative ideal solution (A^-) was defined as:

$$A^- = \{0.036, 0.038, 0.042, 0.097, 0.117, 0.008\}$$

Next, the distances of ideal solution are calculated by Equations (5) and (6), respectively. For example, the positive and negative ideal distance of route 1 can be computed as:

$$S_1^+ = ((0.181 - 0.181)^2 + (0.089 - 0.191)^2 + (0.042 - 047)^2 + (0.097 - 0.097)^2 + (0.117 - 0.139)^2 + (0.009 - 0.010)^2)^{0.5} = 0.105$$

$$S_1^- = ((0.181 - 0.036)^2 + (0.089 - 0.038)^2 + (0.042 - 0.042)^2 + (0.097 - 0.097)^2 + (0.117 - 0.117)^2 + (0.009 - 0.008)^2)^{0.5} = 0.153$$

Thus, the positive ideal distances of each route were defined as 0.105, 0.162, 0.145, and 0.208, respectively. The negative ideal distances of each route were defined as 0.153, 0.097, 0.154, and 0.022, respectively, as shown in Figure 3.

Finally, the relative closeness for alternative routes were calculated using Equation (7). For example, the relative closeness to ideal solutions of each route can be computed as:

$C_1 = 0.153 / (0.105 + 0.153) = 0.593$
$C_2 = 0.097 / (0.162 + 0.097) = 0.375$
$C_3 = 0.154 / (0.145 + 0.154) = 0.515$
$C_4 = 0.022 / (0.208 + 0.022) = 0.096$

As a result of the relative closeness calculation, the route 1 was taken the best alternative route in this case, followed by route 3, route 2, and route 4, in this order, as showed in Figure 3.

To solve this routing problem, ranking for alternative routes has been suggested to the decision makers to ensure the best alternatives for the solution due to the facts as mentioned above. Hence, the C_i values were used to consider ranking of solutions. From Figure 3, route 1 obtained the best alternative road freight route with 0.593, and the last alternative by route 4 with 0.096. Route 3 and route 4 were the second and third alternative route with 0.515 and 0.375, respectively.

The authors discovered that the DSS provides feedback to the users on the accuracy of their choice, and the processing time of the DSS does not take a long time. The DSS was designed to aid individuals in moderately complex decision-making tasks. Moreover, the DSS developed in this way proposed an effective alternative transportation route corresponding to the empirical physical characteristics data while the other studies which proposed the DSS in transportation routing have concentrated on the historical statistical data.

5 Conclusions

It has been proven this DSS can select the best road freight transportation route. The database which was a part of the DSS was used to store possible route data: transportation cost, transportation time, road freight transportation route's physical characteristic potential scores, minimum load capacity of bridges, and the shortest vertical clearance of underpasses or tunnels. The standard criteria for physical road freight transportation route assessment were developed and constructed. There are four different physical characteristic groups: road elements, blackspots, transportation facility, and road competency. Moreover, each criterion consists of five descriptions which were constructed based on suitability and facilitation of freight transportation by the Delphi method, these criteria were used to calculate the route scores. The road freight transportation routing of the DSS was started by the users who defined the data: origin, destination, budget, preferred transportation time, acceptable route scores, and truck weight and truck height. User data and possible route data were compared. The possible routes were then eliminated by one of the following agreements: transportation cost is exceeded the budget, transportation time is longer than preferred time, the potential scores of each criterion are lower than the acceptable scores, the truck weight is greater than the minimum load capacity of the bridge along the route, and the truck height is greater than the shortest vertical clearance of underpass or tunnel along the route. Then, the alternative routes were generated. Additionally, this DSS also responds to the user's needs with FAHP to determine the relative weights of main decision criteria. The routing algorithm integrated the alternative route data, user data, and user needs to select the best road freight transportation route by TOPSIS. The algorithm ensures the best alternative route with the nearest distance to the positive ideal solution and farthest distance to the negative ideal solution.

As a result of the DSS application, the route 3 was taken the best alternatives route in this case because the users concentrated on the transportation cost. According to the cost of route 1, it is the lowest transportation cost. Nonetheless, if the relative weights of the decision criteria changes, the answer of the DSS will be change. For future study, the author will develop this DSS to include multimodal transportation routing.

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