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Article

Design of Decision Support System for Road Freight Transportation Routing using Multilayer Zero One Goal Programming

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Abstract. The objective of this study was to develop a decision support system (DSS) to select the optimal road freight transportation route. This DSS is a proactive road freight transportation routing system which employs the standard criteria from the road freight transportation route's physical characteristics for potential evaluation. The descriptions of potential scale were derived by the Delphi method based on accommodation of transportation. Moreover, the DSS can also calculate the relative weights of the decision criteria by Fuzzy Analytic Hierarchy Process (FAHP). Multilayer Zero One Goal Programming (MZOGP) is used as an optimization algorithm to select road freight transportation routes. The operation of this algorithm is to calculate the total deviation from three objectives: cost, time and, the deviation of road freight transportation route's physical characteristic score which is calculated by comparing the route's physical characteristic potential score with potential scores from users. The approach was tested on a realistic road freight transportation routing operation of a logistics service provider company. The empirical study showed that this DSS works successfully.

Keywords: Multilayer zero one goal programming, road freight route's physical characteristics, proactive road freight transportation routing, decision support system.

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1. Introduction

The economic corridor approach was adopted by the cooperation framework of the Greater Mekong Subregion (GMS) countries: Kingdom of Cambodia, Kingdom of Thailand, Lao People's Democratic Republic (Lao PDR), Socialist Republic of Vietnam, Republic of the Union of Myanmar and the Yunnan Province and Guangxi Zhuang Autonomous Region in southern of the People's Republic of China. The economic corridor connected transportation for the GMS capitals and major economic center [1]. Thailand which is one of the six countries located at the center of the region has integrated their trade routes into an economic corridor network. According to the 2017-2021 strategic plan, Thailand's Ministry of Transport have proposed policies to improve the inland highway network connection to rail, port and airport with neighboring countries. This includes construction of new roads, improvement or expansion of existing roads as required, etc. [2]. As mentioned above, Thailand has the role of a land bridge between the Andaman Sea to the South China Sea.

Appropriate freight transportation routing is a strategy to reveal the efficiency of entrepreneur: decrease logistics cost, deliver products on time, minimize transportation damage or risks, etc. Over the past few decades, there has been a lot of research on appropriate freight transportation routing. Banomyong and Beresford [3] examined alternative routes for exporting commodities with a multimodal transport cost-model. Ko [4] developed a decision support system (DSS) for an international multimodal transportation network, the Fuzzy Analytic Hierarchy Process (FAHP) was employed to determine the priorities of key factors for the network facilitation: cost data, traffic data, reliability data and security data. Kengpol et al. [5] evolved DSS which could optimize multimodal transportation routing within GMS countries, the DSS consisted of quantitative factors: transportation cost and transit time, qualitative factor: freight damaged risk, infrastructure and equipment risk, and another factor risks. Kengpol et al. [6] designed a DSS for multimodal transportation with a multimodal transport cost-model by [3] and environment impact. Kengpol et al. [7] established a new conceptual framework for route selection in multimodal transportation. Kengpol and Tuammee [8] introduced a decision support framework (DSF) for a quantitative risk assessment in multimodal green logistics, the DSF integrated quantitative risk assessment, Analytic Hierarchy Process (AHP) and Data Envelopment Analysis (DEA). Sattayaprasert et al. [9] represented a method which used the model of Hazardous Material (HazMat) transportation routing with AHP to evaluate risk elements: risk of carriage unit explosion, risk of road accidents, and consequences of an incident. Particularly, the risks of road accidents contained number of lanes, lane width, pavement condition, percent of frontage road, etc. Recently, Yuan et al. [10] researched a safety evaluation model for provincial highways with FAHP in Hebei province, this model concentrated on accident severity, geometric feature, traffic facility and traffic environment. The authors discovered that there were a few studies which emphasized on the DSS for multimodal transportation but neglected road freight transportation. In addition, the studies as mentioned above explored transportation cost, transportation time and physical characteristics of route for transportation routing. However, the physical characteristics which are the design of horizontal and vertical alignment on road elements: number of lanes, type of road surface, level of road slope, sight distance of curves have been judged by reactive transportation routing methods: prioritized physical characteristics, calculated accident severity index, assessed risk, etc. The disadvantage of the reactive methods is a procedure requiring statistical data on traffic accidents from the past. Furthermore, none of the studies as mentioned above dealt with the potential evaluation of tangible physical characteristics along the route. The tangible physical characteristics are the road elements which can be seen with the naked eye, counted, measured, and touched, for example, width of lanes, type of road median, road surface, etc. In addition, the studies considered different physical characteristics for appropriate freight transportation routing. Hence, this study aims to solve the problem by establishing a standard criterion for road freight transportation route's physical characteristics with a potential evaluation. The descriptions of potential scales for each criterion were conducted by the Delphi method based on suitability and facilitation of transportation. The method which evaluated the potential of route physical characteristics was a proactive transportation routing method because this method disregarded historical statistical data but also requires the empirical data of tangible physical characteristics.

Moreover, the authors discovered that the Zero One Goal Programming (ZOGP) which is a multiple criteria analysis method has been applied for multimodal transportation routing with determination the relative weights in the past, such as [5-7]. The authors also discovered that the decision-maker specified the relative weights in case many decision criteria had unreliable accuracy and were ineffective. This was based on the psychological result that people could cogitate a limited cognitive capacity to process information, seven plus or minus two items simultaneously [11]. The number of items is seven or less which served as consistency [12]. Especially, the synthesis for the relative weights of AHP or FAHP, these processes required a consistency ratio (C.R.) which not exceeded the acceptable C.R. by Saaty [13, 14]. Thus, the authors developed the Multilayer Zero One Goal Programming (MZOGP) method which was developed from traditional ZOGP to solve the relative weight problem by clustering the items, each cluster has no more than seven items. This approach was then applied for road freight transportation routing in the DSS. The highest layer of MZOGP is an objective function to select the most appropriate alternative with the lowest deviated from the total deviation of main decision criteria which is calculated by the deviation of sub decision criteria in each of the main decision criteria. The lowest layer of MZOGP was a constraint functions of sub decision criteria.

To solve the problem as described earlier, the authors decided to develop a DSS for road freight transportation routing which appraised the potential of a route's physical characteristic by a standard criteria evaluation. The potential of route physical characteristics is considered together with transportation cost and transportation time of route. The transportation cost, transportation time, and the road freight transportation route's physical characteristic potential scores are then compared with user's desires and limitations: budget, limited transportation time, and desirable road freight transportation route's physical characteristic scores. Moreover, this DSS can cogitate the relative weights of decision criteria by FAHP, which eliminated ambiguity and increased flexibility in road routing. Finally, the DSS was applied to road freight transportation routing between Laem Chabang Port in Chonburi to Mukdahan Customs House. This route is a part of the East West Economic Corridor (EWEC), which is an export freight route between Mawlamyine and Danang via Thailand and Lao PDR. This is to confirm that the DSS can be operated empirically and should encourage the government to deal with economic growth.

2. Literature Reviews

2.1. The Standard Criteria for Physical Road Freight Transportation Route Evaluation

A lot of literature has addressed the problem of transportation routing by considering the physical characteristics. Regmi and Hanaoka [15] evaluated infrastructure and operational status of two important intermodal transport corridors from North-East and Central Asia but did not establish standard criteria for potential physical characteristic evaluation. Kengpol et al. [5] created a risk assessment criterion which was adopted from Hallikas et al. [16] in DSS for multimodal transportation routing, physical characteristics were not included. Kengpol et al. [6] presented a DSS to select multimodal routes between Thailand and Vietnam, but did not mention physical characteristics. Kengpol et al. [7] and Kengpol and Tuammee [8], who studied the multimodal transportation routing had acknowledged that a few physical route characteristics were classified in the infrastructure and equipment risks: capacity of bridges on the route, tunnels, slope and the width of roads, etc. However, this study adopted comprehensive risk assessment, without consideration of individual physical route characteristics. Arunyanart et al. [17] explored the export products route from Thailand through Lao PDR to one of the ports in Vietnam by determining the relative weights but ignored the tangible physicals route characteristics. Wang and Yeo [18] studied the problem of secondhand vehicles transportation from Korea to Central Asian countries. The five factors: total cost, reliability, transportation capability, total time, and security were analyzed but did not regard the potential of physical characteristics. Sattayaprasert et al. [9] placed emphasis on the HazMat logistics by combining the risk assessment criteria and mathematical model, which were generated by the relative weights of risk from AHP. One of the risk criteria was road accidents, it was comprised of contributing factors: number of lanes, lane width, type of median, etc. Nonetheless, the others contributing factors not mentioned and taken into account were transportation cost and transportation time. Son et al. [19] exhibited hazardous road selection criteria without budget and restricted time. Polus et al. [20] also demonstrated the evaluation criteria for index of accident severity, geometric feature, traffic facility and traffic environment. Each evaluation criterion was divided by different scoring methods. Additionally, most of the previous work studied physical route characteristics in another context. Polus et al. [20] estimated and quantified the contribution of the infrastructure to highway crashes and developed an Infrastructure Coefficient (IC). Farah et al. [21] tested the correlation between different infrastructure characteristics and enhanced a crash prediction model with IC for two-lane rural highways by applying AHP, but this model was not combined with quantitative factors. Zegeer and Council [22] summarized the relationships between accident experience and cross-sectional roadway elements.

From the literature review, it can be concluded that previous studies have dealt with the physical route characteristics. Although, none of these studies have combined the potential of physical tangible route characteristics with quantitative factors, and the studies did not produce the criteria for road freight transportation route evaluation in [20, 21]. Moreover, the studies described earlier have contemplated the various physical road route characteristics indicators for similar purposes. These problems were solved by Koohathongsumrit and Meethom [23] who indicated the key physical characteristic factors of freight transportation routing, the key factors were revised from [3-10, 17, 19-21] and also interviewed experts. The key factors included the road element physical characteristics, the blackspot physical characteristics, the transportation facility physical characteristics and the road competency physical characteristics. The most important key physical characteristic group was the road elements group since this group consisted of the physical characteristics which were fundamental factors for the others key characteristics. Therefore, the significance of this study is to develop standard criteria for road freight transportation routes referring to physical characteristic potential evaluation. This will be comprised of number of lanes, lane width, road surface, shoulder width, median types and median width. The result of the standard criteria will be used in the DSS for road freight transportation routing.

2.2. The Description of Potential Scale by the Delphi Method

The Delphi method was first announced by Dalkey and Helmer [24] at the Rand corporation to find the consensus of expert's opinions about technological discontinuities, future events, etc. [25]. 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 that three basic characteristics: anonymous response, iteration and controlled feedback, and statistical group response [26-29]. A large number of articles have identified evaluation scale with the Delphi method. Walker [30] constructed the rubric evaluation tool which was conducted by the Delphi method, based on a consultation with recognized experts for mobile technology. Lin [31] proposed the fashion design evaluation rubrics, modified by the Delphi method. Chirstie et al. [32] improved evaluation grading tools within postgraduate courses. Nevertheless, articles which identified the risk or potential evaluation scale for transportation routing: [9-10, 19-21] did not apply the Delphi method to identify the description of evaluation scale.

For this study, the Delphi method will be used to integrate the expert's opinions to establish the description of potential scale for standard criteria route evaluation. The scales can be divided into a five-point consistent scale based on suitability and facilitation of freight transportation.

2.3. Fuzzy Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) was originated in the 1970s by Saaty [33]. It is a systematic and powerful Multiple Criteria Decision Making (MCDM) method in order to solve complex and subjective decision problems. This process was analyzed by pairwise comparison for the relative weights of criteria and alternatives for each criterion and global relative weights of the alternatives, based on expert judgement with crisp nine-point rating scale [34, 35]. The limited of crisp rating scale in the original AHP, in cases where decision-maker cannot express the judgement by crisp numbers since human judgement is vague or not well defined [36, 37], fuzzy logic can be used which provides a mathematical strength to capture the uncertainties associated with human cognitive process. Laarhoven and Pedrycz [38] evolved AHP into Fuzzy Analytic Hierarchy Process (FAHP) by fuzzy theory, which was introduced by Zadeh [39]. Afterwards, there were many procedures to calculate the relative weights in FAHP. Buckley et al. [40] revealed the trapezoidal fuzzy numbers for the relative weights by geometric mean. Cheng [41] initiated a new algorithm in naval tactical missile systems by FAHP based on grade value of membership function. Chang [42] presented an extent analysis method which was a new approach in pairwise comparisons of FAHP with triangular fuzzy numbers. This approach has been used extensively in many different fields, more researches can be found in [34, 36, 37, 43-48]. This approach was used in this study because it is easy, simple, similar to the traditional AHP, and contemplative to the value of fuzzy synthetic extent and degree of possibility for rational relative weights.

There are many studies which have concentrated on the relative weights of decision criteria in multimodal transportation routing or road freight transportation routing: [4-10, 17] but these studies disregarded FAHP. Although, Ko [4] adapted decision criteria in a multimodal transportation network with FAHP. Yuan et al. [10] indicated a safety evaluation model generated by FAHP. For this reason, FAHP was employed to decide on the relative weights of decision criteria with MZOGP in the DSS.

2.4. Multilayer Zero One Goal Programming

Zero One Goal Programming (ZOGP) is a technique for MCDM when a decision maker desires to satisfy several goals [49], to reach the optimal solution [50-52]. This technique offered by Charnes et al. [53] to overcomes the limitation of Linear Programming (LP) which is a completed problem and has a single objective: maximum profit, minimum cost or risk. Due to a few situations, the decision criteria might be composed of the disparate and contradictory objectives. The explication for one objective perchance can influence the others. This technique attempts to minimize deviation from several objectives for limited resources [54]. The value of decision variable is either zero or one, zero variable represents the non-selection, one variable represents the selection. ZOGP has been utilized to solve many real-world problems. Yilmaz and Dağdeviren [51] used a combined approach which was the Fuzzy Preference Ranking Organization Method for Enrichment Evaluation (F-PROMETHEE) and ZOGP for the equipment selection problem. Badri et al. [55], Kim and Emery [56], and Lee and Kim [57] addressed the projects selection problems with ZOGP. Mathirajan and Ramanathan [58] suggested the ZOGP for the tour scheduling problem of a marketing executive in India.

Despite the large number of articles proposing the use of ZOGP, there are only a few comparative studies which integrated ZOGP with the relative weights to the problem of multimodal transportation routing: [5-7], and these studies did not use this combined technique for road freight transportation routing. Moreover, the relative weights of decision criteria in ZOGP are limited by the human perception and memory [11], this issue affects C.R. which exceeds the acceptable C.R. by Saaty [13, 14]. The Multilayer Zero One Goal Programming (MZOGP) is now introduced. The purpose of this new conceptual model is to avoid the MCDM which includes many decision criteria, especially over seven criteria. This model organizes the decision criteria into clusters with hierarchical structure. The objective function selects the most appropriate alternative from the total deviation of main decision criteria in the highest layer of the model, while the deviation of main decision criteria was computed by constrained functions which are identified deviation between deviation of sub-decision criteria and their maximum deviation. Similarly, constrained functions of sub-decision criteria are the lowest layer of this model. The details are clarified in the next section.

3. The DSS for Road Freight Transportation Routing

This section explains the DSS for road freight transportation routing with three main decision criteria: transportation cost which does not exceed the budget, transportation time which is approximate and does not exceed the limited transportation time by users and the road freight transportation route's physical characteristics potential scores which must be greater than or equal to road route score by the user's desire. There are four components of the DSS: database, user's needs, user's desires and limitations, and optimization algorithm. The decision support system for road freight transportation routing as shown below (See Fig. 1).

3.1. Component I: Database

This component is used to store the data for road freight transportation routing of the DSS. The data refers to the alternative routes from origin to destination, it can be classified based on the quantitative data and qualitative data. The details are as follows:

3.1.1. The quantitative data

There are two types of the quantitative data: transportation cost and transportation time. The transportation cost can be subdivided into fixed costs and variable costs. Fixed costs are invariant costs with an increase or decrease in the number of transportable products. Fixed costs are transportation expense of a business that cannot be avoided: depreciation, labor post, insurance cost, etc. Variable costs are variant costs in that proportion to the number of transportable products: back haul cost, fuel cost, transshipment cost, road toll. The quantitative costs depended on the numerous factors: vehicle types, distance, handling, etc.

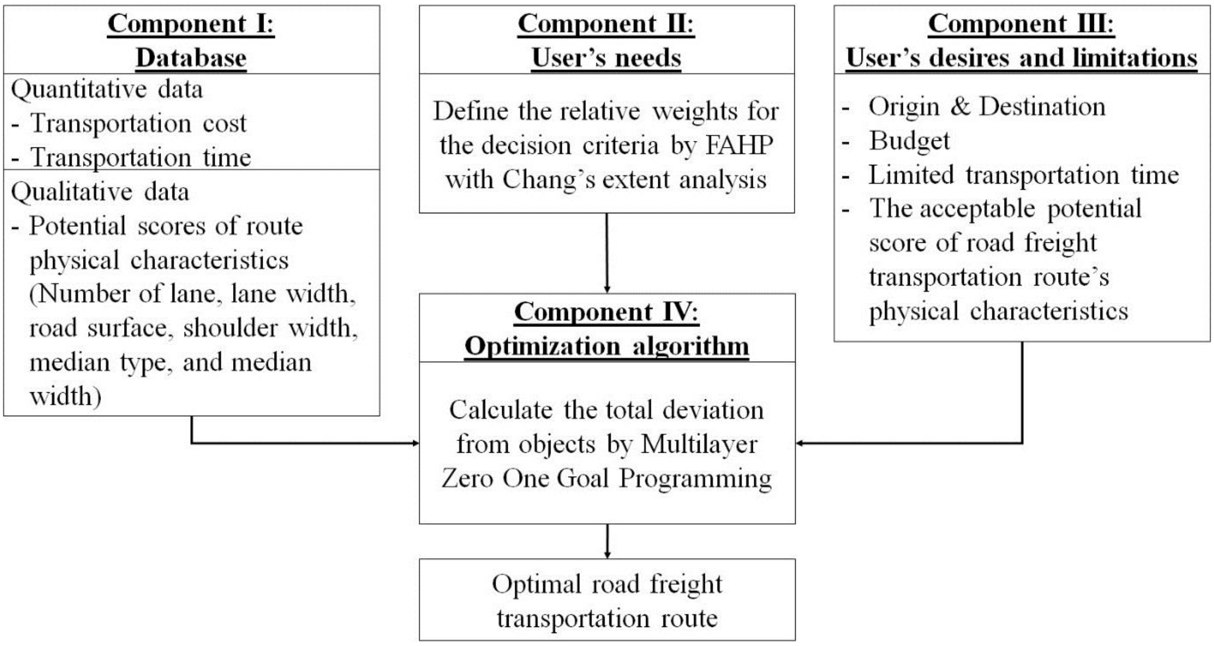

Fig. 1. The decision support system for road freight transportation routing.

3.1.2. The qualitative data

The qualitative data is the potential scores of physical freight route characteristics, which are then transformed by the standard criteria for road freight transportation route evaluation. The qualitative data is the key route physical characteristics: number of lanes, lane width, road surface, shoulder width, types of median, and median width. These physical characteristics were specified and constructed the standard criteria for the road freight transportation evaluation, the potential scale of each criterion was divided into a five-point scale based on suitability and facilitation of freight transportation, the maximum potential is five and minimum is one. The descriptions of each scale were 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 calculation of the potential scores were calculated by the distance weighted summation method. The operation for this method is the potential score summation weighted by the distance in their potential scale and total distance ratio. The standard criteria for road freight transportation characteristic evaluation are as follows:

3.1.2.1. Number of lanes each direction

The number of lanes means the part of highway separated by lane lines or separation lines, to control and guide driver for safety driving. Generally, many public roads have at least one lane in each direction. Standard criterion for the road freight transportation route evaluation of number of lanes for each direction is shown in Table 1. This criterion conforms to [9] who described the risk assessment level for the number of lanes, the risk increased when the number of lanes in each direction decreases.

Table 1. The standard criterion for physical road freight transportation route evaluation of number of lanes in each direction

Potential Scale	Description
5	More than six lanes in each direction
4	Five or six lanes in each direction
3	Four lanes in each direction
2	Three lanes in each direction
1	Less than or equal to two lanes in each direction

3.1.2.2. Lane width

Lane width means the lane space of the roadway, it was measured from the gap between lane lines and separation lines, or adjacent lane lines, or edge line. The standard criterion for route evaluation of lane width is shown in Table 2. In the case of where the route has more than one lane in each direction with unequal lane width, the user must operate by the distance weighted summation method for each lane. Then, the total potential score of lanes is divided by the total number of lanes with weighted distance ratio. This criterion conforms to [9, 10, 19] who described the risk assessment level for lane width, the risk is increased when lane width decreases. This was stated by Polus et al. [20] who expressed that the potential of lane width and wideness increases concurrently.

Table 2. The standard criterion for physical road freight transportation route evaluation of lane width.

Potential Scale	Description
5	Lane wider than 4.00 meters
4	Lane wider than 3.50 meters but narrower than or equal to 4.00 meters
3	Lane wider than 3.25 meters but narrower than or equal to 3.50 meters
2	Lane wider than 3.00 meters but narrower than or equal to 3.25 meters
1	Lane narrower than or equal to 3.00 meters

3.1.2.3. Road surface

The road surface means the type of materials used to construct the road surface or pavement. The road surface must be durable with weather resistance and rolling friction of vehicles [59]. The standard criterion for physical road freight transportation route evaluation of road surface is shown in Table 3. This criterion conforms to Karlaftis and Golias [60] who found that a rigid road surface is better than a flexible road surface in case of freight transportation. According to Kulab [59] and Chotickai [61], they recommended that a rigid road surface is suitable for high traffic volumes while a flexible road surface is suitable for low and medium traffic volumes, and also recommended the length of concrete slabs should be eight to ten meters.

Table 3. The standard criterion for physical road freight transportation route evaluation of road surface.

Potential Scale	Description
5	Rigid road surface with concrete slabs's length greater than 10.00 meters
4	Rigid road surface with concrete slabs's length greater than 8.00 but less than or equal to 10.00 meters
3	Flexible road surface or rigid road surface with concrete slabs's length less than or equal to 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.

3.1.2.4. Shoulder width

The shoulder width means the area from the edge lines to wayside, it does not include the sidewalk [62]. Road shoulders are useful: vehicles in emergency use, moving aside for ambulances, etc. [63]. The standard criterion for physical road freight transportation route evaluation of shoulder width is shown in Table 4. This criterion conforms to [9, 10, 23] who specified the risk assessment level for shoulder width, the risk is increased when shoulder width decreases. According to Zegeer and Council [22], it was discovered that shoulder widening can reduce related accidents by up to 49 percent.

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Table 4. The standard criterion for physical road freight transportation route evaluation of shoulder width.

Potential Scale	Description
5	Shoulder wider than 3.00 meters
4	Shoulder wider than 2.50 meters but narrower than or equal to 3.00 meters
3	Shoulder wider than 2.00 meters but narrower than or equal to 2.50 meters
2	Shoulder wider than 1.50 meters but narrower than or equal to 2.00 meters
1	Shoulder narrower than or equal to 1.50 meters

3.1.2.5. Types of median

Type of median means the types of portion between the dual carriageway which separates the traffic flow in opposite directions. The purposes of a median are to prevent vehicles running in cross directions, use as an area for U-turns, etc. Bureau of location and design [64] published a designed guideline for road medians and road widening which categorized the road medians into four types: flush and painted median, raised median, barrier median and, depressed median. In particular, there are five types of barrier median: guard cable, weak-post w-beam, strong-post w-beam, box beam and concrete. The standard criterion for physical road freight transportation route evaluation of types of median is shown in Table 5.

Table 5. The standard criterion for physical road freight transportation route evaluation of types of median.

Potential Scale	Description
5	Depressed median barrier with barrier or concrete
4	Raised median with barrier or concrete, barrier median and depressed median
3	Raised median with anti-glare
2	Raised median
1	Flush and painted median, moveable median, no median

3.1.2.6. Median width

Median width means the width of the portion of divided highway separating the carriageway for traffic in opposite directions. The standard criterion for physical road freight transportation route evaluation of median width is shown in Table 6. In the case where freight transportation route has a combined median type such as raised median with barrier or concrete and depressed median barrier with barrier or concrete, the widest median was analyzed.

Table 6. The standard criterion for physical road freight transportation route evaluation of median width.

Type	Potential Scale	Description
Flush and painted median	5	Flush and painted median wider than 2.55 meters
	4	Flush and painted median wider than 2.00 meters but narrower than or equal to 2.55 meters
	3	Flush and painted median wider than 1.50 meters but narrower than or equal to 2.00 meters
	2	Flush and painted median wider than 1.00 meters but narrower than or equal to 1.50 meters
	1	Flush and painted median narrower than or equal to 1.00 meters
Raised median	5	Raised median wider than 10.00 meters
	4	Raised median wider than 6.00 meters but narrower than or equal to 10.00 meters
	3	Raised median wider than 4.20 meters but narrower than or equal to 6.00 meters
	2	Raised median wider than 1.60 meters but narrower than or equal to 4.20 meters
	1	Raised median narrower than or equal to 1.60 meters

Table 6. (Cont.).

Type	Potential Scale	Description
Guard cable barrier median	5	Guard cable barrier median wider than 5.00 meters
	4	Guard cable barrier median wider than 4.90 meters but narrower than or equal to 5.00 meters
	3	Guard cable barrier median wider than 4.80 meters but narrower than or equal to 4.90 meters
	2	Guard cable barrier median wider than 4.70 meters but narrower than or equal to 4.80 meters
	1	Guard cable barrier median narrower than or equal to 4.70 meters
Weak-post w-beam barrier median	5	Weak-post w-beam barrier median wider than 4.00 meters
	4	Weak-post w-beam barrier median wider than 3.90 meters but narrower than or equal to 4.00 meters
	3	Weak-post w-beam barrier median wider than 3.80 meters but narrower than or equal to 3.90 meters
	2	Weak-post w-beam barrier median wider than 3.50 meters but narrower than or equal to 3.80 meters
	1	Weak-post w-beam barrier median narrower than or equal to 3.50 meters
Strong-post w-beam barrier median	5	Strong-post w-beam barrier median wider than 2.10 meters
	4	Strong-post w-beam barrier median wider than 2.00 meters but narrower than or equal to 2.10 meters
	3	Strong-post w-beam barrier median wider than 1.90 meters but narrower than or equal to 2.00 meters
	2	Strong-post w-beam barrier median wider than 1.80 meters but narrower than or equal to 1.90 meters
	1	Strong-post w-beam barrier median narrower than or equal to 1.80 meters
Box beam barrier median	5	Box beam barrier median wider than 2.10 meters
	4	Box beam barrier median wider than 1.95 meters but narrower than or equal to 2.10 meters
	3	Box beam barrier median wider than 1.80 meters but narrower than or equal to 1.95 meters
	2	Box beam barrier median wider than 1.65 meters but narrower than or equal to 1.80 meters
	1	Box beam barrier median narrower than or equal to 1.65 meters
Concrete barrier median	5	Concrete barrier median wider than 1.00 meters
	4	Concrete barrier median wider than 0.65 meters but narrower than or equal to 1.00 meters
	3	Concrete barrier median wider than 0.50 meters but narrower than or equal to 0.65 meters
	2	Concrete barrier median wider than 0.25 meters but narrower than or equal to 0.50 meters
	1	Concrete barrier median narrower than or equal to 0.25 meters
Depressed median	5	Depressed median wider than 21.00 meters with at least 1.00 meters of deepness
	4	Depressed median wider than 21.00 meters
	3	Depressed median wider than 18.00 meters but narrower than or equal to 21.00 meters
	2	Depressed median wider than 15.00 meters but narrower than or equal to 18.00 meters
	1	Depressed median narrower than or equal to 15.00 meters

3.2. Component II: User's Needs

This component is used to determine the relative weights for decision criteria in the MZOGP. The users can make a decision according to their desired road freight transportation route, this depends on the situation e.g. budget, time and expertise of the user. The relative weights of DSS were employed by the Chang's extent analysis method. The outline of user needs can be summarized as follows:

3.2.1. Judgement and comparisons

The users compare significance between two objects which are the decision criteria or the route physical characteristic of road elements. All judgements are represented in a square matrix with the triangular fuzzy scales by Kengpol et al. [65] and Gumus [66]. These fuzzy scales harmonize the traditional AHP scales by Saaty [13, 14]. Furthermore, the triangular fuzzy scales can reflect the judgement of users reasonably. If the users consider that the vertical decision criterion is more important than the horizontal decision criterion, the triangular fuzzy scale is chosen. Conversely, the reciprocal triangular fuzzy scale is selected while the horizontal decision criterion is more important than the vertical decision criterion.

3.2.2. Calculation the relative weights

FAHP with the Chang's extent analysis method was applied to specify the relative weights of decision criteria and physical freight route characteristics in the DSS. Let $M_{gi}^{1}, M_{gi}^{2}, \ldots, M_{gi}^{j}$ are the triangular fuzzy scales of j^{th} criterion according to i^{th} criterion, when i = 1, 2, …, n and j = 1, 2, …, m. Then, the fuzzy synthetic extent values (S_i) were defined regarding every i^{th} criterion, when i = 1, 2, …, n. Finally, the relative weights (w) which are not a fuzzy number were calculated by normalizing the lowest degree of possibility value $(d'(C_i))$ regarding i^{th} criterion over the other groups. More details can be found in the [23, 34, 65, 66].

3.2.3. Calculation the consistency ratio

The DSS can verify the reliability of the significance. The triangular fuzzy scales in the square matrix were transformed into traditional AHP scales. The consistency ratios (C.R.) of each pair were calculated, C.R. should be less than or equal to the acceptable C.R. which are proposed by Saaty [13, 14]: 0.1 in the case of comparing more than or equal to five decision criteria, 0.08 in the case of comparing four decision criteria and 0.05 in the case of comparing decision criteria.

3.3. Component III: User's Desires and Limitations

This component involves the user's desires and limitations. The users define origin and destination of road freight transportation route. After that, the budget and limited transportation time are set up by the user. The proper road freight transportation route needs to pass the regulations: the transportation cost of road freight transportation must not exceed the budget and the transportation time should be hardly different and less than the limited transportation time. Moreover, an acceptable potential score of physical characteristics which depends on the user's desires should also be set up, the users who are a decision-makers can determine the level of the acceptable potential score from one to five. If the users desire a route with a very low potential score, the acceptable score will be similar to one. But if the users desire an effective route, the acceptable score will be similar to five. However, the users should not determine the high potential score, it may cause the route to not be chosen. In the same way, the physical road route score of the proper route must be greater than or equal to the acceptable potential score from users for every road element.

3.4. Component IV: Optimization Algorithm

The purpose of this component was to select the appropriate road freight transportation route. For the database, user's needs and user's desires were integrated by MZOGP. The selected road freight transportation route is the route with the lowest total deviation from the goals. There are three layers of MZOGP to calculate the total deviation as follows:

3.4.1. The highest layer: objective function

The objective function aims to select the appropriate road freight transportation route with the lowest total deviation between route data: transportation cost, transportation time, and the potential scores of physical road freight transportation route characteristics and user's desires and limitations: budget, limited transportation time, and the acceptable potential score of freight route's physical characteristics. The objective function is defined as:

$$\text{Min } Z_i = w_c(d_c^+) + w_t(d_t^+) + w_z(d_z^+(z')) \tag{1}$$

When
Z_i = The total deviation from three objectives or main decision criteria for i^{th} route
w_c = The relative weight of cost's objective
w_t = The relative weight of time's objective
w_z = The relative weight of deviation of physical road route score objective
d_c^+ = Over achievements deviation of cost
d_t^+ = Over achievements deviation of time
$d_z^+(z')$ = Over achievements deviation of deviation of physical road route score
i = The i^{th} routes; i = 1, 2, 3, …, n

3.4.2. The second layer: constraint function of cost, time and the deviation of route scores

The cost constraint function focuses on the deviation between transportation cost and budget. The alternative road freight transportation routes with the lowest transportation cost at less than or equal to budget represents the zero deviation, while the other routes with transportation cost at less than or equal to budget represents the deviation depending on their transportation cost.

For the time constraint function, this focuses on the deviation between transportation time and limited transportation time, the alternative road freight transportation routes with transportation time hardly different and less than limited transportation time represents zero deviation. Similarly, the other routes with shorter than transportation time and less than limited transportation time represent the deviation depending on their transportation time.

Moreover, the deviation of physical road freight transportation route scores constraint function shows the deviation between the deviation of road freight transportation route characteristic scores and the maximum deviation of route scores. The alternative routes with the lowest deviation score represents zero deviation.

For the second layer of MZOGP, if either transportation cost or transportation time of the route is greater than user limitations, the route will not be considered. The constraint function of cost, time and the deviation of road freight characteristic scores are defined as:

Cost ; $$c_1x_1 + c_2x_2 + c_3x_3 + \ldots + c_nx_n - d_c^+ = C \tag{2}$$

Time ; $$t_1x_1 + t_2x_2 + t_3x_3 + \ldots + t_nx_n - d_t^+ = T \tag{3}$$

The deviation of physical road route scores ; $$\tilde{z}_1'x_1 + \tilde{z}_2'x_2 + \tilde{z}_3'x_3 + \ldots + \tilde{z}_n'x_n - d_z^+(z') = \text{Max } z_i' \tag{4}$$

When
x_i = Decision variables of i^{th} route
c_i = The coefficient of x_i in cost constraint for i^{th} route
t_i = The coefficient of x_i in time constraint for i^{th} route
$\tilde{z}_i'$ = The deviation of physical road route scores for i^{th} route
C = The percentage difference between budget and the lowest transportation cost
T = The percentage of transportation time as 100 percent
i = The i^{th} routes; i = 1, 2, 3, …, n

The unit of cost, time and deviation of scores are different, the normalize is required by Eq. (5) to Eq. (8).

$$C = [\text{Budget - Minimum transportation cost}] / \text{budget} \times 100 \tag{5}$$

$$c_i = [\text{Budget - Transportation cost of } i^{th} \text{ route}] / \text{budget} \times 100 \tag{6}$$

$$t_i = [\text{Transportation time of } i^{th} \text{ route / Limited transportation time}] \times 100 \tag{7}$$

$$\tilde{z}'_i = [\text{The maximum deviation of physical road route scores - The deviation of road route for } i^{th} \text{ route / The maximum deviation of physical road route scores}] \times 100 \tag{8}$$

To obtain z'_i one must sum up the deviation of physical road route, this is defined as:

$$z'_i = w_{p1}(d^-_{p1}) + w_{p2}(d^-_{p2}) + w_{p3}(d^-_{p3}) + \ldots + w_{pm}(d^-_{pm}) \tag{9}$$

When w_{pk} = The relative weight of the physical road route scores for k^{th} road elements
d^-_{pk} = Under achievements deviation of the physical road route scores for k^{th} road elements
k = The k^{th} road elements; $k = 1, 2, 3, \ldots, m$

3.4.3. The lowest layer: constraint function of route scores

The constraint functions of physical road freight transportation route characteristic potential scores shows the deviation between potential scores for each road element and the potential scores determined by user. The alternative routes in each road element with the highest potential score at greater than or equal to the acceptable potential scores represent the zero deviation, while the other routes with potential score at greater than or equal to the acceptable scores represent the deviation depending on their score.

For the lowest layer of MZOGP, the routes with the potential scores at less than the acceptable route scores are not taken into account. Constraint function of the road freight transportation route characteristics scores is defined as:

The physical road route scores for k^{th} road elements;

$$p_{k1}x_1 + p_{k2}x_2 + p_{k3}x_3 + \ldots + p_{kn}x_n - d^-_{pk} = P_k \tag{10}$$

$$x_1 + x_2 + x_3 + \ldots + x_n = 1 \tag{11}$$

$$w_c(d^+_c),\ w_t(d^+_t),\ w_z(d^+_c(z')),\ w_{pk}(d^-_k) \geq 0$$
$$c_i,\ t_i,\ z'_i,\ p_{ki} \geq 0$$
$$x_i = 0 \text{ or } 1$$

When p_{ki} = The coefficient of x_i for physical road route scores of k^{th} road elements and i^{th} route
P_k = The percentage difference between the maximum physical road route for k^{th} road elements and the physical road route scores for k^{th} road elements by user.

The physical road route scores have different units of evaluation. Thus, p_{ki} has to be normalized, it can be calculated from the difference between the potential scores of routes in each road element and the acceptable potential scores in each road element. These variables and the potential scores have positive correlation. If the potential scores are high, the p_{ki} will be high. The calculation method is shown by Eq. (12).

$$p_{ki} = [\text{The road route scores for } k^{th} \text{ road elements and } i^{th} \text{ route - The road route scores for } k^{th} \text{ road elements by user}] / \text{The road route scores for to } k^{th} \text{ road elements and } i^{th} \text{ route} \times 100 \tag{12}$$

Finally, P_k can be calculated from the difference between the maximum potential scores of routes in each road element and the acceptable potential scores in each road element. These variables can be obtained by considering the maximum p_{ki} in each road element or by Eq. (13).

$$P_k = \text{[The road route scores for } k^{th} \text{ road elements - The road route scores for } k^{th} \text{ road elements by user] / The road route scores for } k^{th} \text{ road elements} \times 100 \quad (13)$$

4. Empirical study between Laem Chabang Port to Mukdahan Customs House

This section demonstrates the application of the DSS for road freight transportation routing: an empirical study between Laem Chabang Port to Mukdahan Customs House which is located on EWEC with neighboring countries and other economic corridors. According to the summary values of 2017's exports, products were at about three billion USD [67]. The DSS was applied to the logistics service provider company which generated. There are four alternative road freight transportation routes as shown in (see Fig. 2).

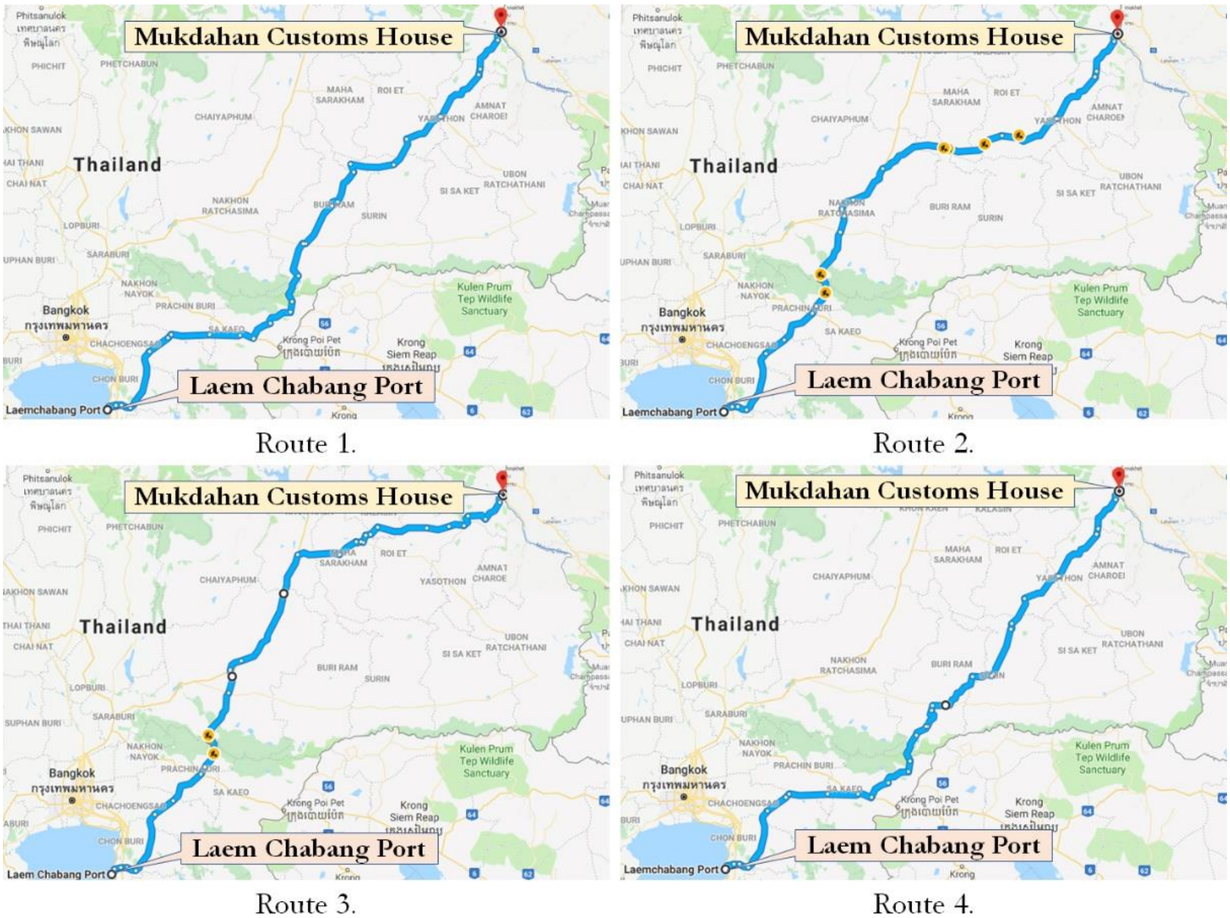

Fig. 2. The alternative road freight transportation routes.

4.1. Data Collection

The authors collected detailed information of each route for decision making. The transportation cost was calculated by the 20ft (Twenty-Foot Equivalent Units: TEU) container transportation. The transportation time was derived from an interview with an expert. Finally, fieldwork of the alternative routes was performed using the standard criteria for the evaluation. The transportation cost, transportation time and the potential road freight transportation route physical characteristic scores are shown in Table 7.

Table 7. The transportation cost (USD), transportation time (Hours) and the road route physical scores.

Alternative Road Freight Transportation Routes	Transportation Cost	Transportation time	The road route physical scores					
			Number of lanes	Lane width	Road surface	Shoulder width	Median types	Median width
1. Muang Mai Klang Road - Nong Khla Mai Road - Route no. 331 - Route no. 304 - Route no. 359 - Suwannasorn Road - Route no. 3395 - Route no. 348 - Route no. 24 - Route no. 218 - Route no. 288 - Route no. 219 - Route no. 2081 - Route no. 215 - Route no. 202 - Route no. 292 - Route no. 2169 - Route no. 212	286	16	1.746	3.950	3.282	2.921	1.866	2.127
2. Muang Mai Klang Road - Nong Khla Mai Road - Route no. 331 - Route no. 304 - Route no. 204 - Route no. 2 - Route no. 207 - Route no. 202 - Route 292 - Route no. 2169 - Route no. 212	297	15	1.534	3.440	3.184	3.705	2.569	2.184
3. Muang Mai Klang Road - Nong Khla Mai Road - Route no. 331 - Route no. 304 -Route no. 204 - Route no. 2 - Route no. 23 - Route no. 2367 - Route no. 2116 - Route no. 2136 - Route no. 2370 - Route no. 212	319	18	2.007	3.515	3.180	3.432	3.483	2.217
4. Muang Mai Klang Road - Nong Khla Mai Road - Route no. 331 - Route no. 304 - Route no. 359 - Suwannasorn Road - Route no. 3395 - Route no. 348 - Route no 2120 - Route no. 24 - Route no. 214 - Route no. 215 - Route no. 202 - Route no. 292 - Route no. 2169 - Route no. 212	284	15	1.770	3.813	3.287	2.928	1.804	2.090

4.2. The Relative Weights of Route Characteristics and Decision Criteria

Three senior executives from the company evaluated the decision criteria and route characteristics with fuzzy triangular scales. The number of decision-makers 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 [68]. 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 decision-makers. This section is divided into two parts: the first part is to calculate the relative weights of route characteristics of road elements; second part is to calculate the relative weights the main decision criteria. The results of route characteristics showed that the lane width was the most important at 0.230, followed by the number of lanes at 0.228, road surface at 0.194, median types at 0.172, median width at 0.089 and shoulder width at 0.088, respectively. The relative weights of route characteristics from the first senior executive are shown in (see Fig. 3).

In the same way, results of the main decision criteria showed that the cost was the most important main criterion at 0.517, followed by the deviation of route characteristic scores at 0.246 and limited transportation time at 0.237, respectively. The relative weights of decision criteria from the first senior executive are shown in (see Fig. 4).

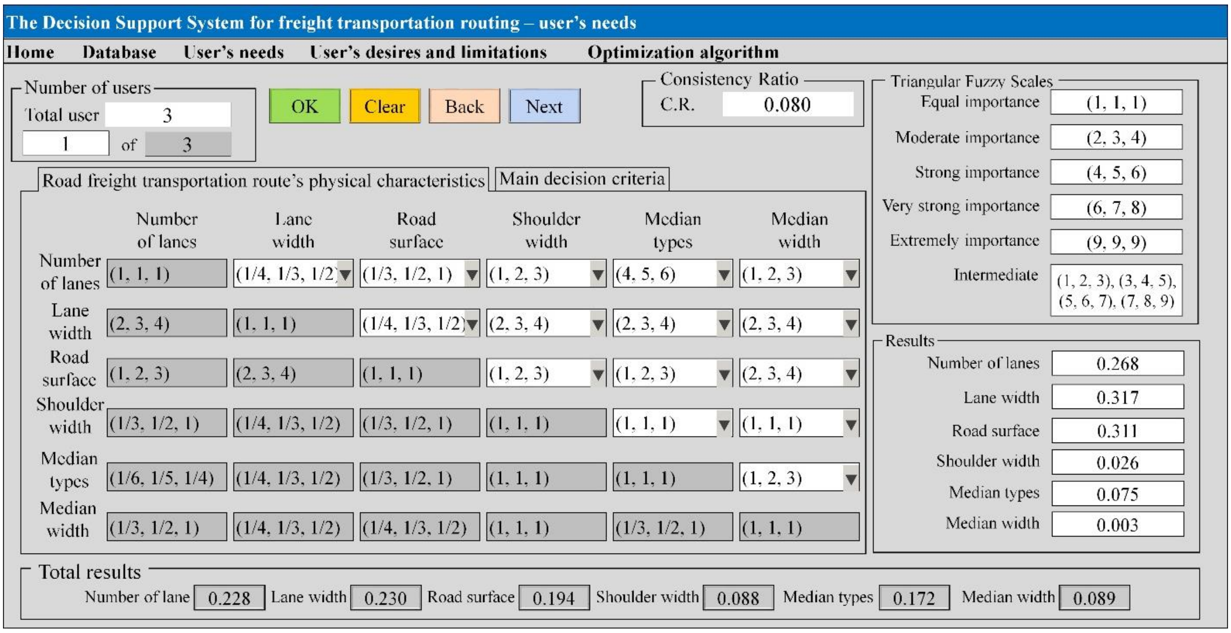

Fig. 3. Screen page of the relative weights of route characteristics from the first senior executive.

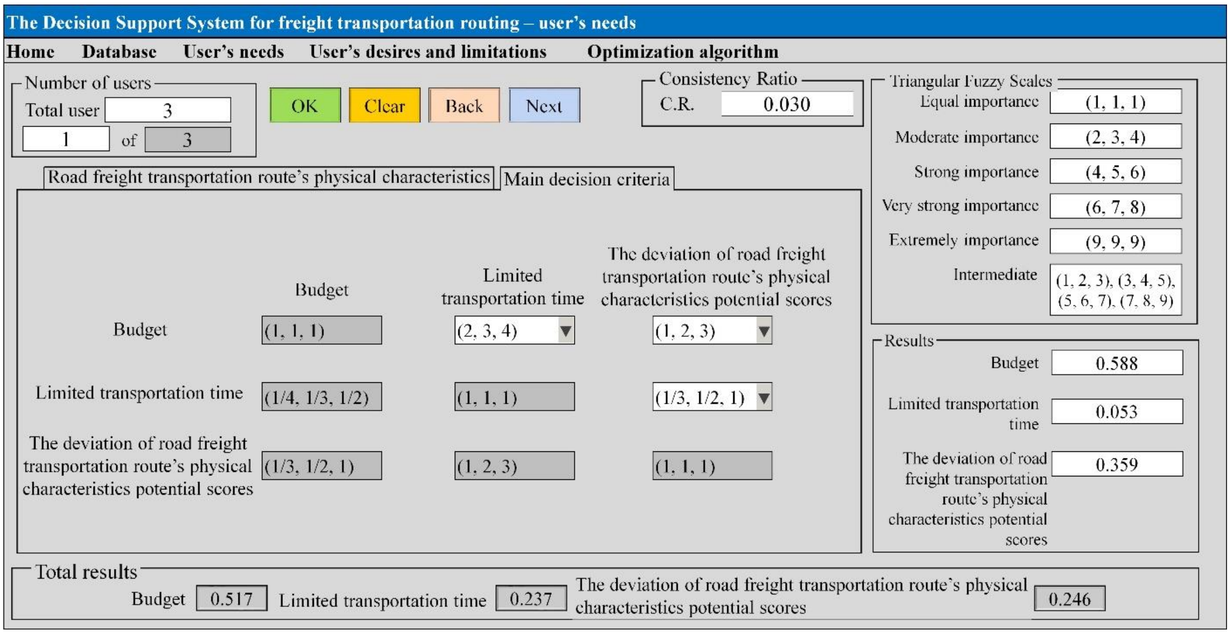

Fig. 4. Screen page of the relative weights of main decision criteria from the first senior executive.

4.3. The Appropriate Road Freight Transportation Route

After collecting the road freight transportation routes data, user needs, desires and limitations, are used by MZOGP as part of the decision support system method to select an appropriate route, this route must have the lowest total deviation of main decision criteria. For this study, the senior executives defined the budget at 320 USD, the limited transportation time at 15 hours and the acceptable potential score of physical characteristics in each route at 1.5 for every road element. From the information, the authors established the MZOGP optimization algorithm to select the appropriate transportation route in the DSS. The details are as follows:

Objective function:

Min Z_i = $0.517(d_c^+) + 0.237(d_t^+) + 0.246(d_z^+(z'))$

Subject to:

Cost	;	$10.625x_1 + 7.188x_2 + 0.313x_3 + 11.250x_4 - d_c^+$	$= 11.250$
Time	;	$106.667x_1 + 100x_2 + 120x_3 + 100x_4 - d_t^+$	$= 100$
The deviation of physical road route scores	;	$5.650x_1 + 11.471x_2 + 84.611x_3 + 0x_4 - d_z^+(z')$	$= 84.611$

$$z_i' = 0.228(d_{p1}^-) + 0.230(d_{p2}^-) + 0.194(d_{p3}^-) + 0.088(d_{p4}^-) + 0.172(d_{p5}^-) + 0.089(d_{p6}^-)$$

Subject to:

Number of lanes	;	$14.089x_1 + 2.216x_2 + 25.262x_3 + 15.254x_4 - d_{p1}^-$	$= 25.262$
Lane width	;	$62.025x_1 + 56.395x_2 + 57.326x_3 + 60.661x_4 - d_{p2}^-$	$= 62.025$
Road surface	;	$54.296x_1 + 52.889x_2 + 52.830x_3 + 54.366x_4 - d_{p3}^-$	$= 54.366$
Shoulder width	;	$48.648x_1 + 59.514x_2 + 56.294x_3 + 48.770x_4 - d_{p4}^-$	$= 59.514$
Median types	;	$19.614x_1 + 41.612x_2 + 56.934x_3 + 16.851x_4 - d_{p5}^-$	$= 56.934$
Median width	;	$29.478x_1 + 31.319x_2 + 32.341x_3 + 28.230x_4 - d_{p6}^-$	$= 32.341$
		$x_1 + x_2 + x_3 + x_4$	$= 1$
		$d_c^+, d_t^+, d_z^+(z'), d_{p1}^-, d_{p2}^-, d_{p3}^-, d_{p4}^-, d_{p5}^-, d_{p6}^-$	≥ 0
		x_i	$= 0$ or 1

When
- Z_i = The total deviation from three objectives for i^{th} route
- $\tilde{z}_i'$ = The deviation of road route physical potential scores for i^{th} route
- x_i = Decision variables of i^{th} routes
- i = The alternative road freight transportation routes; i = 1, 2, 3, 4
- d_c^+ = Over achievements deviation of cost
- d_t^+ = Over achievements deviation of time
- $d_z^+(z')$ = Over achievements deviation of deviation of road route physical score
- d_{p1}^- = Under achievements deviation of number of lanes
- d_{p2}^- = Under achievements deviation of lane width
- d_{p3}^- = Under achievements deviation of road surface
- d_{p4}^- = Under achievements deviation of shoulder width
- d_{p5}^- = Under achievements deviation of median types
- d_{p6}^- = Under achievements deviation of median width

The MZOGP optimization algorithm was applied to the decision support system for freight transportation routing. The total deviation for each route was calculated as shown in (see Fig. 5).

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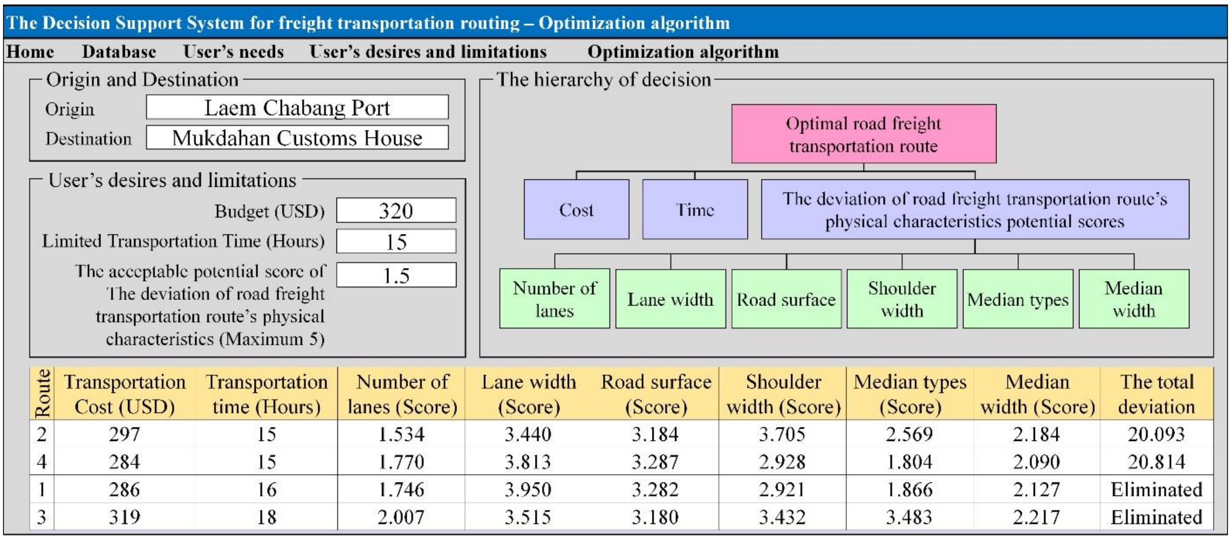
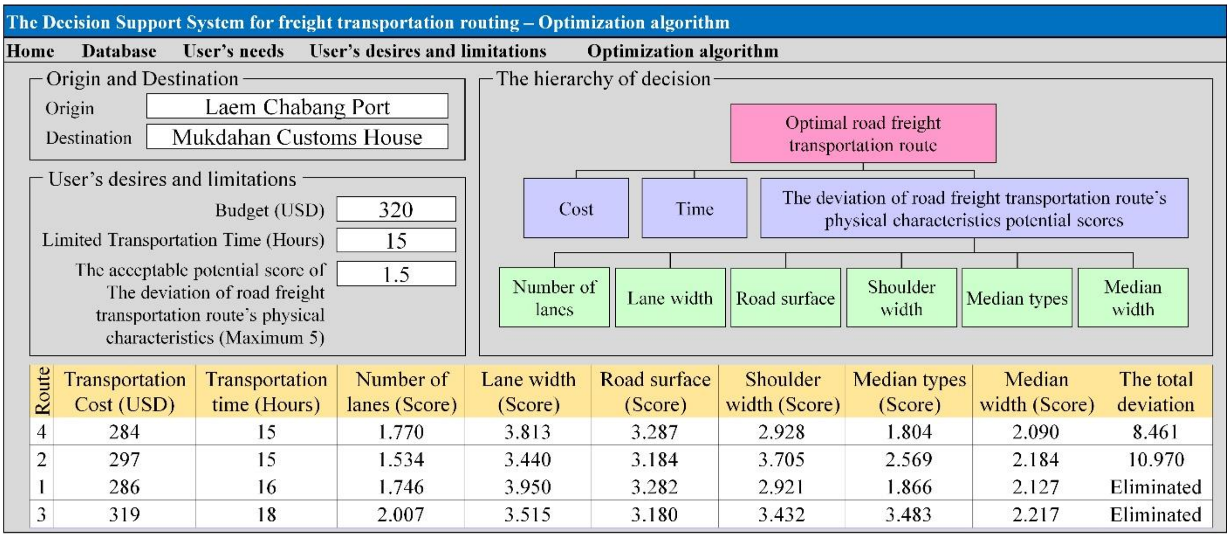


Route	Transportation Cost (USD)	Transportation time (Hours)	Number of lanes (Score)	Lane width (Score)	Road surface (Score)	Shoulder width (Score)	Median types (Score)	Median width (Score)	The total deviation
2	297	15	1.534	3.440	3.184	3.705	2.569	2.184	20.093
4	284	15	1.770	3.813	3.287	2.928	1.804	2.090	20.814
1	286	16	1.746	3.950	3.282	2.921	1.866	2.127	Eliminated
3	319	18	2.007	3.515	3.180	3.432	3.483	2.217	Eliminated

Fig. 5. Screen page of the total deviation for transportation routes.

From the total deviation for each transportation route, the authors discovered that the second alternative road freight transportation route was the optimal route in this case with the total deviation of main decision criteria at 20.093, the transportation cost equaled 297 USD, the transportation time equaled 15 hours. While, number of lanes potential score equaled 1.534, lane width potential score equaled 3.440, road surface potential score equaled 3.184, shoulder width potential score equaled 3.705, median types potential score equaled 2.569, median width potential score equaled 2.184, respectively. Furthermore, the fourth alternative road freight transportation route was taken the second alternative with the total deviation of main decision criteria at 20.814, the transportation cost equaled 284 USD, the transportation time equaled 15 hours. While, number of lanes potential score equaled 1.770, lane width potential score equaled 3.813, road surface potential score equaled 3.287, shoulder width potential score equaled 2.928, median types potential score equaled 1.804, median width potential score equaled 2.090, respectively. In this situation, the first and third alternative road freight transportation route were not considered because the transportation time of both routes were greater than the limited transportation time. In addition, the authors tested the stability of the algorithm by determining the new relative weights of the main decision criteria. The result of cost was at 0.900, followed by transportation time at 0.100, the deviation of route score at 0.100. The optimal route changed from the second alternative road freight route to the fourth alternative route because the DSS concentrated on the route which had the lowest transportation cost, as shown in (see Fig. 6). Conversely, if the users determined the high relative weight to the deviation of route score, the optimal route will be the second alternative route in this case.



Route	Transportation Cost (USD)	Transportation time (Hours)	Number of lanes (Score)	Lane width (Score)	Road surface (Score)	Shoulder width (Score)	Median types (Score)	Median width (Score)	The total deviation
4	284	15	1.770	3.813	3.287	2.928	1.804	2.090	8.461
2	297	15	1.534	3.440	3.184	3.705	2.569	2.184	10.970
1	286	16	1.746	3.950	3.282	2.921	1.866	2.127	Eliminated
3	319	18	2.007	3.515	3.180	3.432	3.483	2.217	Eliminated

Fig. 6. Screen page of the total deviation for transportation routes with the new relative weights.

5. Conclusions and Recommendations

This paper presented a decision support system (DSS) for road freight transportation routing which examines the cost, time and potential physical route characteristic scores. This DSS composed of four components. The first component is database which is used to store the data of road freight transportation routes: transportation cost, transportation time and route characteristic scores. In this component, the standard criteria for physical road freight route characteristic evaluation was constructed, including number of lanes, lane width, road surface, shoulder width, median types and median width. The description of potential scale for the standard criteria were conducted by the Delphi method based on suitability and facilitation of transportation. The second component was user needs, the purpose was to determine the relative weights of the decision criteria and route characteristics by FAHP with Chang's extent analysis. The third component was user desires and limitations: budget, limited transportation time and the acceptable potential score of route characteristic. The last component was used to calculate an appropriate road freight transportation route via MZOGP, this was developed from traditional weighted ZOGP. The purpose of this algorithm was to cluster the objectives or goals which exceed seven into the same group. The total deviation of main decision criteria for each route was calculated by MZOGP. Finally, to confirm that the DSS operated successfully, the authors applied the DSS to an empirical study of a logistics service provider company which provide freight transportation services from Laem Chabang Port to Mukdahan Customs House. The results concluded that the DSS could be used efficiently. The results of the DSS could also be changed based on user desires, limitations, and relative weights of decision criteria. In addition, the data of route characteristics could probably change. Therefore, the survey to update the route physical characteristics data is required frequently. Especially, the road surface should be updated every year to make the decision as efficient as possible.

For future studies, the first issue would be to include more route characteristics such as blackspots and road competency. The second issue, multimodal freight transportation routing with many alternative routes should be integrated into the DSS. The last issue would be to develop a new algorithm for when the problem has a larger scale of alternatives.

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