Design of a Decision Support System on Selection of Multimodal Transportation with Environmental Consideration between Thailand and Vietnam

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Abstract

The objective of this research is to design and develop a decision support system (DSS) to select multimodal transportation route between Thailand and Vietnam under the conditions in term of budget, time, transport risk, and the environmental impact. The developed DSS model uses Analytic Hierarchy Process (AHP) as a tool to bring consistency weight whose decision criteria (both quantitative and qualitative) are expressed in subjective measures according to the point of view of users. Next, weighting derived from the results of AHP is taken as a weight of objective function in goal programming model. In this research, the Zero-One Goal Programming model is used to generate an optimal multimodal transportation routing based upon the criteria in term of budget, time, transport risk, and importantly, the environmental setting which is important to a number of countries. The case study of this research is a transported service, originating from Bangkok in Thailand to a destination at Da Nang port in Vietnam. There are, for example, the user can set the budget at 5,000 USD for 8-day period of transportation, with route risk scale and the environmental impact scale. The results found that the optimal route is sea transport departed from Bangkok to Da Nang Port, and truck service is deliver goods to customers. Transportation cost is equal to 1,080 USD for 8-day period of transportation, route risk scale is equal to 2, an environmental impact scale is equal to 3 and standard deviation is equal to 15.99. The results show that the DSS can guide to choose the lowest cost route in accordance with overall criteria, and minimise the environmental impact effectively. The results analysis, recommendations and limitations are also presented.

Keywords: *Decision Support System, Multimodal Transportation, Analytic Hierarchy Process (AHP), Zero-One Goal Programming (ZOGP)*

1 Introduction

The developing economics of GMS (Greater Mekong Sub-region) have show that they have become increasingly linked into the global economy through trade, investment credit and technology. (Banomyong et al., 2006) Therefore, The Thai Government places increasingly emphasis on business activities amongst GMS countries. In 2007, the office of the National Economic and Social Development Board (NESDB) established the strategic plan of Thailand's Logistics Development 2007-2011 that defines Thailand's vision as A World Class Logistics System so that it can support business and trade amongst GMS countries. Transportation is an important component of national economy. International multimodal transportation is a fastness-emphasised activity to response the market demand and obviously plays a key role in this region for increasing intense trade competition (Kengpol et al., 2009)

From the case literature reviewed, it is found that the selection multimodal transportation routes have emphasised on selecting multimodal transportation route for minimum cost or minimum time by using only quantitative criteria without combination qualitative criteria and importantly the environmental setting which is important to a number of countries attention in model. In recent, environmental issues in logistics are currently in place in various regions of the world. In the future, proactive environmental management will be essential for the transportation industry and for organisations managing multimodal transportation hubs that integrate several types of freight carriers, logistics services and manufacturing or processing activities at a single site. (Rondinelli et al., 2000) Therefore, environmental aspects are integrated with the model in this research. The objective of this research is to design and develop a decision support system to select multimodal transportation route between Thailand and Vietnam under the conditions in term of budget, time, transport risk, and importantly, the environmental impact. The quantitative and qualitative criteria should be included to achieve an optimal multimodal transportation route. That means users can make decision under their needs in multimodal transportation route.

2 Literature reviews

There is a lot of literature on multimodal transportation routing problems. The choice of transport mode has a direct impact on transport cost. Several researches from the previous researches for selecting multimodal transportation route have emphasised on selecting multimodal transportation route for minimum cost or minimum time by using only quantitative criteria without qualitative criteria. Except, Banomyong (2001) has considered risk of route but not combined in model. In recent year a number of risk analysis researches have occurred. In 2004, Giglio et al. introduced a new approach to assess properly the hazmat transport risk on the road of petroleum products made by tank trucks for real time risk. Hoj et al. (2002) focused on risk analysis of transportation on road and railway from a European and concentrate on the planning of new transportation links and the transport of dangerous goods, mainly through tunnels. Several researchers in this area are usually concerned with using other methods. Therefore, the purpose of the model in this research is to assist the decision maker (The logistics service provider) for selecting multimodal transportation route based upon budget, time, risk and environmental impact.

2.1 *Multimodal Transport Cost-Model*

The multimodal transport cost-model has been adapted from Beresford and Dubey in 1990 and improved by Beresford in 1999. (Banomyong, 2001) This model includes both transport and intermodal transfer as components. The choices of multimodal transport combinations are based upon factors others than just transportation costs, which are directly related to transit time, distance, and intermodal transfer. (Kengpol et al., 2009)

2.2 *The Analytic Hierarchy Process (AHP)*

The AHP developed by Saaty, has been studied extensively and used in a number of applications related to multiple criteria decision making (MCDM) in last 20 year. (Ho et al., 2006) The AHP is a structured technique for dealing with complex decisions and helps the decision makers find the one that best suits their needs and their understanding of the problem. It can be integrated with other techniques. AHP has been also widely used in the decision making problem by academics and practitioners. (Ghodsypour et al., 1998; Kengpol, 2004; Kengpol, 2008; Kengpol et al., 2001; Kengpol et al.,2006; Korpela et al., 1996; Korpela et al., 1999)

The principles of AHP based upon Saaty (1980) are as follows. The first step of AHP begins by decomposing a complex MCDM problem into a graphical hierarchical form to represent goal, criteria, sub-criteria and alternative. The second step, user construct a hierarchy, priorities should be determined for the elements at every level of the hierarchy. Finally, the full mathematical model can be further clarified in Saaty (1980). The advantage of AHP is the weight result from AHP can deliver consistency ratio (CR) in the significant weight by pairwised comparison criteria. Therefore, the result received can assist user to assess weight.

2.3 *Zero-One Goal Programming (ZOGP)*

Goal Programming (GP) was first used by Charnes, Cooper and Ferguson in 1955. GP is a technique that achieves the optimal solution. GP is a method that requires ordinal and cardinal information for multiple objective decisions making. In GP, deviation variables (from goals) with assigned priorities and weights are minimised instead of optimising the objective criterion directly as in Linear Programming (LP). (Tabucanon, 1988) It can be thought of as an extension of linear programming to handle multiple, normally conflicting objective function. In the Linear Programming maximum or minimum objective function is set for only one quantity to manage on its optimum value, however, in the GP is able to carry several goals related to each other. Therefore, the decision maker can set the priority or weight to specify each multiple goals. The initial goal programming formulations ordered the unwanted deviations into a number of priority levels, with the minimisation of a deviation in a higher priority level being infinitely more important than any deviations in lower priority levels.

3 The decision support model for the selection of multimodal transportation

From the several previous studies the quantitative criteria in selecting multimodal transportation route are cost and time at minimum time and/or minimum cost. (Banomyong, 2001; Bookbinder et al., 1998; Chang, 2008; Min, 1991) This research uses the same criteria (cost, time, risk and added environmental impact scale into this model) to combine in newly developed DSS, but change cost criterion to budget of user, time to limitation time, risk to the lower confidence index of transportation and environmental impact to the lower impact index of CO_2 emission in transportation. This DSS consists of four main parts which have been illustrated in Figure 1.

Part I: The database for the user's making decision that the detail is shown as follows. (1) The possible multimodal transportation route from origin to destination. (2) Transportation cost and time for each route and transit by using multimodal transport cost-model as a tool. (3) The risk of route is in confidence index form. And (4) the environmental impact of route and mode of transportation is in impact index form.

Part II: User defines origin and destination and limits quantitative and qualitative criteria.

Part III: The combination between the quantitative and qualitative criteria by AHP in DSS. The user is able to find the significant weight of each criterion for each transportation situation. The weight from user is integrated in objective function of ZOGP which is the last part of the system.

Part IV: The application of the ZOGP in selecting multimodal transportation route. ZOGP can calculate an optimal multimodal transportation route in this case study.

Procedure of user for using in this DSS has 4 steps. First step, user collects data. Second step, user selects the origin and destination and limits quantitative and qualitative criteria. Third step, user weights criteria by AHP for using in ZOGP. Last step, user calculates optimal route by using ZOGP that has the minimum deviation in user's case study.

Figure 1: System model of decision support system

3.1 *Preliminary Databases*

According to Figure 1, this part is the data preparation of each route for the DSS that consist of possible multimodal transportation route for origin and destination, budget, time, risk and environmental impact of each route. They collect data from brainstorming of experts and logistics service providers in Thailand and Vietnam. Cost and time are calculated by multimodal transport cost-model that it is included cost and time for transportation in case of changing the transportation mode.

The routing risk is the importance of uncertainty for a decision situation that depends on the cost of reversing a commitment once made. (Banomyong, 2001) The term “risk analysis” is used in this paper to denote methods, which aim to develop a comprehensive understanding, and awareness of the risk associated with the decision involved in the selection of multimodal transport route. Confidence index stated that all decision problems have certain general characteristics. The confidence index is used for risk analysis. This confidence index is based on a five point type scale in Table 1. (Banomyong, 2001) In this paper, the confidence index is derived from interview experts and logistics service providers in Thailand and Vietnam in field of political science, security and safety of route and flexible of route.

In this research, the environmental impact is considered in CO_2 emission term. The environmental performance of transports is determined by several factors. In the Freight Calculator, only a few of those factors are used. The calculation is based on scientific data for default vehicles and load factors. After that, the author converts results of these calculations (CO_2 emission) into environmental impact index form. This environmental impact index is based on a five point type scale in Table 2. In this paper, the environmental impact index is derived from interviewing environmental experts. More details of CO_2 emission can be seen in Appendix.

Table 1: Confidence index scale

Confidence Index (CI)	Description
1	almost no confidence
2	not very confident
3	fairly confident
4	confident
5	very confident

Table 2: Environmental impact index scale

Environmental Impact Index	Description
1	almost no impact
2	not very impact
3	fairly impact
4	impact
5	very impact

3.2 *The AHP Model*

The procedure for using the AHP can be summarized as: The first step, User design model of the problem as a hierarchy that contains of the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternative, which have been illustrated in Figure 2. Next step, the user is assigned to set the significant weight of each criterion both of quantitative and qualitative for selecting transportation route by pairwised comparison. After that, user checks the consistency of the judgments. Finally, DSS uses the significant weight of each criterion for optimisation by ZOGP in the next step. More details of AHP can be seen in Appendix.

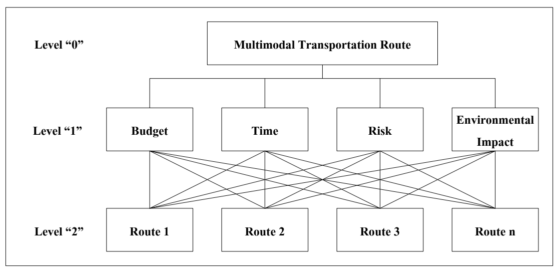

Figure 2: AHP structure for choice multimodal transportation route

3.3 *Zero-One Goal Programming (ZOGP)*

GP is an extension of mathematical programming models that enables a decision maker to specify desirable goals for each objective. (Kruger, 2006) To achieve this, problem are generally formulated using deviation variables d_i^- and d_i^+. The variable d_i^- represents underachievement of goal constraints for each objective and d_i^+ similarly represents overachievement of goal constraints for each objective. In this step, ZOGP can eventually calculate for an optimal multimodal transportation route. The weight from AHP and limited data from Part III are used to formulate the objective function and constraint. The model of combination of AHP and ZOGP is presented below.

$$\text{Minimum} = \sum_{i=1}^{n}\left(g_i d_i^- + g_i d_i^+\right)$$
$$= w_1\left(g_1 d_1^- + g_1 d_1^+\right) + w_2\left(g_2 d_2^- + g_2 d_2^+\right) + w_3\left(g_3 d_3^- + g_3 d_3^+\right) + w_4\left(g_4 d_4^- + g_4 d_4^+\right) \quad (1)$$

Subject to:

Budget $\quad c_1 X_1 + c_2 X_2 + \ldots + c_n X_n \le 100 \quad (2)$

Time $\quad t_1 X_1 + t_2 X_2 + \ldots + t_n X_n \le 100 \quad (3)$

Risk $\quad r_1 X_1 + r_2 X_2 + \ldots + r_n X_n \le R \quad (4)$

Environmental Impact $\quad e_1 X_1 + e_2 X_2 + \ldots + e_n X_n \le E \quad (5)$

$$X_1 + X_2 + \ldots + X_n = 1 \quad (6)$$
$$w_i, d_i^-, d_i^+ \ge 0, \quad i = 1,2,3,4$$
$$c_j, t_j, r_j, e_j \ge 0, \quad j = 1,2,3,\ldots,n$$
$$X_j = 0 \text{ or } 1, \quad j = 1,2,3,\ldots,n$$

In this research, 4 objectives are combined into the objective functions of ZOGP for minimising deviation from user requires. The first objective is the budget of transportation (g_1) that is not over from user limit. The second objective is the time of transportation (g_2) that is not over from user limit. The third objective is the risk of route (g_3) that user sets. Finally, the fourth objective is environmental impact (g_4) that user sets.

In these data, each objective has different unit, therefore this paper have to formulate all unit to percentage.

Deviation Variables

d_i^-, d_i^+ = Percentage vectors of under-achievements and overachievements of targeted for each objective.

Decision variables

X_j = Zero-one variables representing the non-selection (i.e., a zero) or selection (i.e., a one) of $j = 1,2,3,\ldots,n$ route, subject to criteria constrain in the right hand side (budget, time, confidence index risk and environmental impact index from user).

Parameters

w_i = The weights for each criteria coefficients relating to deviation of each goal that can obtain from AHP. (w_1 is weight of budget, w_2 is weight of time, w_3 is weight of risk, w_4 is weight of environmental impact)

c_j = The coefficient of X_j in budget constrain, it is a cost of each route in percentage of user budget. The right hand side of this equation is percentage budget user (100 %). c_j = (cost of route j x 100/ budget of user).

t_j = The coefficient of X_j in time constrain, it is percentage of time of each route and user time limit. The right hand side of this equation is percentage user time limit (100 %). t_j = (time of route j x 100/ user time limit).

r_j = The coefficient of X_j in risk constrains, it is percentage of different maximum confidence index, 5 and route confidence index. R is right hand side of risk constrain. r_j = [(maximum confidence index, 5 - confidence index of route j) x 100/ (maximum confidence index, 5)].

R = The percentage of different maximum confidence index, 5 and confidence index is set from user. R = [(maximum confidence index, 5 - user confidence index) x 100/ (maximum confidence index, 5)].

e_j = The coefficient of X_j in environmental impact constrains; it is percentage of different maximum environmental impact index, 5 and route environmental impact index. E is right hand side of environmental impact constrain. e_j = [(maximum environmental impact index, 5 - environmental impact index of route j) x 100/ (maximum environmental impact index, 5)].

E = The percentage of different maximum environmental impact index, 5 and environmental impact index is set from user. E = [(maximum environmental impact index, 5 - user environmental impact index) x 100/ (maximum environmental impact index, 5)].

In equation (6), it controls that one route is optimum for one situation.

4 Case study in transportation route between Thailand (Bangkok) and Vietnam (Da Nang)

It is to study in transport service, origin from Bangkok, Thailand to destination Da Nang, Vietnam. The information are, for example, cost of this route by truck in 20 ft. (1 Twenty-Foot Equivalent Units: TEU) container about 1,370 USD, time 2 days, confidence index 3 and environmental impact index 3. The database in this DSS is derived from collecting data through interview with Thai Business (Vietnam) Association (TBA), logistics service providers in Thailand and Vietnam about transportation route in budget, time, risk and environmental impact. This origin and destination have 11 multimodal transportation routes illustrated in Table 3.

Table 3: Database of multimodal transportation route

Route	Budget (USD)	Time (days)	Risk (CI)	Environmental Impact (EI)	Route	Budget (USD)	Time (days)	Risk (CI)	Environmental Impact (EI)
1. BKK###HMC---Da Nang	2967.5	8	3	4	7. BKK---HMC***Da Nang	7880	4	4	4
2. BKK###HMC+++Da Nang	1631.5	10	3	3	8. BKK***HMC+++Da Nang	5334	6	2	3
3. BKK***Da Nang	4580	2	2	2	9. BKK***HMC---Da Nang	6580	4	3	4
4. BKK###Da Nang	1080	8	2	3	10. BKK***HMC###Da Nang	5378	6	2	2
5. BKK---HMC###Da Nang	4298	7	4	4	11. BKK###HMC***Da Nang	5257.5	7	2	2
6. BKK---HMC+++Da Nang	4254	7	4	4					

Remark: truck ---, train +++, air *** and sea ###

From the limitation of user, the budget at 5,000 USD, time 8 days, confidence index at least 3, environmental impact index at least 3 and the relative weight criteria from AHP as budget 0.374, time 0.229, risk 0.133 and environmental impact 0.264 with consistency ratio not over 0.1 to fine out the optimal route.

The results found that the optimal route is sea transport departed from Bangkok to Da Nang Port, and truck service is deliver goods to customers (route No. 4). Transportation cost is equal to 1,080 USD for 8-day period of transportation, route risk scale is equal to 2, an environmental impact scale is equal to 3 and standard deviation is equal to 15.99. It can decrease the transportation cost about 290 USD. The results show that the DSS can guide to choose the lowest cost route in accordance with overall criteria, and minimize the environmental impact effectively.

5 Conclusions and recommendations

The objective of this research is to design and develop a DSS to select multimodal transportation route between Thailand and Vietnam under the conditions in term of budget, time, transport risk, and importantly, the environmental impact. Therefore, this paper presented a new DSS to select multimodal transportation route. From the several previous studies, a research gap found on selecting multimodal transportation route for minimum cost or minimum time by using only quantitative criteria without qualitative criteria. Therefore, the authors fills this gap by combining quantitative and qualitative criteria in this model. The DSS model is the combination of a number of models beginning with the multimodal transport cost-model to achieve cost and time of each multimodal transportation routes, followed by AHP to weight of quantitative and qualitative criteria for ZOGP in the next step to optimize route for user needs in each criteria, the models have been already examined in an in-depth collaboration with major logistics firms in Thailand and Vietnam.

The contribution of this research lies in a development of a new approach that is flexible and applicable to logistics service provider, in selecting multimodal transportation route under user needs in quantitative and qualitative criteria for decision making for minimum time or minimum cost. This DSS is simple and flexible for all users for limiting budget, time, risk and environmental impact for transportation. The results from this DSS show that the DSS can guide to choose the lowest cost route in accordance with overall criteria, and minimize the environmental impact effectively. The advantage of this research is that user can select the optimal multimodal transportation route and give the significant weight as needed.

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7 Appendix

7.1 *The Analytic Hierarchy Process (AHP)*

The problem can be decomposed into a multi-level hierarchy. From Figure 2, the hierarchical structure based upon the AHP Methodology. At level “0”, the goal is to choose a multimodal transportation route. At level “1”, the main criteria are budget, time, risk and environmental impact. And at level “2”, the alternatives are route 1, route 2 and route n.

The weights are applied to all the factors inter and intra hierarchy. The AHP method provides a structured framework for setting priorities on each level of the hierarchy using pairwise comparisons that are quantified using 1–9 scales (Saaty, 1980). Let $C_1 \ldots, C_m$ be m criteria and $W = (w_1, \ldots, w_m)$ be their normalized relative importance weight vector which is to be determined by using pairwise comparisons and satisfies the normalization condition (Joshi et al., 2011)

$$\sum_{j=1}^{m} w_j = 1 \text{ with } w_j \geq 0 \text{ for } j = 1, \ldots, m \qquad (7)$$

The pairwise comparisons between the m decision factors can be conducted on scale (1–9) by asking questions to experts or decision makers like, which criterion is more important with regards to the decision goal. The answers to these questions form an $m \times m$ pairwise comparison matrix as follows:

$$A = (a_{ij})_{m\times m} = \begin{array}{c} C_1 \\ C_2 \\ \vdots \\ C_m \end{array} \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}$$

where

a_{ij} = A quantified judgment on $w_i w_j$ with $a_{ii} = 1$ and $a_{ij} = 1/a_{ji}$ for $i, j = 1,2, \ldots, m$

If the pairwise comparison matrix $A = (a_{ij})_{m\times m}$ satisfies $a_{ij} = a_{ik}a_{kj}$ for any $i, j, k = 1,2, \ldots, m$ then A is addressed to be perfectly consistent; otherwise it is addressed to be inconsistent. From the pairwise comparison matrix A, the weight vector W can be determined by solving the following characteristic equation (8):

$$AW = \lambda_{\max} W \qquad (8)$$

where

$\lambda_{\max}$ = the maximum eigenvalue of A. Thepairwise comparison matrix A should have an acceptable consistency, which can be checked by following consistency ratio (CR):

$$CR = \frac{(\lambda_{\max} - n)/(n-1)}{RI} \quad (9)$$

If $CR \leq 0.1$, the pairwise comparison matrix is considered to have an acceptable consistency; otherwise, it required to be revised (Saaty, 1980).

7.2 *CO_2 Emission*

The Calculation of the amount of air pollution emissions in this paper is the estimation of CO_2 emission stemming from energy use in Thailand. The CO_2 emissions are calculated from the amount of energy consumption and the CO_2 emission factor by fuel type, with reference to the estimation methodologies and CO_2 emission factors prescribed in the 2006 Guidelines of the Intergovernmental Panel on Climate Change (IPCC), using the following calculation formular:

$$CO_2\ Emission = \sum (EF_{Fuel} \times FC_{Fuel}) \quad (10)$$

where

EF_{Fuel} = The CO_2 emission coefficient of each fuel type (Emission Factor)

FC_{Fuel} = The amount of utilization of each fuel type (Fuel Consumption)

After that, the author converts results of these calculations (CO_2 emission) into environmental impact index form. This environmental impact index is based on a five point type scale in Table 2. In this paper, the environmental impact index is derived from interviewing environmental experts.

8 References

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