THE DECISION MAKING OF FREIGHT ROUTE
IN MULTIMODAL TRANSPORTATION
BETWEEN THAILAND AND CAMBODIA

BY

KWANJIRA KAEWFAK

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF MASTER OF
ENGINEERING (LOGISTICS AND SUPPLY CHAIN SYSTEMS
ENGINEERING)
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A Thesis Presented

By

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MAY 2017
Abstract

THE DECISION MAKING OF FREIGHT ROUTE IN MULTIMODAL TRANSPORTATION BETWEEN THAILAND AND CAMBODIA

by

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Bachelor of Science, Sirindhorn International Institute of Technology, Thammasat University, 2015

Master of Engineering, Sirindhorn International Institute of Technology, Thammasat University, 2017

This paper develops a framework for route selection in multimodal transportation about the case study of transportation from Thailand to Cambodia in beverage industries. The optimized route can help optimize cost, lead time, and risk in the systems. The route selection process applies a five phases framework to determine an optimal multimodal route. The first phase is to define areas of study and identify all the related routes. The second phase is to calculate time and cost of each route. The third phase is to integrate quantitative and qualitative decision making which are assessed by the experts or Logistics Service Providers for each criterion. The fourth phase is to prioritize criteria by using Analytic Hierarchy Process. The final phase is to optimize the route by using the Zero-one goal programming. The results have shown that the approach can provide guidance in choosing the optimal cost, time and risk effectively.

Keywords: Analytic hierarchy process (AHP), Multimodal transportation risk, Quantitative risk assessment (QRA), Zero-one goal programming model.
Acknowledgements

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Chapter 1
Introduction

Multimodal transportation, as defined by Multimodal Transport Handbook published by UNCTAD, intermodal transportation is the transport of products by several modes of transport from one point or port of origin via one or more interface points to a final point or port where one of the carriers organize the whole transport. The Government of Thailand has considered multimodal transport as an important development in making industry and international trade more efficient and competitive. The multimodal transport operation with the emphasis on door-to-door delivery, supply driven transport services provided by various parties within the transport chain. The local industry and international trade can benefit from smooth flow of goods and better control over transport chain. Recognizing the benefit of the multimodal transport concept, Thailand has taken initiatives in improving laws and regulations would create the necessary environment for it to progress. (Multimodal Transport Act B.E.,2005)

In recent year, Thailand had many chances to promote multimodal transport, for example in the export and import of containers among countries. The trade between Asia and Europe and North of America is the major premise to the development of demand in multimodal transport. Thailand are intensifying building infrastructure serving multimodal transport (Thi Bich Bui, 2011). Multimodal transport is more popular with the support from the development of technology leading to competition among companies and among countries in general.

Since ASEAN Economic Cooperation (AEC) will become fully functional by 2015, Thailand has been developing economics corridors and cooperating with neighboring country, including Cambodia. There will be opportunities for trade of goods with Cambodia which the top import origins of Cambodia are Thailand ($4.44B), China ($3.26B), Vietnam ($2.52B), Singapore ($1.05B) and Hong Kong ($902M).

To achieve cooperation among the country, the connections through multimodal transportation systems should be an area of focus which the main economic corridors
linking to gateway, interchange nodes, the road connecting to the rural areas and the markets should be emphasized. The infrastructure would help save time, lower transportation costs, reduce risks and encourage trade along the corridor.

Nowadays, Thailand has looked to reduce costs of logistics and transportation in order to remain competitive among other countries. The selected multimodal transportation routes have focused on multimodal transportation route for minimum cost and time dealing with the minimum risks and environment setting (Min, 1991; Southworth and Peterson, 2000; Banomyong and Bresford, 2001; Ham et al., 2005; Chang, 2008; Kengpol et al., 2012; Meethom and Chimmanee, 2013).

Therefore, the objectives of this research is to develop a framework for route selection in multimodal transportation with case study of Thailand and Cambodia which can optimize cost, lead time, risk in multimodal transportation systems (Kengpol et al., 2012). This research proposes the development of a framework for route selection in multimodal transportation which includes a five phases framework to select an optimal multimodal transportation route. The first phase is to define areas of study and identify all the routes. The second phase is to study and collect the multimodal transportation route. The third phase is to integrate quantitative and qualitative decision making. The fourth phase is to prioritize criteria by using AHP. The final phase is to optimize the route by using the Zero-one goal programming.

1.1 Background

Thailand is a newly industrialized country. Its economy is heavily export-dependent, with exports accounting for more than two-thirds of its gross domestic product (GDP). In recent years, with the emergence of ASEAN Economic Cooperation (AEC) will become fully functional by 2015. It is the key turning point of Thai economy in all aspects trades on goods, services, investment flows, skilled labors and capitals.

The expectation from the University of Thai Chamber of Commerce found out that exports from Thailand to ASEAN countries in the year 2015 will increase 2.7 percent,
up to 2.29 hundred thousand million baht. This will cause Thai export to ASEAN countries to increase by 39.5 percent in 2015.

Cambodia is the top of the list, thanks to their recent spurt in GDP and consumption, which looks set to continue for many years to come (Table 1.1). The market offers massive opportunities for Thai companies, which already offer the kinds of industrial products and consumer goods these countries need. Cambodia is smaller but also very promising, with GDP growth ready to clock in at 7.3% this year. Manufacturers continue to build or expand factories there, supporting robust growth in exports of products like garments and footwear at least for the medium term. Rising FDI and continuing development aid will help sustain momentum.

Table 1.1 Economic forecast for Southeast Asian Countries:
GDP Growth 2016-2017 (World Bank, 2016)

<table>
<thead>
<tr>
<th>Country</th>
<th>2016</th>
<th>2017</th>
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<tr>
<td>Brunei Darussalam</td>
<td>1.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Cambodia</td>
<td>7.0</td>
<td>7.1</td>
</tr>
<tr>
<td>Indonesia</td>
<td>5.0</td>
<td>5.1</td>
</tr>
<tr>
<td>Lao People’s Dem. Rep.</td>
<td>6.8</td>
<td>7.0</td>
</tr>
<tr>
<td>Malaysia</td>
<td>4.1</td>
<td>4.4</td>
</tr>
<tr>
<td>Myanmar</td>
<td>8.4</td>
<td>8.3</td>
</tr>
<tr>
<td>Philippines</td>
<td>6.4</td>
<td>6.2</td>
</tr>
<tr>
<td>Singapore</td>
<td>1.8</td>
<td>2.0</td>
</tr>
<tr>
<td><strong>Thailand</strong></td>
<td><strong>3.2</strong></td>
<td><strong>3.5</strong></td>
</tr>
<tr>
<td>Viet Nam</td>
<td>6.0</td>
<td>6.3</td>
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<tr>
<td><strong>Average</strong></td>
<td><strong>4.5</strong></td>
<td><strong>4.6</strong></td>
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Phnom Penh's is Cambodia's economic center as it accounts for a large portion of the Cambodian economy. The main economy is based on commercial interests such as garments, trading, and small and medium enterprises. The Bureau of Urban Affairs of Phnom Penh Municipality has plans to expand and construct new infrastructure to
accommodate the growing population and economy. High rise buildings will be constructed at the entrance of the city and near the lakes and riverbanks. Furthermore, new roads, canals, and a railway system will be used to connect Camko City and Phnom Penh.

Figure 1.1 Cambodia map

Demand for Thai products from buyers in Cambodia in particular has been rising fast, in tandem with their booming economies. International investors are clamoring to set up operations within these countries in order to tap the local markets, but Thai companies have a next-door neighbor advantage. Thai products are already well known in these countries and considered high in quality.
Figure 1.2 Trade Share of commodity groups 2013 (World Trade Organization, 2016)

From Figure 1.2 manufactured goods make up almost all of Cambodia’s exports. In 2013, 94.3% of total exports were manufactured goods, while only 5.2% of exports were agricultural products and a negligible 0.1% of exports were fuels and mining products. Manufactures also make the largest import commodity group with 48% while fuels and mining products account for 9.8% and agricultural products 5.3%.

Thailand’s top exports to Cambodia in 2014 were fuel, electrical machinery and equipment, gold, vehicles, electrical appliances, sugar, beverages, cement, plastics and rubber. Year-on-year growth in Cambodia’s imports of Thai goods was an impressive 13%.

Especially, beverage is the top-five ranking of exporting product to Cambodia. Packaged food and beverage consumption per capita is growing in Cambodia as disposable income increases. According to ADB report, Cambodia is one of the fastest growing nations in the region increasing 6.8% growth in 2015 and sustaining this rate for 2016 while most packaged food and drinks are imported, an increasing number of food and drinks manufacturers have started production in the Kingdom.
1.2 Problem Statement

Thailand logistics quality is considered to be relatively low in the ASEAN-context, or when compared to developed countries. The logistics costs in Thailand are considered to be high, and are a concern of the Thai government and industries. The logistics cost in Thailand composes of 49% transport costs, 42% inventory costs and 9% administration costs. The high percentage (49%) from the transport costs results from the lack of multimodal transport options, large share of costly road transport, and the relatively large portion of low value goods in transport. Inefficient inventory management also contributes significantly to the high cost.

1.3 Project Objectives

- To develop a framework for route selection in multimodal
- To select an optimal multimodal transportation route
- To optimize multimodal transportation routes that can help firms reduce cost, lead time and risk in multimodal transportation systems

1.4 Scopes of Study

- This research is specified on the study of multimodal route on roads, train and ship excepting air transport mode because of the higher cost and energy use.
- This research studies on the case study between Thailand and Cambodia, originating from Bangkok in Thailand to the destination in Phnom Penh in Cambodia.
- The relative weight criteria of quantitative criteria decision and quantitative criteria decision which are assessed by the experts or Logistics service providers for each criterion.
- The freight of transport focuses on beverage products.
1.5 Steps of research process

- Defining areas of study and identifying all the routes. Gathering the database of shippers, logistics service provider and government officers.

- Studying the freight route in multimodal transportation originating from Bangkok in Thailand to the destination in Phnom Penh in Cambodia which are used in the real situation. These routes are composed of three transport modes, road, ship and train.

- Studying the relative researches in multimodal transportation and research dealing with decision making both quantitative and qualitative decision. Creating the cost, time, and weight of risk assessment in each route.

- Determining the significant weights of criteria for each situation by using the Analytics Hierarchy Process (AHP). The new conceptual framework for quantitative risk assessment (QRA) in multimodal transportation from the points of view of shippers, logistics service providers (LSPs) and government officer are proposed to combine into the model of this research.

- Optimizing multimodal transportation route with the Zero-one goal programming (ZOGP) methodology. The significant weight from AHP, parameters and limited data from entrepreneurs are used to formulate the objective function and constraints.

- Analyzing and conclusion

1.6 Benefits

The result of this research can guidance in selecting the lowest cost, time and risk with other criteria effectively. The benefit of this research is that user can choose the optimal multimodal transportation route and set the significant weight as needed.
Furthermore, the risk calculation that user can reduce bias of risk assessment on each multimodal transportation route.

1.7 Research Schedule

From Table 1.2
Table 1.2 Research Schedule

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<th>Task</th>
<th>Description</th>
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<td>and government officers. Studying general information of Cambodia country.</td>
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<td>2</td>
<td>Studying the freight route in multimodal transportation originating from</td>
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<td>modes, road, ship and train.</td>
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<td>Studying the relative researches in multimodal transportation and</td>
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<td>decision. Creating the cost, time, and weight of risk assessment for each</td>
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<td>Analyzing and conclusion</td>
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Chapter 2
Literature Review

In this chapter emphasized the past studies, journals, and articles from several reliable resources had to be researched. Then conduct a literature review as a group to find the best summarization for each different topic: multimodal transportation and route selection in multimodal transportation, Analytical Hierarchy (AHP), Zero – one goal programming model (ZOGP) and the other related researches.

2.1 Multimodal transportation and route selection in multimodal transportation

Multimodal transportation, as defined by the European Conference of Ministers of Transport, is the combination of two or more modes of transport to move passengers or goods from one source to a destination (Kengpol et al., 2012). The previous research study found that most of the selected multimodal transportation route for minimum cost and minimum time; however, there are few researches dealing with minimum risk (Min, 1991; Southworth and Peterson, 2000; Banomyong and Bresford, 2001; Ham et al., 2005; Chang, 2008; Kengpol et al., 2012; Meethom and Chimmanee, 2013). At the present, in the field of container multimodal transportation, research focused on slot allocation and pricing is scarce with most studies focused on network planning and path optimization (Chang, 2008; Chang et al., 2010; Fan et al., 2010; Van Riessen et al., 2013; Ziliaskopoulos and Wardell, 2000). Additionally, Banomyong and Beresford (2001) have considered a cost model of multimodal transportation. Moreover, Southworth and Peterson (2000) adapted Commodity flow survey on the selecting multimodal transportation in USA. Furthermore, several researchers have studied only risk on one single mode transport but have not studied risk on multimodal transportation in the research (Tsai and Su, 2004; Scenna and Cruz, 2005; Verma, 2011).
2.2 Risk Analysis

At the present, there are a lot of researches on transportation risk assessment because an accident may arise unexpectedly at any point along the way and transportation risks have a critical effect on the quality of transportation (Kengpol et al., 2012). The previous research study found that the transportation risk assessment has presented the risk analysis of dangerous goods (Scenna and Cruz, 2005; Verma, 2011; Reniers and Dullaert, 2013). Meethom and Chimmanee (2013) found that the selection in multimodal transportation route between Thailand and Northeast India. This research used the mathematical model for decision that uses quantitative and qualitative criteria. The decision model has five criteria that consist of: budget, time, and risk. The risk analysis is divided into two processes:

- Risk Identification
- Risk Assessment

The quantitative risk analysis process has emphasized the risk level of an activity by which people, environment or system might be in dangerous. In transportation risk assessment, quantitative risk can be calculated by the probability of accident occurrence by the accident consequence as indicated in Equation (Tsai and Su, 2004; Soons et al., 2006; Kengpol et al., 2012; Hallikas, et al., 2014)

\[ R = P \times C \]

Where R is risk level, P is the probability or frequency of accident occurrence, C is the consequences of the accident
Table 2.1 Level of the probability or frequency of accident occurrence (P)

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<thead>
<tr>
<th>Level</th>
<th>The probability or frequency of accident occurrence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Not definitely possible</td>
<td>The accident occurrence is not high possible.</td>
</tr>
<tr>
<td>2</td>
<td>Not quite possible</td>
<td>The accident occurrence is not quite possible.</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>The accident occurrence is moderate possible.</td>
</tr>
<tr>
<td>4</td>
<td>Might be Possible</td>
<td>The accident occurrence might be possible.</td>
</tr>
<tr>
<td>5</td>
<td>Definitely possible</td>
<td>The accident occurrence is definitely possible.</td>
</tr>
</tbody>
</table>


Table 2.2 Level of the consequences of the accident (C)

<table>
<thead>
<tr>
<th>Level</th>
<th>The consequences of the accident impact on logistics service provider</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Not impact at all</td>
<td>The consequences of the accident do not have impact at all.</td>
</tr>
<tr>
<td>2</td>
<td>Small impact</td>
<td>The consequences of the accident have a small impact.</td>
</tr>
<tr>
<td>3</td>
<td>Moderate impact</td>
<td>The consequences of the accident have a moderate impact.</td>
</tr>
<tr>
<td>4</td>
<td>High impact</td>
<td>The consequences of the accident have high impact.</td>
</tr>
<tr>
<td>5</td>
<td>Strong impact</td>
<td>The consequences of the accident have very high impact.</td>
</tr>
</tbody>
</table>

2.3 Analytic Hierarchy Process (AHP)

In the 1970s, Thomas L. Saaty developed the analytic hierarchy process (AHP) technique, which constructs a decision-making problem in various hierarchies as goal, criteria, sub-criteria, and decision alternatives. The theoretical background and mathematical concept of the AHP methodology have been expressed in several books and articles (Vargas, 1990; Saaty, 1990, 2001b; Saaty and Vargas, 2001; Sipahi and Timor, 2010). The AHP technique performs pairwise comparisons to measure the relative importance of elements at each level of the hierarchy and evaluates alternatives at the lowest level of the hierarchy in order to make the best decision among multiple alternatives (Sipahi and Timor, 2010).

Analytic Hierarchy Model (AHP) that has been applied to wide variety of filed such as conflict resolution, project selection, resource allocation, project risk assessment, transportation, healthcare and manufacturing (Liberatore, 1987; Khorramshahgoletal., 1988; Mustafa and Al-Bahar, 1991; Wu and Wu, 1998; Meade and Presley, 2002; Bhushan and Rai, 2004; Braunscheweig and Becker, 2004; Dalal et al., (2010) by assigning rational weights to a number of factors (that may have hierarchical relationships among them). Furthermore, the most popular application areas for integrated AHP were summarized. Liberatore and Nydick (2008) studied 50 AHP articles in medical and healthcare published since 1997. These articles were classified by “publication year”, “journal”, “healthcare category”, “method of analyzing alternatives”, “participants”, and “application type”.

To make a decision in an organized way to generate priorities and need to decompose the decision into the following steps:

- To develop a graphical representation of the problem in terms of the overall goal, the criteria, and the decision alternatives. (i.e., the hierarchy of the problem)

- To specify his/her judgments about the relative importance of each criterion in terms of its contribution to the achievement of the overall goal.
- To indicate a preference or priority for each decision alternative in terms of how it contributes to each criterion.

- Given the information on relative importance and preferences, a mathematical process is used to synthesize the information (including consistency checking) and provide a priority ranking of all alternatives in terms of their overall preference.

![AHP hierarchical structure model](image)

**Figure 2.1 AHP hierarchical structure model**

AHP divide the problem into criteria according to the nature and the goal of the problem. It breaks down the factors into target hierarchy, standards hierarchy and scheme hierarchy according to the relationship between factors. The standards hierarchy can be broken down further to form a hierarchical structure model (as shown in Figure 2.1) which can be analyzed quantitatively and qualitatively to obtain the weights of importance of the lowest hierarchy criteria against the highest hierarchy criteria. AHP finds the final synthesis weights through pairwise comparisons to get objective and accurate results. (Xi, X. and Qin, Q, 2013)
2.4 Zero-One Goal Programming (ZOGP)

Goal Programming was first introduced by Charnes and Cooper. It is a mathematical approach that assigns optimal values to set variables in situations involving multiple and conflicting goals. These goals are measured in incommensurable units, and a clear priority exists among these goals. This approach has been applied to many diverse problems such as project selection, course assignments, media planning and defense management. ZOGP model has been applied very frequently because it is simple to use and understand (Chen and Shyu, 2006). The literatures as in Ho (2008) are specifically brought to review, as they are a good source of ideas in integrating the AHP with ZOGP. Schniederjans and Garvin (1997) have also emphasized how AHP weighting can be combined in ZOGP model to include resource limitation in a cost driver selection process.
Chapter 3
Research Methodology

The research methodology will illustrate the process of data collection, analysis and conclusion. This research proposes the development of a framework of route selection in multimodal transportation which has been tested on a realistic multimodal transportation, originating from Bangkok in Thailand to a destination at Phnom Penh in Cambodia. It includes a five-step framework to select an optimal multimodal transportation route from Figure 3.1

**Step I: Define areas of study and identify all the routes**
Reviewing import and export information between Thailand and Cambodia. Gathering the data of shippers, logistics service provider and government officers.

**Step II: Studying and collecting the multimodal transportation route**
Studying the freight route in multimodal transportation originating from Bangkok in Thailand to the destination in Phnom Penh in Cambodia which are used in the real situation. These routes are composed of three transport modes, road, ship and train.

**Step III: Integrated quantitative and qualitative decision making**
Studying the relative researches in multimodal transportation and research dealing with decision making both quantitative and qualitative decision. Creating the cost, time, and weight of risk assessment in each route.
3.1 Define areas of study and identify all the routes

- Review import and export information between Thailand and Cambodia. Especially, the freight of transport focuses on beverage product.
- Gather the data of shippers, logistics service provider and government officers.
- Identify of all freight route between Bangkok, Thailand and Phnom Penh in Cambodia.
- This research is restricted on the study of multimodal planning among roads, train and ship transportations. However, it does not concern air transportation because of its higher cost and energy usage.
3.2 Studying and collecting the multimodal transportation route

Studying the freight route in multimodal transportation originating from Bangkok in Thailand to the destination in Phnom Penh in Cambodia which are used. These routes are composed of three transport modes, road, ship and train. These data can be collected from interview and brainstorming of expert and LSPs.

3.3 The multiple criteria decision making of freight route in multimodal transportation that uses quantitative and qualitative criteria.

The previous research study (Kengpol et al., 2012; Meethom and Chimmanee, 2013) used the mathematical model for decision that used quantitative and qualitative criteria. The decisions model has seven criteria that consist of: budget, time, risk of freight damaged, risk of infrastructure and equipment, operational risks, and risk of other factors.

- Quantitative decision criteria

Quantitative decision criteria in this research are cost and time. The selection of a transport mode or combination of transport mode has a direct impact on transportation cost and time (Kengpol et al., 2012). Finding and creating the cost and time in each realistic multimodal transportation route.

- Qualitative decision criteria

This phase is risk calculation process. There are two processes in this phase. The first process is risk identification. The second process is risk assessment. More detail can be seen as follows:

Process I: Risk Identification. The analysis of the nature of multimodal transportation risk. This research adopts the risk factors in previous researchers (Kengpol et al., 2012; Meethom and Chimmanee, 2013). The risk factor can be assessed in terms of following criteria:
(1) Risk of freight Damaged are defined as the situation of loss of products during transfer mode, damaged from transportation, damaged from delivery to customer, damaged from changing the transport mode.

(2) Risk of infrastructure and equipment are defined as slope and the width of roads, capacity of road, train or ship, risk of shipment in the rainy season, accident rate, traffic volume.

(3) Operational Risks are defined as lack of skilled workers, standardization of document, interpretation problems with document or contracts.

(4) Risk of other factors are defined as climate changes, financial crisis, appearance of route or building.

Process II: Risk Assessment is a quantitative risk analysis process. This is used to determine the risk level of an activity by which people, environment or system might be in hazard. In transportation risk assessment, quantitative risk can be calculated by the probability of accident occurrence by the accident consequence as indicated in Equation (Tsai and Su, 2004; Soons et al., 2006; Kengpol et al., 2012):

$$ R = P \times C $$

Where $R$ is risk level, $P$ is the probability or frequency of accident occurrence, $C$ is the consequences of the accident.

The failure modes or risk factors in multimodal transportation are obtained from previous research and information from the LSPs interview.

### 3.4 The decision making of freight route in multimodal transportation

The objective of this research is to select the freight route in multimodal transportation between Bangkok in Thailand and Phnom Penh in Cambodia which reduces cost, lead time and risk in multimodal transportation systems. The multiple criteria decision making of freight route in multimodal transportation that uses
quantitative and qualitative criteria. The quantitative decision criteria are cost and time and the qualitative decision criteria are the risk of freight damaged, risk of infrastructure and equipment, operational risks, political risks, and risk of other factors. The systems of decision making are divided into 3 parts:

- The database of decision making systems composes of possible freight route in multimodal transportation and database of multiple criteria decision making of freight route in multimodal transportation that uses quantitative and qualitative criteria
- The responses of decision makers are used to create the origins and destination, cost, time and risks. Moreover, the significant weights of each criterion for each transportation situation are derived from expert 3 groups:
  (1) A logistics Services Provider that serve logistics service between Thailand to Cambodia.
  (2) An expert who has experience between Thailand and Cambodia freight route.
  (3) A government officers who is working in Department of rural roads and has experience between Thailand and Cambodia route.

To begin with, the LSPs have to determine the weight of criteria. The AHP method is used to determine the weight of criteria and use Expert Choice software that is based on multi-criteria decision making. The corresponding consistency index for the paired comparison matrix is less than 0.1 (CI < 0.1) that the pairwise comparison matrix is considered to have an acceptable consistency (Kengpol et al., 2012).

After defining the relative weight criteria, the significant weight of each criterion is integrated in the objective function of ZOGP methodology (Kengpol et al., 2012).

- The final phase is the ZOGP methodology to optimize multimodal transportation route. The significant weight obtained via the AHP method in the previous is added into the objective function of ZOGP. The significant weight from AHP, parameters and limited data from previous phases are used to formulate the objective function and constraints.
The model of integrated AHP and ZOGP is presented as following (Kengpol et al., 2012; Meethom and Chimmanee, 2013)

\[
\text{Minimize } Z = \sum_{i=1}^{m} (w_i d_i^+ + w_i d_i^-)
\]

\[
= w_1(d_1^+) + w_2(d_2^+) + w_3(d_3^+) + \ldots + w_m(d_m^+)
\]

Subject to

\[
\begin{align*}
\text{Budget:} & \quad c_1x_1 + c_2x_2 + \ldots + c_nx_n - d_i^+ + d_i^- = C & (3-2) \\
\text{Time:} & \quad t_1x_1 + t_2x_2 + \ldots + t_nx_n - d_i^+ + d_i^- = T & (3-3) \\
\text{Risk of freight damaged:} & \quad f_1x_1 + f_2x_2 + \ldots + f_nx_n - d_i^+ + d_i^- = F & (3-4) \\
\text{Risk of infrastructure:} & \quad r_1x_1 + r_2x_2 + \ldots + r_nx_n - d_i^+ + d_i^- = R & (3-5) \\
\text{Operational Risks:} & \quad o_1x_1 + o_2x_2 + \ldots + o_nx_n - d_i^+ + d_i^- = O & (3-6) \\
\text{Risk of other factors:} & \quad l_1x_1 + l_2x_2 + \ldots + l_nx_n - d_i^+ + d_i^- = L & (3-7) \\
\end{align*}
\]

\[
x_1 + x_2 + \ldots + x_n = 1
\]

\[
w_i d_i \geq 0, \text{ for } I = 1, 2, \ldots, m
\]

\[
c_j, t_j, f_j, r_j, o_j, p_j, l_j \geq 0 \text{ or } j = 1, 2, \ldots, n
\]

\[
x_j = 0 \text{ or } 1 : j = 1, 2, \ldots, n
\]

The Equations (3-1)-(3-7) can be defined by the deviation variables, decision variables and parameters. The Equation (3-8) controls that only one route is optimum for one situation (Kengpol et al., 2012b)

By

**Deviation Variables**

\[d_i^+ = \text{The overachievement of goal } i\]
\( d_i \) = The underachievement of goal \( i \)

**Decision Variables**

\( x_j \) represents the Zero-one variables representing the non-selection (i.e. zero) or selection (i.e. one) of route \( j = 1, 2, 3, ..., n \), subject to criteria right hand side (budget, time and risk) (Kengpol et al., 2012b).

**Parameters**

\( w_i \) = Weight of decision criteria

\( c_j \) = The coefficient of \( x_j \) in budget constraint that is cost of each route in percentage of the under budget.

\( c_j = \left( \frac{\text{Budget limited by user} - \text{Cost of route } j}{\text{Budget limited by user}} \right) \times 100 \)

\( C \) = The right hand side of Equation (3-2) is percentage of budget limited by user that is presented below:

\( C = \frac{\text{Budget limited by user} - \text{Minimum cost of all route}}{\text{Budget limited by user}} \)

\( t_j \) = The coefficient of \( x_j \) in transport time constraint that is a percentage of transport time of each route which is limited by user:

\( t_j = \left( \frac{\text{Transport time limited by user} - \text{Transport time of route } j}{\text{Transport time limited by user}} \right) \times 100 \)

\( T \) = The right hand side of Equation (3-3) is percentage of transport time limited by user

\( T = 100 \% = 1 \)

\( f_j \) = The coefficient of \( x_j \) in risk of freight damaged constraints.
\[ f_j = \left( \text{Risk of freight damaged limited by user} - \text{Risk of freight damaged of route } j \right) \times 100 \]

\[ F = \text{The right hand side of risk of freight damaged constraints in Equation (3-4)} \]

\[ F = \left( \text{Risk of freight damaged limited by user} - \text{Minimum Risk of freight damaged of all route} \right) / \text{Risk of freight damaged limited by user} \]

\[ r_j = \text{The coefficient of } x_j \text{ in risk of infrastructure constraints:} \]

\[ r_j = \left( \text{Risk of infrastructure limited by user} - \text{Risk of infrastructure of route } j \right) \times \text{Risk of infrastructure limited by user} \times 100 \]

\[ R = \text{The right hand side of risk of infrastructure constraints in Equation (3-5)} \]

\[ R = \left( \text{Risk of infrastructure limited by user} - \text{Minimum risk of infrastructure of all route} \right) / \text{Risk of infrastructure limited by user} \]

\[ o_j = \text{The coefficient of } x_j \text{ in operational risks constraints:} \]

\[ o_j = \left( \text{Operational risks limited by user} / \text{Operational risks of route } j \right) \times \text{Operational risks limited by user} \times 100 \]

\[ O = \text{The right hand side of operational risks in Equation (3-6)} \]

\[ O = \left( \text{Operational risks limited by user} - \text{Minimum operational risks of all route} \right) / \text{Operational risks limited by user} \]

\[ l_j = \text{The coefficient of } x_j \text{ in risk of other factors constraints:} \]

\[ l_j = \left( \text{Risk of other factors limited by user} - \text{Risk of other factors of route } j \right) \times \text{Risk of other factors limited by user} \times 100 \]

\[ L = \text{The right hand side of Risk of other factors in Equation (3-8)} \]
\[ L = \frac{\text{Risk of other factors limited by user} - \text{Minimum risk of other factors of all route}}{\text{Risk of other factors limited by user}} \]
Chapter 4
Result

This section emphasized the new conceptual framework for route selection in multimodal transportation: a case study is conducted on realistic multimodal transportation route between Bangkok in Thailand and Phnom Penh in Cambodia.

4.1 The possible multimodal transportation routes which originate from Bangkok in Thailand to destination in Phnom Penh in Cambodia.

Studying the freight route in multimodal transportation originating from Bangkok in Thailand to the destination in Phnom Penh in Cambodia which are used. These routes are composed of three transport modes, road, ship and train. These data can be collected from interview and brainstorming of experts. There are 10 possible multimodal transportation routes have been illustrated in Table 4.1

Table 4.1 Database of 10 Possible Multimodal Transportation Routes

<table>
<thead>
<tr>
<th>Number of route</th>
<th>Route</th>
<th>Transportation Modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bangkok - Aranyaprathet - Banteaymeanchey - Battambang - Pursat - Kampong Chhnang - Phnom Penh</td>
<td>Truck</td>
</tr>
<tr>
<td>2</td>
<td>Bangkok - Aranyaprathet - Banteaymeanchey - Siem Reap - Kampong Thom - Kampong Cham - Phnom Penh</td>
<td>Truck</td>
</tr>
<tr>
<td>Number of route</td>
<td>Route</td>
<td>Transportation Modes</td>
</tr>
<tr>
<td>----------------</td>
<td>-------</td>
<td>----------------------</td>
</tr>
<tr>
<td>3</td>
<td>Bangkok - Trat - Koh Kong - Kampong Speu - Phnom Penh</td>
<td>Truck</td>
</tr>
<tr>
<td>4</td>
<td>Bangkok - Trat - Koh Kong - Sihanoukville - Phnom Penh</td>
<td>Truck</td>
</tr>
<tr>
<td>5</td>
<td>Bangkok - Ban Laem, Chanthaburi - Pailin - Battambang - Pursat - Kampong Chhnang - Phnom Penh</td>
<td>Truck</td>
</tr>
<tr>
<td>6</td>
<td>Bangkok - Ban Pak kad, Chanthaburi - Pailin - Battambang - Pursat - Kampong Chhnang - Phnom Penh</td>
<td>Truck</td>
</tr>
<tr>
<td>7</td>
<td>Bangkok - Aranyaprathet = Banteaymeancheay = Battambang = Pursat = Kampong Chhnang = Phnom Penh</td>
<td>Truck and Train</td>
</tr>
<tr>
<td>8</td>
<td>Bangkok - Ban Hat Lek Port, Trat # Sihanoukville Port - Phnom Penh</td>
<td>Truck and Ship</td>
</tr>
<tr>
<td>9</td>
<td>Bangkok - Laemchabang Port # Sihanoukville Port - Phnom Penh</td>
<td>Truck and Ship</td>
</tr>
<tr>
<td>10</td>
<td>Bangkok - Ban Hat Lek Port, Trat # Koh Kong Port - Phnom Penh</td>
<td>Truck and Ship</td>
</tr>
</tbody>
</table>

Notes: - is truck mode, = is train mode, # is ship mode
In these figures show the map of realistic multimodal transportation route between Bangkok in Thailand and Phnom Penh in Cambodia.

(1) Bangkok - Aranyaprathet - Banteaymeanchey - Battambang - Pursat - Kampong Chhnang - Phnom Penh (Highway No. 5). This route is truck transport mode departing from Bangkok to Phnom Penh and this is the most popular way to transport the freight.

Figure 4.1 Route 1 map of route between Bangkok and Phnom Penh

(2) Bangkok - Aranyaprathet - Banteaymeanchey - Siem Reap - Kampong Thom - Kampong Cham - Phnom Penh (Highway No. 5-6). This route is truck transport mode departing from Bangkok to Phnom Penh.

Figure 4.2 Route 2 Map of route between Bangkok and Phnom Penh
(3) Bangkok - Trat - Koh Kong - Kampong Speu - Phnom Penh. This route is truck transport mode departing from Bangkok to Phnom Penh (Highway No. 48-4). Koh Kong is linked to Phnom Penh and Sihanoukville by highway 48, which branches off National Highway 4 at Sre Ambel. The road is paved and complete with 5 bridges. However, Koh Kong is not suitable for heavy cargo because the route in Koh Kong province has many high mountains.

Figure 4.3 Route 3 Map of route between Bangkok and Phnom Penh

(4) Bangkok - Trat - Koh Kong - Sihanoukville - Phnom Penh. This route is truck transport mode departing from Bangkok to Phnom Penh (Highway No. 48-4).

Figure 4.4 Route 4 Map of route between Bangkok and Phnom Penh
(5) Bangkok - Ban Laem, Chanthaburi - Pailin - Battambang - Pursat - Kampong Chhnang - Phnom Penh. This route is truck transport mode departing from Bangkok to Phnom Penh.

Figure 4.5 Route 5 Map of route between Bangkok and Phnom Penh

(6) Bangkok - Ban Pak kad, Chanthaburi - Pailin - Battambang - Pursat - Kampong Chhnang - Phnom Penh. This route is truck transport mode departing from Bangkok to Phnom Penh.

Figure 4.6 Route 6 Map of route between Bangkok and Phnom Penh
(7) Bangkok - Aranyaprathet - Banteaymeanchey - Battambang - Pursat - Kampong Chhnang - Phnom Penh. This route is truck and train transport mode departing from Bangkok to Phnom Penh.

Figure 4.7 Route 7 Map of route between Bangkok and Phnom Penh

(8) Bangkok - Ban Hat Lek Port, Trat # Sihanoukville Port - Phnom Penh. This route is truck and ship transport mode departing from Bangkok to Phnom Penh.

Figure 4.8 Route 8 Map of route between Bangkok and Phnom Penh
(9) Bangkok - Laemchabang Port # Sihanoukville Port - Phnom Penh. This route is truck and ship transport mode departing from Bangkok to Phnom Penh.

Figure 4.9 Route 9 Map of route between Bangkok and Phnom Penh

(10) Bangkok - Ban Hat Lek Port, Trat # Koh Kong Port - Phnom Penh. This route is truck and ship transport mode departing from Bangkok to Phnom Penh.

Figure 4.10 Route 10 Map of route between Bangkok and Phnom Penh
4.2 The multiple criteria decision making of freight route in multimodal transportation that uses quantitative and qualitative criteria.

- Quantitative decision criteria

Quantitative decision criteria in this research are cost and time. The selection of a transport mode or combination of transport mode has a direct impact on transportation cost and time (Kengpol et al., 2012). Finding and creating the cost and time in each realistic multimodal transportation route. From the possible multimodal transportation route in the previous phase, the selection of transport mode has different impact on transportation cost and transportation time. Transportation cost and time for each possible multimodal transportation route is conducted on a realistic transportation cost and time which are derived from collecting through Logistics Service Providers. There have been illustrated in Table 4.2

Table 4.2 Database of Transportation Cost and Transportation Time

<table>
<thead>
<tr>
<th>Number of route</th>
<th>Route</th>
<th>Time (hrs.)</th>
<th>Cost (baht)</th>
<th>Distances (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bangkok - Aranyaprathet - Banteaymeanchey - Battambang - Pursat - Kampong Chhnang - Phnom Penh</td>
<td>15</td>
<td>70,200</td>
<td>670</td>
</tr>
<tr>
<td>2</td>
<td>Bangkok - Aranyaprathet - Banteaymeanchey - Siem Reap - Kampong Thom - Kampong Cham - Phnom Penh</td>
<td>16</td>
<td>71,047</td>
<td>690</td>
</tr>
<tr>
<td>3</td>
<td>Bangkok - Trat - Koh Kong - Kampong Speu - Phnom Penh</td>
<td>16</td>
<td>72,317</td>
<td>720</td>
</tr>
<tr>
<td>4</td>
<td>Bangkok - Trat - Koh Kong - Sihanoukville - Phnom Penh</td>
<td>16</td>
<td>76,552</td>
<td>820</td>
</tr>
<tr>
<td>5</td>
<td>Bangkok - Ban Laem, Chanthaburi - Pailin - Battambang - Pursat - Kampong Chhnang - Phnom Penh</td>
<td>15</td>
<td>79,432</td>
<td>888</td>
</tr>
<tr>
<td>6</td>
<td>Bangkok - Ban Pak kad, Chanthaburi - Pailin - Battambang - Pursat - Kampong Chhnang - Phnom Penh</td>
<td>12</td>
<td>72,105</td>
<td>715</td>
</tr>
<tr>
<td>7</td>
<td>Bangkok - Aranyaprathet - Banteaymeanchey - Battambang - Pursat - Kampong Chhnang - Phnom Penh</td>
<td>20</td>
<td>41,650</td>
<td>593</td>
</tr>
</tbody>
</table>
Ref. code: 25595822042171UCZ

33

<table>
<thead>
<tr>
<th>Number of route</th>
<th>Route</th>
<th>Time (hrs.)</th>
<th>Cost (baht)</th>
<th>Distances (km.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Bangkok - Ban Hat Lek Port, Trat # Sihanoukville Port - Phnom Penh</td>
<td>72</td>
<td>42,581</td>
<td>754</td>
</tr>
<tr>
<td>9</td>
<td>Bangkok - Laemchabang Port # Sihanoukville Port - Phnom Penh</td>
<td>72</td>
<td>46,481</td>
<td>712</td>
</tr>
<tr>
<td>10</td>
<td>Bangkok - Ban Hat Lek Port, Trat # Koh Kong Port - Phnom Penh</td>
<td>72</td>
<td>30,849</td>
<td>694</td>
</tr>
</tbody>
</table>

Notes: - is truck mode, = is train mode, # is ship mode

- Qualitative decision criteria

This phase is risk calculation process. There are two processes in this phase. The first process is risk identification. The second process is risk assessment. More detail can be seen as follows.

Process I: Risk Identification. The analysis of the nature of multimodal transportation risk. This research adopts the risk factors in previous researchers. The risk factor can be assessed in terms of following criteria:

1. Risk of Freight Damaged are defined as the situation of loss of products during transfer mode, damaged from transportation, damaged from delivery to customer, damaged from changing the transport mode.
2. Risk of infrastructure and equipment are defined as slope and the width of roads, capacity of road, train or ship, risk of shipment in the rainy season, accident rate, traffic volume.
3. Operational Risks are defined as lack of skilled workers, standardization of document, interpretation problems with document.
4. Risk of other factors are defined as climate changes, financial crisis, appearance of route or building.

Process II: Risk Assessment. It is a quantitative risk analysis process. This is used to determine the risk level of an activity by which people, environment or system might be in hazard. In transportation risk assessment, quantitative risk can be calculated by the probability of accident occurrence by the accident consequence as indicated in Equation:

\[ R = P \times C \]

Where R is risk level, P is the probability or frequency of accident occurrence, C is the consequences of the accident.
Table 4.3 Level of the probability or frequency of accident occurrence (P)

<table>
<thead>
<tr>
<th>Level</th>
<th>The probability or frequency of accident occurrence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Not definitely possible</td>
<td>The accident occurrence is not definitely possible</td>
</tr>
<tr>
<td>2</td>
<td>Not quite possible</td>
<td>The accident occurrence is not quite possible</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
<td>The accident occurrence is moderate possible</td>
</tr>
<tr>
<td>4</td>
<td>Might be Possible</td>
<td>The accident occurrence might be possible</td>
</tr>
<tr>
<td>5</td>
<td>Definitely possible</td>
<td>The accident occurrence is definitely possible</td>
</tr>
</tbody>
</table>


Table 4.4 Level of the consequences of the accident (C)

<table>
<thead>
<tr>
<th>Level</th>
<th>The consequences of the accident impact on logistics service provider</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No impact at all</td>
<td>The consequences of the accident are not impact at all</td>
</tr>
<tr>
<td>2</td>
<td>Not quite impact</td>
<td>The consequences of the accident are not quite impact</td>
</tr>
<tr>
<td>3</td>
<td>Moderate impact</td>
<td>The consequences of the accident are moderate impact</td>
</tr>
<tr>
<td>4</td>
<td>Might be impact</td>
<td>The consequences of the accident might be impact</td>
</tr>
<tr>
<td>5</td>
<td>Definitely impact</td>
<td>The consequences of the accident are definitely impact</td>
</tr>
</tbody>
</table>


The failure modes or risk factors in multimodal transportation are obtained from previous research and information from the LSPs interview. The result of risk assessment analysis of the multimodal transport route is shown in Table 4.4
### Table 4.5 The Result of Risk Assessment Analysis of The Multimodal Transport

<table>
<thead>
<tr>
<th>No. of route</th>
<th>Route</th>
<th>Time (hrs)</th>
<th>Budget (baht)</th>
<th>Risk of freight damaged</th>
<th>Risk of infrastructure and equipment</th>
<th>Operational Risk</th>
<th>Risk of other factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bangkok - Aranyaprathet - Banteaymeancheay - Battambang - Pursat - Kampong Chhnang - Phnom Penh</td>
<td>15</td>
<td>70,200</td>
<td>(2)(3) = 6</td>
<td>(2)(2) = 4</td>
<td>(2)(2) = 4</td>
<td>(2)(2) = 4</td>
</tr>
<tr>
<td>2</td>
<td>Bangkok - Aranyaprathet - Banteaymeancheay - Siem Reap - Kampong Thom - Kampong Cham - Phnom Penh</td>
<td>16</td>
<td>71,047</td>
<td>(2)(3) = 6</td>
<td>(2)(3) = 6</td>
<td>(2)(2) = 4</td>
<td>(2)(2) = 4</td>
</tr>
<tr>
<td>3</td>
<td>Bangkok - Trat - Koh Kong - Kampong Speu - Phnom Penh</td>
<td>16</td>
<td>72,317</td>
<td>(8)(2) = 16</td>
<td>(3)(3) = 9</td>
<td>(2)(3) = 6</td>
<td>(3)(3) = 9</td>
</tr>
<tr>
<td>4</td>
<td>Bangkok - Trat - Koh Kong - Sihanoukville - Phnom Penh</td>
<td>16</td>
<td>76,552</td>
<td>(4)(4) = 16</td>
<td>(5)(2) = 10</td>
<td>(2)(3) = 6</td>
<td>(3)(3) = 9</td>
</tr>
<tr>
<td>5</td>
<td>Bangkok - Ban Laem, Chanthaburi - Pailin - Battambang - Pursat - Kampong Chhnang - Phnom Penh</td>
<td>15</td>
<td>79,432</td>
<td>(2)(3) = 6</td>
<td>(3)(2) = 6</td>
<td>(3)(3) = 9</td>
<td>(2)(3) = 6</td>
</tr>
<tr>
<td>6</td>
<td>Bangkok - Ban Pak kad, Chanthaburi - Pailin - Battambang - Pursat - Kampong Chhnang - Phnom Penh</td>
<td>12</td>
<td>72,105</td>
<td>(2)(3) = 6</td>
<td>(3)(3) = 9</td>
<td>(3)(3) = 9</td>
<td>(3)(2) = 6</td>
</tr>
<tr>
<td>7</td>
<td>Bangkok - Aranyaprathet - Banteaymeancheay - Battambang - Pursat - Kampong Chhnang - Phnom Penh</td>
<td>20</td>
<td>41,650</td>
<td>(2)(2) = 4</td>
<td>(3)(3) = 9</td>
<td>(3)(2) = 6</td>
<td>(2)(2) = 4</td>
</tr>
<tr>
<td>8</td>
<td>Bangkok - Ban Hat Lek Port, Trat # Sihanoukville Port - Phnom Penh</td>
<td>72</td>
<td>42,581</td>
<td>(2)(1) = 2</td>
<td>(3)(3) = 9</td>
<td>(4)(4) = 16</td>
<td>(2)(2) = 4</td>
</tr>
<tr>
<td>9</td>
<td>Bangkok - Laemchabang Port # Sihanoukville Port - Phnom Penh</td>
<td>72</td>
<td>46,581</td>
<td>(2)(1) = 2</td>
<td>(3)(3) = 9</td>
<td>(4)(3) = 12</td>
<td>(3)(2) = 6</td>
</tr>
<tr>
<td>10</td>
<td>Bangkok - Ban Hat Lek Port, Trat # Koh Kong Port - Phnom Penh</td>
<td>72</td>
<td>30,849</td>
<td>(2)(1) = 2</td>
<td>(3)(3) = 9</td>
<td>(4)(4) = 16</td>
<td>(3)(2) = 6</td>
</tr>
</tbody>
</table>

### 4.3 Prioritized criteria by using AHP methodology

In this phase, the significant weights of each criterion for each transportation situation are derived from expert 3 groups:

- A logistics Services Provider that serve logistics service between Thailand to Cambodia.
- An expert who has experience between Thailand and Cambodia freight route.
- A government officers who is working in Department of rural roads and has experience between Thailand and Cambodia route.
They are asked to determine the significant weight of criteria for each transportation situation by using the AHP method. To begin with, the experts have to determine the weight of criteria. The AHP method is used to determine the weight of criteria and use Expert Choice software that is based on multi-criteria decision making. The corresponding consistency index for the paired comparison matrix is less than 0.1 ($CI < 0.1$) that the pairwise comparison matrix is considered to have an acceptable consistency. Therefore, there are six criteria which are integrated in the objective function of zero-one goal programming. The six criteria consist of transportation cost, transportation time, risk of freight damaged, risk of infrastructure, operational risk and other risks. The pairwise comparison matrix for six criteria provided by the experts are as follow these tables.

Table 4.6 The pairwise comparison matrix provided by the government officers.

<table>
<thead>
<tr>
<th></th>
<th>Budget</th>
<th>Time</th>
<th>Risk of freight damaged</th>
<th>Risk of infrastructure</th>
<th>Operational Risk</th>
<th>Other Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Time</td>
<td>0.5</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Risk of freight damaged</td>
<td>0.33</td>
<td>0.25</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Risk of infrastructure</td>
<td>0.25</td>
<td>0.33</td>
<td>0.33</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Operational Risk</td>
<td>0.20</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Other Risks</td>
<td>0.33</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4.7 The relative weight criteria from AHP provided by the government officer

<table>
<thead>
<tr>
<th></th>
<th>Budget</th>
<th>Time</th>
<th>Risk of freight damaged</th>
<th>Risk of infrastructure</th>
<th>Operational Risk</th>
<th>Other Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weights</td>
<td>0.355382</td>
<td>0.246886</td>
<td>0.143148</td>
<td>0.0971519</td>
<td>0.0840125</td>
<td>0.0735198</td>
</tr>
</tbody>
</table>

The relative weight criteria from AHP provided by the government officer are of transportation cost 0.355, transportation time 0.247, risk of freight damaged 0.143, risk of infrastructure 0.097, operational risk 0.084 and other risks 0.074.
Table 4.8 The pairwise comparison matrix provided by the beverage company I.

<table>
<thead>
<tr>
<th></th>
<th>Budget</th>
<th>Time</th>
<th>Risk of freight damaged</th>
<th>Risk of infrastructure</th>
<th>Operational Risk</th>
<th>Other Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget</td>
<td>1</td>
<td>7</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Time</td>
<td>0.14</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Risk of freight damaged</td>
<td>0.13</td>
<td>0.67</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Risk of infrastructure</td>
<td>0.13</td>
<td>0.33</td>
<td>0.50</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Operational Risk</td>
<td>0.13</td>
<td>0.25</td>
<td>0.33</td>
<td>0.50</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Other Risks</td>
<td>0.13</td>
<td>0.33</td>
<td>0.33</td>
<td>0.33</td>
<td>0.5</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4.9 The relative weight criteria from AHP provided by the beverage company I.

<table>
<thead>
<tr>
<th></th>
<th>Budget</th>
<th>Time</th>
<th>Risk of freight damaged</th>
<th>Risk of infrastructure</th>
<th>Operational Risk</th>
<th>Other Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weights (Eigen Vector)</td>
<td>0.583268</td>
<td>0.163711</td>
<td>0.096705</td>
<td>0.0708194</td>
<td>0.047406</td>
<td>0.0380898</td>
</tr>
</tbody>
</table>

The relative weight criteria from AHP provided by the beverage company I are of transportation cost 0.583, transportation time 0.164, risk of freight damaged 0.097, risk of infrastructure 0.071, operational risk 0.047 and other risks 0.038.

Table 4.10 The pairwise comparison matrix provided by the beverage company II.

<table>
<thead>
<tr>
<th></th>
<th>Budget</th>
<th>Time</th>
<th>Risk of freight damaged</th>
<th>Risk of infrastructure</th>
<th>Operational Risk</th>
<th>Other Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget</td>
<td>1</td>
<td>7</td>
<td>9</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Time</td>
<td>0.14</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Risk of freight damaged</td>
<td>0.11</td>
<td>0.5</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Risk of infrastructure</td>
<td>0.13</td>
<td>0.33</td>
<td>0.50</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Operational Risk</td>
<td>0.14</td>
<td>0.33</td>
<td>0.33</td>
<td>0.50</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Other Risks</td>
<td>0.13</td>
<td>0.33</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 4.11 The relative weight criteria from AHP provided by the beverage company II.

<table>
<thead>
<tr>
<th></th>
<th>Budget</th>
<th>Time</th>
<th>Risk of freight damaged</th>
<th>Risk of infrastructure</th>
<th>Operational Risk</th>
<th>Other Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weights</td>
<td>0.591831</td>
<td>0.145125</td>
<td>0.0977293</td>
<td>0.0683087</td>
<td>0.053583</td>
<td>0.043421</td>
</tr>
<tr>
<td>(Eigen Vector)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The relative weight criteria from AHP provided by the beverage company II are of transportation cost 0.591, transportation time 0.145, risk of freight damaged 0.098, risk of infrastructure 0.068, operational risk 0.054 and other risks 0.043.

Table 4.12 The pairwise comparison matrix provided by the beverage company III.

<table>
<thead>
<tr>
<th></th>
<th>Budget</th>
<th>Time</th>
<th>Risk of freight damaged</th>
<th>Risk of infrastructure</th>
<th>Operational Risk</th>
<th>Other Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget</td>
<td>1</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Time</td>
<td>0.2</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Risk of freight damaged</td>
<td>0.17</td>
<td>0.50</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Risk of infrastructure</td>
<td>0.17</td>
<td>0.50</td>
<td>0.33</td>
<td>1</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Operational Risk</td>
<td>0.13</td>
<td>0.50</td>
<td>0.33</td>
<td>0.25</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Other Risks</td>
<td>0.13</td>
<td>0.50</td>
<td>0.33</td>
<td>0.33</td>
<td>0.50</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4.13 The relative weight criteria from AHP provided by the beverage company III.

<table>
<thead>
<tr>
<th></th>
<th>Budget</th>
<th>Time</th>
<th>Risk of freight damaged</th>
<th>Risk of infrastructure</th>
<th>Operational Risk</th>
<th>Other Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weights</td>
<td>0.526428</td>
<td>0.140309</td>
<td>0.136185</td>
<td>0.0997523</td>
<td>0.053453</td>
<td>0.043872</td>
</tr>
<tr>
<td>(Eigen Vector)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The relative weight criteria from AHP provided by the beverage company III are of transportation cost 0.526, transportation time 0.140, risk of freight damaged 0.136, risk of infrastructure 0.099, operational risk 0.053 and other risks 0.044.
Table 4.14 The pairwise comparison matrix provided by the beverage company IV.

<table>
<thead>
<tr>
<th></th>
<th>Budget</th>
<th>Time</th>
<th>Risk of freight damaged</th>
<th>Risk of infrastructure</th>
<th>Operational Risk</th>
<th>Other Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget</td>
<td>1</td>
<td>9</td>
<td>8</td>
<td>8</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Time</td>
<td>0.11</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Risk of freight damaged</td>
<td>0.13</td>
<td>0.33</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Risk of infrastructure</td>
<td>0.13</td>
<td>0.33</td>
<td>0.50</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Operational Risk</td>
<td>0.14</td>
<td>0.25</td>
<td>0.33</td>
<td>0.50</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Other Risks</td>
<td>0.15</td>
<td>0.25</td>
<td>0.50</td>
<td>0.50</td>
<td>0.5</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4.15 The relative weight criteria from AHP provided by the beverage company IV.

<table>
<thead>
<tr>
<th></th>
<th>Budget</th>
<th>Time</th>
<th>Risk of freight damaged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weights (Eigen Vector)</td>
<td>0.602021</td>
<td>0.159169</td>
<td>0.0875749</td>
</tr>
<tr>
<td>Risk of freight damaged</td>
<td>0.0635087</td>
<td>0.0484705</td>
<td>0.039255</td>
</tr>
</tbody>
</table>

The relative weight criteria from AHP provided by the beverage company IV are of transportation cost 0.602, transportation time 0.159, risk of freight damaged 0.088, risk of infrastructure 0.064, operational risk 0.048 and other risks 0.039.

Table 4.16 The pairwise comparison matrix provided by the Logistics Service Provider I.

<table>
<thead>
<tr>
<th></th>
<th>Budget</th>
<th>Time</th>
<th>Risk of freight damaged</th>
<th>Risk of infrastructure</th>
<th>Operational Risk</th>
<th>Other Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget</td>
<td>1</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Time</td>
<td>0.13</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Risk of freight damaged</td>
<td>0.13</td>
<td>0.25</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Risk of infrastructure</td>
<td>0.13</td>
<td>0.33</td>
<td>0.33</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Operational Risk</td>
<td>0.11</td>
<td>0.33</td>
<td>0.50</td>
<td>0.5</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Other Risks</td>
<td>0.11</td>
<td>0.33</td>
<td>0.50</td>
<td>0.5</td>
<td>0.5</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 4.17 The relative weight criteria from AHP provided by the Logistics Service Provider I.

<table>
<thead>
<tr>
<th></th>
<th>Budget</th>
<th>Time</th>
<th>Risk of freight damaged</th>
<th>Risk of infrastructure</th>
<th>Operational Risk</th>
<th>Other Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weights (Eigen Vector)</td>
<td>0.599926</td>
<td>0.160608</td>
<td>0.0876008</td>
<td>0.0616481</td>
<td>0.0501317</td>
<td>0.0400857</td>
</tr>
</tbody>
</table>

The relative weight criteria from AHP provided by the Logistics Service Provider I are of transportation cost 0.599, transportation time 0.161, risk of freight damaged 0.088, risk of infrastructure 0.062, operational risk 0.050 and other risks 0.040.

Table 4.18 The pairwise comparison matrix provided by the Logistics Service Provider II.

<table>
<thead>
<tr>
<th></th>
<th>Budget</th>
<th>Time</th>
<th>Risk of freight damaged</th>
<th>Risk of infrastructure</th>
<th>Operational Risk</th>
<th>Other Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget</td>
<td>1</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>Time</td>
<td>0.13</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Risk of freight damaged</td>
<td>0.13</td>
<td>0.33</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Risk of infrastructure</td>
<td>0.11</td>
<td>0.33</td>
<td>0.33</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Operational Risk</td>
<td>0.11</td>
<td>0.33</td>
<td>0.50</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Other Risks</td>
<td>0.14</td>
<td>0.33</td>
<td>0.50</td>
<td>0.50</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4.19 The relative weight criteria from AHP provided by the Logistics Service Provider II.

<table>
<thead>
<tr>
<th></th>
<th>Budget</th>
<th>Time</th>
<th>Risk of freight damaged</th>
<th>Risk of infrastructure</th>
<th>Operational Risk</th>
<th>Other Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weights (Eigen Vector)</td>
<td>0.603532</td>
<td>0.151498</td>
<td>0.0913122</td>
<td>0.0551648</td>
<td>0.0499097</td>
<td>0.0485831</td>
</tr>
</tbody>
</table>
The relative weight criteria from AHP provided by the Logistics Service Provider II are of transportation cost 0.604, transportation time 0.151, risk of freight damaged 0.091, risk of infrastructure 0.055, operational risk 0.050 and other risks 0.049.

After defining and showing the decision matrix of assessment result for the six criteria, which are assessed by the experts. The optimal pairwise comparison matrix from the seven experts are shown in table.

Table 4.20 the pairwise comparison matrix for the six criteria provided by 7 experts

<table>
<thead>
<tr>
<th></th>
<th>Budget</th>
<th>Time</th>
<th>Risk of Freight Damaged</th>
<th>Risk of Infrastructure</th>
<th>Operational Risk</th>
<th>Other Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget</td>
<td>1</td>
<td>6</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Time</td>
<td>0.17</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Risk of freight damaged</td>
<td>0.14</td>
<td>0.33</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Risk of infrastructure</td>
<td>0.14</td>
<td>0.33</td>
<td>0.33</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Operational Risk</td>
<td>0.14</td>
<td>0.33</td>
<td>0.33</td>
<td>0.50</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Other Risks</td>
<td>0.14</td>
<td>0.33</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4.21 The relative weight criteria from AHP provided by 7 experts

<table>
<thead>
<tr>
<th></th>
<th>Budget</th>
<th>Time</th>
<th>Risk of Freight Damaged</th>
<th>Risk of Infrastructure</th>
<th>Operational Risk</th>
<th>Other Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weights (Eigen Vector)</td>
<td>0.549</td>
<td>0.171</td>
<td>0.110</td>
<td>0.069</td>
<td>0.055</td>
<td>0.046</td>
</tr>
</tbody>
</table>

Maximum Eigen Value = 6.44549

CI = 0.0890976

The relative weight criteria from AHP are of transportation cost 0.549, transportation time 0.171, risk of freight damaged 0.110, risk of infrastructure 0.069, operational risk 0.055 and risk of other factors 0.046 and the maximum eigenvalue $\lambda_{\text{max}}$ is 6.445. The consistency index for the above paired comparison matrix (CI) is 0.089 and the corresponding (CR) is 0.002.
Because the corresponding consistency is less than 0.1 (CR < 0.1), the pairwise comparison matrix is considered to have an acceptable consistency. The result shown in table 4.22.

Table 4.22 The Relative Weight Criteria From AHP

<table>
<thead>
<tr>
<th>Expert</th>
<th>Budget</th>
<th>Time</th>
<th>Risk of freight damaged</th>
<th>Risk of infrastructure and equipment</th>
<th>Operational Risk</th>
<th>Risk of other factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government Officer</td>
<td>0.355</td>
<td>0.247</td>
<td>0.143</td>
<td>0.097</td>
<td>0.084</td>
<td>0.074</td>
</tr>
<tr>
<td>Beverage Company 1</td>
<td>0.583</td>
<td>0.164</td>
<td>0.097</td>
<td>0.071</td>
<td>0.047</td>
<td>0.038</td>
</tr>
<tr>
<td>Beverage Company 2</td>
<td>0.592</td>
<td>0.145</td>
<td>0.098</td>
<td>0.068</td>
<td>0.054</td>
<td>0.043</td>
</tr>
<tr>
<td>Beverage Company 3</td>
<td>0.526</td>
<td>0.140</td>
<td>0.136</td>
<td>0.100</td>
<td>0.053</td>
<td>0.044</td>
</tr>
<tr>
<td>Beverage Company 4</td>
<td>0.602</td>
<td>0.159</td>
<td>0.088</td>
<td>0.064</td>
<td>0.048</td>
<td>0.039</td>
</tr>
<tr>
<td>Logistics Service Provider 1</td>
<td>0.600</td>
<td>0.161</td>
<td>0.088</td>
<td>0.062</td>
<td>0.050</td>
<td>0.040</td>
</tr>
<tr>
<td>Logistics Service Provider 2</td>
<td>0.604</td>
<td>0.151</td>
<td>0.091</td>
<td>0.055</td>
<td>0.050</td>
<td>0.049</td>
</tr>
<tr>
<td>Weight (Eigen Vector)</td>
<td>0.549</td>
<td>0.171</td>
<td>0.110</td>
<td>0.069</td>
<td>0.055</td>
<td>0.046</td>
</tr>
</tbody>
</table>

4.4 Optimization by using ZOGP methodology

The final phase is the ZOGP methodology to optimize multimodal transportation route. The significant weight obtained via the AHP method in the previous is added into the objective function of ZOGP. The significant weight from AHP, parameters and limited data from previous phases are used to formulate the objective function and constraints.

In this case study, the limitations of criteria are set as the constraints and the relative weight criteria from AHP method as transportation cost 0.55, transportation time 0.17, risk of freight damaged 0.11, risk of infrastructure and equipment 0.07, operational risk 0.05 and other risks 0.05 with CR not over 0.1 to find the optimal route. Because all the data in each objective function of this research has a different unit, all units are converted into percentage. The coefficient of $x_j$ in each constraint that is criteria of each route in percentage of the under criteria is presented.
\( c_j \) = The coefficient of \( x_j \) in budget constraint that is cost of each route in percentage of the under budget.

\[ c_j = \left( \frac{\text{Budget limited by user} - \text{Cost of route j}}{\text{Budget limited by user}} \right) \times 100 \]

\( t_j \) = The coefficient of \( x_j \) in transport time constraint that is a percentage of transport time of each route which is limited by user:

\[ t_j = \left( \frac{\text{Transport time limited by user} - \text{Transport time of route j}}{\text{Transport time limited by user}} \right) \times 100 \]

\( f_j \) = The coefficient of \( x_j \) in risk of freight damaged constraints:

\[ f_j = \left( \frac{\text{Risk of freight damaged limited by user} - \text{Risk of freight damaged of route j}}{\text{Risk of freight damaged limited by user}} \right) \times 100 \]

\( r_j \) = The coefficient of \( x_j \) in risk of infrastructure constraints:

\[ r_j = \left( \frac{\text{Risk of infrastructure limited by user} - \text{Risk of infrastructure of route j}}{\text{Risk of infrastructure limited by user}} \right) \times 100 \]

\( o_j \) = The coefficient of \( x_j \) in operational risks constraints:

\[ o_j = \left( \frac{\text{Operational risks limited by user} - \text{Operational risks of route j}}{\text{Operational risks limited by user}} \right) \times 100 \]

\( l_j \) = The coefficient of \( x_j \) in risk of other factors constraints:

\[ l_j = \left( \frac{\text{Risk of other factors limited by user} - \text{Risk of other factors of route j}}{\text{Risk of other factors limited by user}} \right) \times 100 \]
Table 4.23 The coefficient of $x_j$ in each constraint that is criteria of each route

<table>
<thead>
<tr>
<th>Route</th>
<th>The coefficient of $x_j$ in each constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$c_j$</td>
</tr>
<tr>
<td>1) Bangkok - Aranyaprathet - Banteaymeanchey - Battambang - Pursat - Kampong Chhnang - Phnom Penh</td>
<td>-8.00</td>
</tr>
<tr>
<td>2) Bangkok - Aranyaprathet - Banteaymeanchey - Siem Reap - Kampong Thom - Kampong Cham - Phnom Penh</td>
<td>-18.41</td>
</tr>
<tr>
<td>3) Bangkok - Trat - Koh Kong - Kampong Speu - Phnom Penh</td>
<td>-3.31</td>
</tr>
<tr>
<td>4) Bangkok - Trat - Koh Kong - Sihanoukville - Phnom Penh</td>
<td>-9.36</td>
</tr>
<tr>
<td>5) Bangkok - Ban Laem, Chanthaburi - Pailin - Battambang - Pursat - Kampong Chhnang - Phnom Penh</td>
<td>0.71</td>
</tr>
<tr>
<td>6) Bangkok - Ban Pak kad, Chanthaburi - Pailin - Battambang - Pursat - Kampong Chhnang - Phnom Penh</td>
<td>9.87</td>
</tr>
<tr>
<td>7) Bangkok - Aranyaprathet = Banteaymeanchey = Battambang = Pursat = Kampong Chhnang = Phnom Penh</td>
<td>16.69</td>
</tr>
<tr>
<td>8) Bangkok - Ban Hat Lek Port, Trat # Sihanoukville Port - Phnom Penh</td>
<td>14.84</td>
</tr>
<tr>
<td>Route</td>
<td>The coefficient of $x_j$ in each constraint</td>
</tr>
<tr>
<td>-------</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>$c_j$</td>
</tr>
<tr>
<td>9) Bangkok - Laemchabang Port #</td>
<td>7.04</td>
</tr>
<tr>
<td>Sihanoukville Port - Phnom Penh</td>
<td>38.30</td>
</tr>
</tbody>
</table>

The model of integrated AHP and ZOGP is presented as follows:

$$\text{Minimize } Z = \sum_{i=1}^{m} (w_i d_i^- + w_i d_i^+)$$

$$= 0.55(d_i^-) + 0.17(d_i^-) + 0.11(d_i^-) + 0.07(d_i^-) + 0.05(d_i^-) + 0.05(d_i^-)$$

Subject to

**Budget**

-8.00$x_1$-18.41$x_2$-3.31$x_3$-9.36$x_4$+0.71$x_5$+9.87$x_6$+16.69$x_7$+14.84$x_8$

$+7.04x_9+38.30x_{10}-d_i^- + d_i$ = 0.38

**Time**

-25.00$x_1$-33.33$x_2$-33.33$x_3$-33.33$x_4$-36.36$x_5$+20.00$x_6$+(0)$x_7$+50.00$x_8$

$-50.00x_9-50.00x_{10}-d_i^- + d_i$ = 1

**Risk of freight damaged**

-50.00$x_1$-50.00$x_2$-33.33$x_3$-33.33$x_4$+(0)$x_5$+(0)$x_6$+(0)$x_7$

+(0)$x_8$+(0)$x_9$-50.00$x_{10}$- $d_i^- + d_i$ = 0.67

**Risk of infrastructure**

-100$x_1$-50.00$x_2$-50.00$x_3$+(0)$x_4$+50.00$x_5$-50.00$x_6$+(0)$x_7$

-50.00$x_8$-50.00$x_9$+(0)$x_{10}$- $d_i^- + d_i$ = 0.78

**Operational Risks**

(0)$x_1$-100.00$x_2$-200.00$x_3$+(0)$x_4$-50.00$x_5$-50.00$x_6$+(0)$x_7$

-33.33$x_8$-33.33$x_9$-33.33$x_{10}$- $d_i^- + d_i$ = 1.00

**Risk of other factors**

(0)$x_1$+(0)$x_2$-50.00$x_3$-50.00$x_4$+(0)$x_5$+(0)$x_6$+(0)$x_7$+33.33$x_8$

+(0)$x_9$-50.00$x_{10}$- $d_i^- + d_i$ = 0.33

45
\[ x_1 + x_2 + \ldots + x_n = I \]

\[ w_i d_i \geq 0, \text{ for } I = 1,2,\ldots,m \]

\[ c_j, t_j, f_j, r_j, o_j, l_j \geq 0 \text{ or } j = 1,2,\ldots,n \]

\[ x_j \text{ or } l : j = 1,2,\ldots,n \]

By

Deviation Variables

\( \text{di}^+ \) = The overachievement of goal \( i \)

\( \text{di}^- \) = The underachievement of goal \( i \)

Decision Variables

\( x_j \) represents the Zero-one variables representing the non-selection (i.e. zero) or selection (i.e. one) of route \( j \) = 1, 2, 3, ..., \( n \), subject to criteria right hand side (budget, time and risk) (Kengpol et al., 2012b).

Parameters

\( w_i \) = Weight of decision criteria

\( c_j \) = The coefficient of \( x_j \) in budget constraint that is cost of each route in percentage of the under budget.

\[ c_j = \left( \frac{\text{Budget limited by user} - \text{Cost of route } j}{\text{Budget limited by user}} \right) \times 100 \]

for example multimodal transportation route 1;

\[ c_1 = \left( \frac{65,000-70,200}{65,000} \right) \times 100 = -8.00 \]

\( C \) = The right hand side of Equation is percentage of budget limited by user that is presented below:

\[ C = \left( \frac{\text{Budget limited by user} - \text{Minimum cost of all route}}{\text{Budget limited by user}} \right) \]

for example multimodal transportation route 1;

\[ C = \left( \frac{80,000-50,000}{80,000} \right) = 0.38 \]

46
$t_j$ = The coefficient of $x_j$ in transport time constraint that is a percentage of transport time of each route which is limited by user.

$t_j = \frac{(\text{Transport time limited by user} - \text{Transport time of route } j)}{\text{Transport time limited by user}} \times 100$

for example multimodal transportation route 1;

$t_1 = \frac{(12 - 15)}{12} \times 100 = -25$

$T$ = The right hand side of Equation is percentage of transport time limited by user

$T = 100 \% - 1$

for example multimodal transportation route 1;

$T = (48-48) = 1$

$f_j$ = The coefficient of $x_j$ in risk of freight damaged constraints:

$f_j = \frac{(\text{Risk of freight damaged limited by user} - \text{Risk of freight damaged of route } j)}{\text{Risk of freight damaged limited by user}} \times 100$

for example multimodal transportation route 1;

$f_1 = \frac{(4 - 6)}{4} \times 100 = -50$

$F$ = The right hand side of risk of freight damaged constraints in Equation (3.4)

$F = \frac{(\text{Risk of freight damaged limited by user} - \text{Minimum Risk of freight damaged of all route})}{\text{Risk of freight damaged limited by user}}$

for example multimodal transportation route 1;

$F = \frac{(6 - 2)}{6} = 0.67$

$r_j$ = The coefficient of $x_j$ in risk of infrastructure constraints:

$r_j = \frac{(\text{Risk of infrastructure limited by user} - \text{Risk of infrastructure of route } j)}{\text{Risk of infrastructure limited by user}} \times 100$

for example multimodal transportation route 1;

$r_1 = \frac{(2.4 - 2)}{2} \times 100 = -100$

$R$ = The right hand side of risk of infrastructure constraints in Equation (3.5)

$R = \frac{(\text{Risk of infrastructure limited by user} - \text{Minimum risk of infrastructure of all route})}{\text{Risk of infrastructure limited by user}}$
for example multimodal transportation route 1; R = (9-2)/9 = 0.78

\[ o_j = \frac{[\text{Operational risks limited by user} - \text{Operational risks of route } j \times \text{Operational risks limited by user}]}{\times 100} \]

for example multimodal transportation route 1; \( o_1 = \frac{(4-4)}{1} \times 100 = 0 \)

\( O = \text{The right hand side of Operational Risks in Equation (1)} \)

\( O = \frac{\text{Operational Risk limited by user} - \text{Minimum operational risk of all route}}{\text{operational risk limited by user}} \)

for example multimodal transportation route 1; \( O = \frac{6-6}{6} = 1.00 \)

\[ l_j = \frac{[\text{Risk of other factors limited by user} - \text{Risk of other factors of route } j \times \text{Risk of other factors limited by user}]}{\times 100} \]

for example multimodal transportation route 1; \( l_1 = \frac{(4-4)}{4} \times 100 = 0 \)

\( L = \text{The right hand side of Risk of other factors in Equation (3.8)} \)

\( L = \frac{\text{Risk of other factors limited by user} - \text{Minimum risk of other factors of all route}}{\text{Risk of other factors limited by user}} \)

for example multimodal transportation route 1; \( L = \frac{6-4}{6} = 0.33 \)

This mathematic model of integrated AHP and ZOGP is solved on a spreadsheet software. The result found that the optimal route is truck transport mode departing from Bangkok to Phnom Penh (Route1). Transportation cost is equal to 70,200 Baht for 15-hour period of transportation, risk of freight damaged is equal to 6, risk of infrastructure and equipment is equal to 4, operational risk is equal to 4 and risk of other factors is equal to 4. The ZOGP program is shown in figure 4.11.
Figure 4.11 The result of the optimal route in ZOGP program
Chapter 5
Conclusions and Recommendations

5.1 Conclusion

The objective of this research is to formulate a mathematical model to optimize a multimodal transportation route which can reduce cost, lead time and transportation risk in multimodal transportation system effectively. In order to achieve that, this new conceptual framework for route selection in multimodal transportation consists of five phases. In this research, the risk calculation begins with the LSPs analysing Then, the quantitative risk analysis and risk picture diagram are used to assess the risk level and define a set of assessment grades in linguistic terms. Next, this proposed methodology applies the AHP to determine the weights of the criteria and assessment grades. After that, the AHP method is used again to prioritize criteria. The significant weight of criteria obtained from AHP can be integrated in the objective function of ZOGP. Finally, the zero-one goal programming is used to generate the optimal route.

For the first step, finding 10 possible multimodal transportation routes between Bangkok and Phnom Penh
1. Bangkok - Aranyaprathep - Banteaymeanchey - Battambang - Pursat - Kampong Chhnang - Phnom Penh
2. Bangkok - Aranyaprathep - Banteaymeanchey - Siem Reap - Kampong Thom - Kampong Cham - Phnom Penh
3. Bangkok - Trat - Koh Kong - Kampong Speu - Phnom Penh
4. Bangkok - Trat - Koh Kong - Sihanoukville - Phnom Penh
5. Bangkok - Ban Laem, Chanthaburi - Pailin - Battambang - Pursat - Kampong Chhnang - Phnom Penh
6. Bangkok - Ban Pak kad, Chanthaburi - Pailin - Battambang - Pursat - Kampong Chhnang - Phnom Penh
This phase is risk calculation process. There are two processes in this phase. The first process is risk identification. The second process is risk assessment. More detail can be seen as follows:

**Process I: Risk Identification.** The analysis of the nature of multimodal transportation risk. This research adopts the risk factors in previous researchers. The risk factor can be assessed in terms of following criteria:

1. **Risk of Freight Damaged** are defined as the situation of loss of products during transfer mode, damaged from transportation, damaged from delivery to customer, damaged from changing the transport mode.
2. **Risk of infrastructure and equipment** are defined as slope and the width of roads, capacity of road, train or ship, risk of shipment in the rainy season, accident rate, traffic volume.
3. **Operational Risks** are defined as lack of skilled workers, standardization of document, interpretation problems with document.
4. **Risk of other factors** are defined as climate changes, financial crisis, appearance of route or building.

**Process II: Risk Assessment.** It is a quantitative risk analysis process. This is used to determine the risk level of an activity by which people, environment or system might be in hazard. In transportation risk assessment, quantitative risk can be calculated by the probability of accident occurrence by the accident consequence as indicated in Equation:
\[ R = P \times C \]

Where \( R \) is risk level, \( P \) is the probability or frequency of accident occurrence, \( C \) is the consequences of the accident.

- the decision making of freight route in multimodal transportation

The selection of multimodal route between Bangkok and Phnom Penh are divided into 3 parts:

The databases of decision making system are possible multimodal transportation route and quantitative decision criteria are transportation cost and transportation time and qualitative decision criteria are risk assessment in each multimodal transportation routes.

The significant weights of each criterion for each transportation situation is obtained by conducting AHP methodology The LSPs are asked to determine the significant weight of criteria who are derived from expert 3 groups:

1. A logistics Services Provider that serve logistics service between Thailand to Cambodia.
2. An expert who has experience between Thailand and Cambodia freight route.
3. A government officers who is working in Department of rural roads and has experience between Thailand and Cambodia route.

After that, the relative weight criteria from AHP are of transportation cost 0.549, transportation time 0.171, risk of freight damaged 0.110, risk of infrastructure 0.069, operational risk 0.055 and risk of other factors 0.046.

The final phase is the ZOGP methodology to optimize multimodal transportation route. The significant weight obtained via the AHP method in the previous is added into the objective function of ZOGP. The significant weight from AHP, parameters and limited data from previous phases are used to formulate the objective function and constraints.

The result found that the optimal route is truck transport mode departing from Bangkok to Phnom Penh (Route1). Transportation cost is equal to 70,200 Baht for 15-
hour period of transportation, risk of freight damaged is equal to 6, risk of infrastructure and equipment is equal to 4, operational risk is equal to 4 and risk of other factors is equal to 4.

5.2 Recommendation and limitations

The decision making of freight route in multimodal transportation, the quantitative risk analysis process has emphasized the risk level of an activity by which people, environment or system might be in dangerous. In transportation risk assessment, quantitative risk can be calculated from experts that evaluation of the opinions and feelings of the experts is the main factor. This is subjective assessment. It depends on the experience of each evaluator and should be standardized. Moreover, the limitations of this research are characteristic of beverage product that are focused on plastic bottle drinking water only. The weight of beverage product is approximately 20 tons.

Using ZOGP methodology to optimize multimodal transportation route, the result might not meet requirement because ZOGP in the Linear Programming maximum or minimum objective function is set for only one quantity to manage on its optimum value.

For further study, this research plans to develop a new algorithm to solve the multimodal transportation problem when the problem has a larger scale of alternatives.
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Articles


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Appendices
Appendix A
แบบสัมภาษณ์การประเมินความเสี่ยงของเส้นทาง

เรียน ท่านผู้บริหาร

เนื่องจากงานวิจัยเรื่องการเลือกเส้นทางการขนส่งสินค้าระหว่างประเทศไทยกับประเทศกัมพูชา มีวัตถุประสงค์เพื่อเลือกเส้นทางขนส่งสินค้าประเภทเครื่องดื่มที่เหมาะสมที่สุดระหว่างประเทศไทยกับประเทศกัมพูชาจากการศึกษาข้อมูลจากงานวิจัยที่ผ่านมาพบว่าเส้นทางการขนส่งสินค้าประเภทเครื่องดื่มมีอยู่หลายเส้นทาง โดยแต่ละเส้นทางมีความเสี่ยงที่แตกต่างกัน จึงขอความอนุเคราะห์จากท่านผู้บริหารช่วยประเมินความเสี่ยงของแต่ละเส้นทางเพื่อใช้เป็นข้อมูลในการวิจัย การประเมินความเสี่ยงนั้นผู้วิจัยจะใช้ทฤษฎีของ Hallikas, et al.(2004) ซึ่งในการประเมินจะอาศัยการให้คะแนน 2 ส่วน คือ
1. ระดับคะแนนความน่าจะเป็นในการเกิดความเสี่ยง (P)
2. ระดับคะแนนความรุนแรงของผลกระทบจากความเสี่ยง (C)

ความเสี่ยงที่จะประเมินมีด้วยกัน 3 ประเภท คือ
1. ความเสี่ยงด้านอุปกรณ์ หมายถึง ความเสียหายหรือสูญหายที่เกิดขึ้นกับตัวสินค้า เป็นต้น
2. ความเสี่ยงของโครงสร้างพื้นฐานและอุปกรณ์อันเป็นความสะดวกในการขนส่ง หมายถึง ความเสี่ยงของเส้นทาง ความกว้างของถนน ลู่มินค์ สะพาน อัตราการเกิดอุบัติเหตุ ปริมาณการจราจร เป็นต้น
3. ความเสี่ยงด้านปฏิบัติการ หมายถึง หน้าที่ที่เกี่ยวกับสัญญาหรือติดต่อธุรกิจการส่งออก มาตรฐานการจัดการควบคุมอาวุธที่เกี่ยวกับการส่งออกหรือเอกสารผ่านแดน กฎหมายระเบียบที่เกี่ยวกับด้านต่างๆ เป็นต้น
4. ความเสี่ยงอื่นๆ หมายถึง ภูมิอากาศที่แปรปรวน ปัญหาที่เกิดขึ้นที่ติดต่อธุรกิจการเงิน เป็นต้น

ผู้วิจัยขอรับรองว่าข้อมูลของท่านจะนำไปใช้เพื่อประโยชน์ในการวิจัยเท่านั้น ไม่นำไปใช้ทางอื่น ขอแสดงความนับถือ
ขวัญจิรา แก้วแฝก

ขอแสดงความนับถือ
ขวัญจิรา แก้วแฝก
การพิจารณาประเมินความเสี่ยงต่าง ๆ ของเส้นทางขนส่งสินค้าระหว่างประเทศไทยกับประเทศกัมพูชา

การพิจารณาประเมินความเสี่ยงต่าง ๆ ของเส้นทางขนส่งสินค้าระหว่างประเทศไทยกับประเทศกัมพูชา

ค่าชี้แจง ให้คิดตามข้อเสนอแนะของท่าน หากท่านจะพิจารณาประเมินความเสี่ยงต่าง ๆ ของเส้นทางขนส่งสินค้าทั้งหมด ท่าน
ต้องทำการพิจารณาทุกเส้นทางขนส่งสินค้าทั้งหมดด้วย มีระดับคะแนนความเสี่ยงจะเป็นที่จะเกิดความเสี่ยงและความรุนแรงของ
ผลกระทบจากความเสี่ยงอยู่ในระดับใด โดยใส่หมายเลข 1 ถึง 5 ลงในช่อง P และ C ที่ท่านเห็นสมควรของความ
เสี่ยงทั้ง 3 ชนิด เกณฑ์การประเมินมีดังต่อไปนี้

ตารางการประเมินระดับคะแนนความเสี่ยง (P)

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<th>ระดับ</th>
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<td>3</td>
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<td>4</td>
<td>มีความเป็นไปได</td>
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<td>มีความเป็นไปไดเป็นอย่างมาก</td>
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ตารางการประเมินระดับคะแนนความรุนแรงของผลกระทบจากความเสี่ยง (C)

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ตารางการประเมินระดับคะแนนความรุนแรงของผลกระทบจากความเสี่ยง

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Appendix B

แบบสัมภาษณ์การให้น้ำหนักความสำคัญของเกณฑ์การตัดสินใจเลือกเส้นทางการขนส่งสินค้า

เรียน ท่านผู้บริหาร

เนื่องจากงานวิจัยเรื่องการเลือกเส้นทางการขนส่งสินค้าระหว่างประเทศไทยกับประเทศกัมพูชา มีวัตถุประสงค์เพื่อเลือกเส้นทางการขนส่งสินค้าที่เหมาะสมที่สุด โดยการเลือกเส้นทางนั้นจะใช้เกณฑ์การตัดสินใจ 6 เกณฑ์ ได้แก่ 1) งบประมาณ 2) เวลา 3) ความเสี่ยงด้านการขนสินค้า 4) ความเสี่ยงของโครงสร้างพื้นฐานและอุปกรณ์ อ่านอย่างสะดวกในเส้นทาง 5) ความเสี่ยงด้านการปฏิบัติการ และ 6) ความเสี่ยงด้านอื่นๆ จึงขอความอนุเคราะห์จากท่านผู้บริหารประเมินความสำคัญของเกณฑ์การตัดสินใจแต่ละเกณฑ์ ที่มีผลต่อการเลือกเส้นทางการขนส่งสินค้าในความคิดเห็นของท่าน เพื่อให้เป็นข้อมูลในการทำวิจัยของนักศึกษา ขอแสดงความนับถือ

ขวัญจิรา แก้วแฝก

ขอแสดงความนับถือ
ขวัญจิรา แก้วแฝก
### เกณฑ์เปรียบเทียบความสำคัญ

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<th>ระดับคะแนน</th>
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### เกณฑ์การตัดสินใจ

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Appendix C
A zero-one goal programming approach for route selection

• OPL 12.6.0.0 Model
• Author: Kwan
• Creation Date: 11 เม.ย. 2560 at 14:15:34

{int} index_j = {1, 2, 3, 4, 5, 6, 7, 8, 9, 10};
{int} index_i = {1, 2, 3, 4, 5, 6};

float c[index_j] = ...;
float t[index_j] = ...;
float f[index_j] = ...;
float r[index_j] = ...;
float o[index_j] = ...;
float l[index_j] = ...;
float w[index_i] = ...;
float C = ...;
float T = ...;
float F = ...;
float R = ...;
float O = ...;
float L = ...

dvar float dplus[index_i];
dvar float dminus[index_i];
dvar boolean x[index_j];

minimize
sum_i in index_i)
  w[i]*dplus[i] + w[i]*dminus[i];

subject to{
  sum_j in index_j) x[j] = 1;
SheetConnection sheet("Cambodia Route.xlsx");

c from SheetRead(sheet, "Input!B2:K2");
t from SheetRead(sheet, "Input!B3:K3");
f from SheetRead(sheet, "Input!B4:K4");
r from SheetRead(sheet, "Input!B5:K5");
o from SheetRead(sheet, "Input!B6:K6");
l from SheetRead(sheet, "Input!B7:K7");
w from SheetRead(sheet, "Input!B10:G10");

C from SheetRead(sheet, "Input!B12");
T from SheetRead(sheet, "Input!B13");
F from SheetRead(sheet, "Input!B14");
R from SheetRead(sheet, "Input!B15");
O from SheetRead(sheet, "Input!B16");
L from SheetRead(sheet, "Input!B17");