CONCEPTUAL IDEA OF HAZARDOUS MATERIALS TRASPORTATION ROUTING BY CONSIDERING RISK INDEX AS A COSTS COMPONENT

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Abstract

There are many problems existing in the Thailand's logistics supply chain for hazardous materials movement, especially for highway mode logistics. Moreover, these problems are rather complicated in legal aspects, especially for transportation route selection and permission. This research means to propose the concept of using road incident risk index to be used as a component in selecting an appropriate route for hazardous material logistics. The model of route assignment is applied based on the utility functions which are composed of several criterions and parameters. Some information using in the analysis of this model are collected from field experts, but the route selection model has calculated with data in the factitious situation.

1. Introduction

In developing country as Thailand, the improvement of the ability to compete in the world market has essentially focused. Upgrading industrial sectors is now concerned as the most important part of the improvement. The needs of Hazardous Materials (HazMat) using in manufacturing have highly grown up and brought the increment in the amount of HazMat import and transportation volume. As the HazMat traffic volume is increasing, the chances of HazMat transportation incident, especially for road, are increasing, as well.

Road incidents or accidents involved in HazMat cause wide range of properties damage, injuries, and fatalities. Apart from the instantaneous lost after event, effect of HazMat may harm either people or environments in long-term. Preparation and policies to handle the occurrences of incidents and HazMat-related activities on the public road must be carefully located.

2. Literature Review

Recently, Hamedi et al. [1] had developed a method to minimize the weighted cost, and to avoid risk accumulation by routing HazMat carriers and scheduling their departure times, while several possible intermediate stops are made on the path from the origin to the destination. A mathematical model is developed to integrate routing and scheduling, so that the travel cost and the potential risk on links and nodes can be balanced while keeping the maximum level of risk exposed to the network below a given threshold. A shortest path based solution approach is embedded in the heuristic to solve the routing problem in a time dependent network. The results show that the heuristic can provide good quality solutions for larger network and fleet size.

Huang and Fery [2] tried to build a framework for determining the optimal routes of hazardous material transportation. A simple characterization of the efficient routes is used to select the best ones with no need for any input from the decision-maker. A case study with 8 objective functions has been carried out on a road network in Singapore. A geographical information system (GIS) is used to quantify road link attributes, which are assumed linear and deterministic for the sake of simplicity. The proposed algorithm derives four significantly different routes, which conform to intuition.

In [1], incident risk are only considered objective. Conversely, the concerns raised in [2] advocate a multiplication of objectives for the HAZMAT routing problem. A selected route should also minimize the transportation costs as well as the expected value of estimated risk including population exposure, environmental and property risk, and so forth. This approach requires to locate the multiple objectives of the problem and process the trade-offs between several conflicting objectives.

3. Basic Concept of Model Development

This study purposes to develop a model of routing of HazMat by using *existing models* with *a new created index*. To generate the risk level index is the first step of the modeling. To generate the risk level of HazMat incidents for any routes, there are various connected parameters should be prioritized carefully. Analytical Hierarchy Process (AHP) is chosen in this study, due to the limited number of samples in some groups. This is because AHP have been known as a good technique to deal with small sample size. Next, we should consider which model to be selected for an analysis. Due to the unknown sample distribution type, primarily, any models can be selected without consideration of inconsistency.

In this study, several models are selected for comparing the result of the validation of this index with route choice models. Each model will be used to approve its validity and consistency of the new index to be added to the route choice model.. The assessment of appropriateness for each model with adding of the new risk index will be the next step to be considered.

There are three types of models to be selected in this study; for example, Logit model, Probit model, and Shortest Path model. For Logit and Probit models, this index will be considered as a new parameter in the utility function with its own coefficient. For Shortest Path technique, the new index will be converted to be in the same norm of time or cost; thus, it can be directly added to time or cost value.

In order to develop the model based on theses three techniques, three concepts must be added as the basic assumptions.

- Saturated volume or capacity restraint will not be considered in this model because the small increment in HazMat traffic volume might not significantly affect the overall traffic.
- Transport route will be suggested to the service providers, but will not be used as a law or regulation. Therefore, the consideration of their utility will be made.
- Risk of incident occurrence with a severe consequence, such as HazMat incident is considered as a parameter in service providers' decision.

Figure 1 shows a general concept of making the new route assignment model in this study.

4. Development of Framework and Mathematical Model

There are two main steps to develop the mathematical model for assigning the routes of HazMat movement. First step is to create the function of transporters' utility for choosing a route. Utility in this case means the function of human's criterions to make a decision for selection. Decision makers will select choice with highest utility. In section the next means to determine weight of each parameter for calculating the utility.. Second, models are used to assign the appropriate route to be chosen based on the utility of decision maker and/or impedance of route.

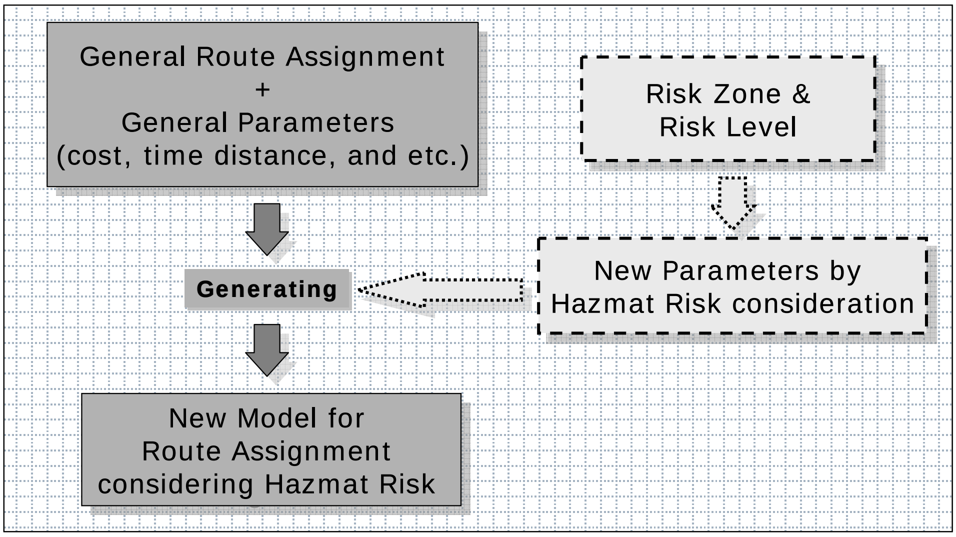

Figure 1 Chart shows Basic Concept for Developing Route Assignment Model

- Utility Function and Determination of Parameters' Weight

As mentioned, this section aims to find the weight of each parameter using in the utility function in both Risk Zoning (Phase I) and a Part of Route Assignment (Phase II). Therefore, the basic concept of utility will be discussed. The utility function is composed of two components: the systematic, and the disturbances. The systematic in this case means the observable attributes which are deterministic parts, and the disturbances are the errors from many sources such as imperfect information, measurement error, and the omission of important mode. The assumption of logit model is that all disturbances are independently and identically distributed (IID), and Gumbel-distributed. According to Ben-Akiva and Lerman (2000), the utility of an alternative is defined as the following basic equations.

$$U_{in} = V_{in} + \varepsilon_{in} \quad (1)$$
$$V_{in} = \beta_k X_{ink} \quad (2)$$

Where: U_{it} is the utility of alternative i from the perspective of the decision-maker n; V_{in} is the deterministic or observable portion of the utility (systematic component); ε_{in} is the error terms (disturbance component); β_k is the vector of parameters of attribute k; and X_{ink} is the vector of attribute k of individual n choosing alternative i.

The systematic component consists of parameters of each attribute and alternative attributes of decision-makers. The attributes used in this component can be obtained from the questionnaire.

- Risk Assessment by Analytical Hierarchy Process (AHP)

In order to assess to the level of importance for each parameter, unless available sample size is to less standardized questionnaire can also be considered. In this study, AHP is selected because of small number of samples available in some groups such as the group of experts and government officers. There are control indicators (CR, Consistency Ratio; CI, Consistency Index; RI, Random Index) to be calculated in AHP method, to recheck the suitability of the result.

AHP relative measurement method, widely known as the Evaluation and Choice model, is used to calculate the priorities by comparing the importance of each alternative against each other. Interviewee, who answers the questionnaire, has to enter his/her judgments about the relative importance of the criteria and alternatives in the completed pair wise comparison questionnaire. This means that the larger the numbers of alternatives or criteria, the greater the numbers of pair wise comparisons are provided for decision-makers to answer.

Figure 2 presents the example of Attribute Questionnaire.

$$Number\ of\ PairWise\ Comparison = {}_nC_2 = \frac{n(n-1)}{2} \quad (3)$$

Where n is the number of criteria or alternatives.

Left-hand side is more important										Right-hand side is more important
Alternative 1	5	4	3	2	1	2	3	4	5	Alternative 2
Alternative 1	5	4	3	2	1	2	3	4	5	Alternative 3
Alternative 1	5	4	3	2	1	2	3	4	5	Alternative 4
Alternative 1	5	4	3	2	1	2	3	4	5	Alternative 5
Alternative 2	5	4	3	2	1	2	3	4	5	Alternative 3
Alternative 2	5	4	3	2	1	2	3	4	5	Alternative 4
Alternative 2	5	4	3	2	1	2	3	4	5	Alternative 5
Alternative 3	5	4	3	2	1	2	3	4	5	Alternative 4
Alternative 3	5	4	3	2	1	2	3	4	5	Alternative 5
Alternative 4	5	4	3	2	1	2	3	4	5	Alternative 5

Figure 2 Example of AHP Attribute Questionnaire

- Multinomial Logit Route Assignment Model

The probability of individual *n* choosing alternative *i* from the set of alternatives C_n can be obtained by the below equation (Ben-Akiva and Lerman, 2000).

$$P_n(i) = \frac{e^{V_{in}}}{\sum_{j \in C_n} e^{V_{jn}}} \quad (4)$$

The parameters of the utility function can be calibrated by the maximum likelihood method (Ben-Akiva and Lerman, 2000). Parameters are obtained by solving the given equation, as shown below, by using Newton-Raphson Method.

$$\frac{\partial L}{\partial \beta_k} = \sum_{n=1}^{N} \sum_{i \in C_n} \left[y_{in} - P_n(i) \right] X_{ink} = 0 \quad (5)$$

$$\frac{\partial^2 L}{\partial \beta_k \partial \beta_l} = -\sum_{n=1}^{N} \sum_{i \in C_n} P_n(i) \left[X_{ink} - \sum_{j \in C_n} X_{jnk} P_n(j) \right] \cdot \left[X_{inl} - \sum_{j \in C_n} X_{jnl} P_n(j) \right] \quad (6)$$

Where: y_{in} of 1, if observation *n* choose alternative *i*, and 0, otherwise; and $P_n(i)$ is the probability of individual *n* choose alternative *i*.

5. Zone Risk Index

In order to make a risk assessment for each zone affected by transportation of HazMat, there are many criteria have to be taken into account. In this study, there are four criterion picked up as a pilot data. Description of each criterion and its level is used to indicate the risk index or level of each zone, and is summarized as shown in Table 1.

Table 1 Description of Criteria and its Level using in Zone Risk Assessment

Criteria	*Level*	*Description*
Landuse	High	CBD, Commercial Zone, Residential Zone, Urban Area
	Medium	Suburban Area, National Park
	Low	Agricultural Zone, Paddy field, Forrest
Population Density	High	> 1000 Households per 10 sq km
	Medium	> 100 and ≤ 1000 Households per 10 sq km
	Low	≤ 100 Households per 10 sq km
Number of Heritages in Zone	High	> 3 points per 10 sq km
	Medium	> 1 and ≤ 3 points per 10 sq km
	Low	No heritage
Number of Critical Area	High	> places per 3 sq km
	Medium	> 1 and ≤ 3 places per 10 sq km
	Low	No critical place

The interview is separately made for two main purposes, (1) to prioritize the weight of each criterion, and (2) to rank the level of each criteria. Risk indexes for both zone risk and route risk are calculated in Equation 7, and its result is presented in Table 2 and 3.

$$\text{Risk Index} = \Sigma\,(\text{Weight of Criterion}_i \times \text{Priority of Level}_i) \quad (7)$$

In this case, the weight of each criterion is produced and follows the value of priority generated by AHP technique. There are three levels of criteria estimated for four criterion analyzed in this case. Hence, 3^4 numbers of combinatorial level can be used for computing 3^4 numbers of risk indexes.

Table 2 Weight of Zone Criteria

Weight Priority of each Criteria				*Level of Inconsistency*
Landuse	Pop den	Heritige	Critic	
0.086	**0.491**	**0.248**	**0.174**	**0.04**

Table 3 Zone Risk Index of each level

Zone Class by Characters: *(Landuse / Pop den / Heritage / Critic)*	*Criteria*				*Zone Risk Index*
	Landuse	*Pop den*	*Heritige*	*Critic*	
High / High / High / High	**0.540**	**0.674**	**0.571**	**0.443**	**1.00**
High / High / High / Low	**0.540**	**0.674**	**0.571**	**0.169**	**0.92**
High / High / Low / Low	**0.540**	**0.674**	**0.143**	**0.169**	**0.74**
High / High / High / Med	**0.540**	**0.674**	**0.571**	**0.387**	**0.98**
High / High / Med / Med	**0.540**	**0.674**	**0.286**	**0.387**	**0.87**
Low / Low / Low / Low	**0.163**	**0.100**	**0.143**	**0.169**	**0.21**
Low / Low / Low / High	**0.163**	**0.100**	**0.143**	**0.443**	**0.29**
Low / Low / High / High	**0.163**	**0.100**	**0.571**	**0.443**	**0.47**
Low / Low / Low / Med	**0.163**	**0.100**	**0.143**	**0.387**	**0.28**
Low / Low / Med / Med	**0.163**	**0.100**	**0.286**	**0.387**	**0.34**
Med / Med / Med / Med	**0.297**	**0.226**	**0.286**	**0.387**	**0.46**
Med / Med / Med / High	**0.297**	**0.226**	**0.286**	**0.443**	**0.48**
Med / Med / High / High	**0.297**	**0.226**	**0.571**	**0.443**	**0.60**
Med / Med / Med / Low	**0.297**	**0.226**	**0.286**	**0.169**	**0.40**
Med / Med / Low / Low	**0.297**	**0.226**	**0.143**	**0.169**	**0.34**
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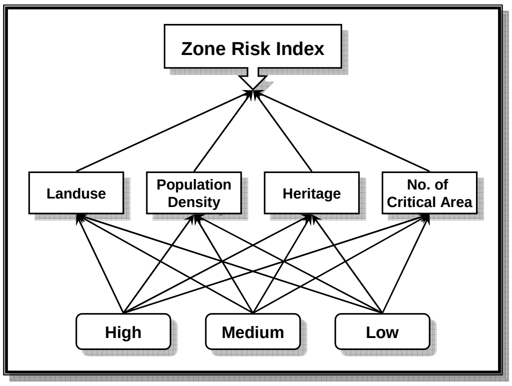

Figure 3 The Bottom-Up Hierarchical Structuring Strategy for Zone Risk

6. Route Risk Index

In evaluating the risk index of route, the same method is used. The results of AHP are presented in Table 5 and 6, based on the details described in Table 4. Figure 2 illustrates the structure of AHP strategy using in generating the risk index.

Table 4 Description of Criteria and its Level using in Route Risk Assessment

Criteria	*Level*	*Decription*
Volume / Capacity Ratio	High	> 0.8
	Medium	> 0.4 and ≤ 0.8
	Low	≤ 0.4
Number of Lane (each direction)	High	1 lanes
	Medium	2 lanes
	Low	> 2 lanes
Lane Width	High	≤ 3.0 m
	Medium	> 3.0 and ≤ 0.8 m
	Low	> 3.5 m
Availability of Frontage Road	High	No
	Medium	Yes / only 1 lane
	Low	Yes / more than 1 lane
Number of Access Points (per 1 km)	High	> 10 points
	Medium	> 3 and ≤ 10 points
	Low	< 3 points
Roadside Environment (identified by Zone Risk Index)	High	Zone Risk Index > 0.6
	Medium	> 0.4 Zone Risk Index ≤ 0.6
	Low	Zone Risk Index ≤ 0.4

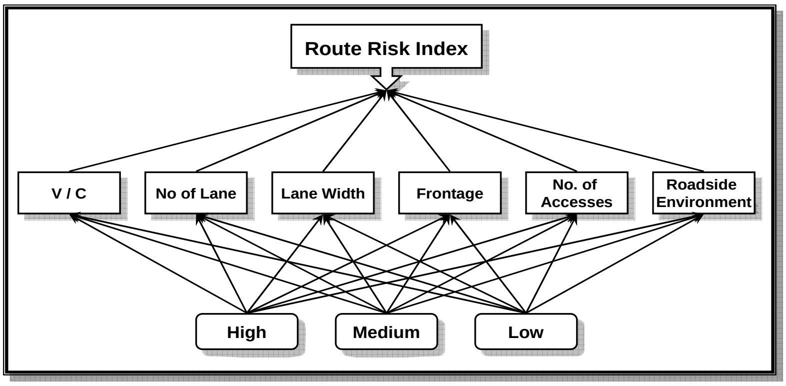

Figure 4 The Bottom-Up Hierarchical Structuring Strategy for Route Risk

Table 5 Weight of Route Criteria

Weight Priority of each Criteria						*Level of Inconsistency*
V/C	No of Lane	Lane Width	Frontage	No of Access	Zone Risk	
0.230	**0.110**	**0.071**	**0.159**	**0.184**	**0.246**	**0.06**

Table 6 Route Risk Index of each level

Route Class by Characters: *(V/C / No of Lane / Lane Width / Frontage / No of Access / Zone)*	*Criteria*						*Route Risk Index*
	V/C	*No of Lane*	*Lane Width*	*Frontage*	*No of Access*	*Zone Risk*	
High / High / High / High / High / High	**0.413**	**0.493**	**0.500**	**0.594**	**0.625**	**0.571**	**1.00**
High / High / High / Low / High / High	**0.413**	**0.493**	**0.500**	**0.157**	**0.625**	**0.571**	**0.87**
High / High / Low / Low / Med / Med	**0.413**	**0.493**	**0.250**	**0.157**	**0.238**	**0.286**	**0.57**
High / High / High / Med / Med / Med	**0.413**	**0.493**	**0.500**	**0.249**	**0.238**	**0.286**	**0.63**
High / High / Med / Med / Low / Low	**0.413**	**0.493**	**0.250**	**0.249**	**0.136**	**0.143**	**0.50**
Low / Low / Low / Low / High / High	**0.260**	**0.196**	**0.250**	**0.157**	**0.625**	**0.571**	**0.71**
Low / Low / Low / High / High / High	**0.260**	**0.196**	**0.250**	**0.594**	**0.625**	**0.571**	**0.84**
Low / Low / High / High / Med / Med	**0.260**	**0.196**	**0.500**	**0.594**	**0.238**	**0.286**	**0.61**
Low / Low / Low / Med / Med / Med	**0.260**	**0.196**	**0.250**	**0.249**	**0.238**	**0.286**	**0.47**
Low / Low / Med / Med / Low / Low	**0.260**	**0.196**	**0.250**	**0.249**	**0.136**	**0.143**	**0.37**
Med / Med / Med / Med / High / High	**0.327**	**0.311**	**0.250**	**0.249**	**0.625**	**0.571**	**0.79**
Med / Med / Med / High / High / High	**0.327**	**0.311**	**0.250**	**0.594**	**0.136**	**0.571**	**0.72**
Med / Med / High / High / Med / Med	**0.327**	**0.311**	**0.500**	**0.594**	**0.238**	**0.286**	**0.66**
Med / Med / Med / Low / Med / Med	**0.327**	**0.311**	**0.250**	**0.157**	**0.238**	**0.286**	**0.50**
Med / Med / Low / Low / Low / Low	**0.327**	**0.311**	**0.250**	**0.157**	**0.136**	**0.143**	**0.40**
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For route risk index, there are six criteria included considering with three levels of each, therefore 3^6 were computed and presented in Table 6

7. Analysis of Factitious Situation

In analysis of route selection, the risk index will be taken into consideration, and added with other conservative parameters as discussed in the last section. For demonstrating the method, a simple factitious situation of selecting a route for moving HazMat form the distribution point to the retailer was assumed. Figure 5 and Table 7 described detail information of the assumed case study.

Table 7 Route Character of the Assumed Case

Route Option	*Criteria*	*Level*	*Decription*
Route # 1	**Landuse**	Low	Paddy Field
	Population Density	Low	50 Households per 10 sq km
	Number of Heritages in Zone	Low	No heritage
	Number of Critical Area	High	4 places per 10 sq km
	Volume / Capacity Ratio	High	0.87
	Number of Lane (each direction)	High	1 lanes
	Lane Width	Med	3.0 m
	Frontage Road	Med	Yes / 1 lanes
	Number of Access Points (per 1 km)	Low	2 points
	Roadside Envir.	Low	0.29
	Travel Time	-	During design period is approximately 1.5 hrs
Route # 2	**Landuse**	High	Urban Area
	Population Density	High	1200 Households per 10 sq km
	Number of Heritages in Zone	Low	No heritage
	Number of Critical Area	Low	No critical place
	Volume / Capacity Ratio	Low	0.33
	Number of Lane (each direction)	Low	3 Lanes
	Lane Width	Low	3.5 m
	Frontage Road	High	No
	Number of Access Points (per 1 km)	High	21 points
	Roadside Envir.	High	0.74
	Travel Time	-	During design period is approximately 1.1 hrs
Route # 3	**Landuse**	Med	Suburban Area
	Population Density	Med	500 Households per 10 sq km
	Number of Heritages in Zone	Low	No heritage
	Number of Critical Area	Low	No critical place
	Volume / Capacity Ratio	Med	0.45
	Number of Lane (each direction)	Med	2 lanes
	Lane Width	Low	2.85 m
	Frontage Road	Low	Yes / 2 lanes
	Number of Access Points (per 1 km)	Low	2 points
	Roadside Envir.	Low	0.34
	Travel Time	-	During design period is approximately 1.3 hrs

As assumption mentioned in Chapter 3, utility function used to investigate the selection for these three routes is the same. Function used in this assignment was assumed, as well, with the specific coefficient of risk index. The function is shown in Equation 8.

$$U_i = 2.5(\text{travel time}) + 1.6(\text{risk from HazMat}) \quad (8)$$

This equation weights travel time 36 percents more than risk index value. And from the result of previous section, route risk indexes for three routes (#1-3) of 0.50, 0.84, and0.40 respectively. Following basic logit model $(P_i=e^{(-U_i)}/\Sigma e)$, products of volume sharing for these three routes are equal to 22%, 35%, and 43% as comparatively shown in Table 8.

Table 8 shows the comparison results among travel time and risk in HazMat routing. However, the values of the percent of volume sharing do not mean to express the real volume sharing, but they illustrate the priority of choosing of each route. In this case, the Route No. 3 comes up with the highest rank to be selected.

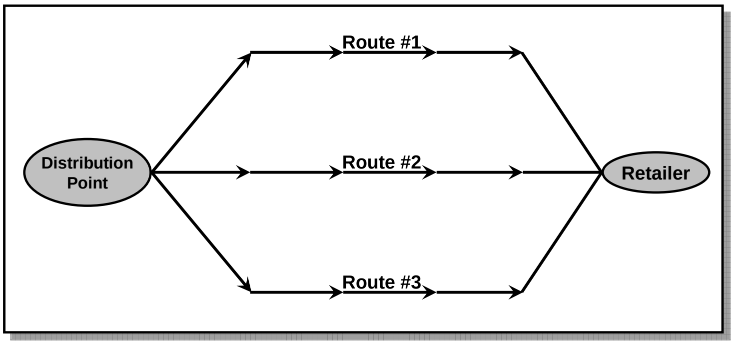

Figure 5 Three routes assumed

Table 8 Result of Analysis of Factitious Situation

Route	V /C	Travel Time (TT)	Risk Index (RI)	Utility	Rank by TT	Rank by RI	Exp(-U_i)	% of Volume Share
#1	High	1.5	0.50	4.55	3	3	0.011	22
#2	Low	1.1	0.84	4.09	1	2	0.017	35
#3	Medium	1.3	0.40	3.89	2	1	0.020	43
						Total	0.048	100

8. Summary and Conclusions

The result of this research provides only a preliminary idea for making a detailed analysis and collection in the future.

The results in the previous section show the possibility of conflicting in between single consideration of travel time and the comparatively investigation with RI. However, theses results and equations were produced without validation and calibration; it can not be located as a decisive output. As mention at the start of this chapter, the entire analysis aims at demonstrated the using in the method of the proposed idea, to gather more detail information needed for developing the model is expected as an outcome of the pre-research.

The larger size of samples should be collected in the future study to bring more reliability for the modeling method as well as to be able to conduct any statistical tests of hypotheses.

According to the output of this study, calibrating and scaling methods for the risk indexes must be performed to develop a reliable model. Furthermore, calibration and validation for locating the coefficient of Equation 8 have to be proceeded.

9. Acknowledgement

To the late Prof. Yordphol Tanaboriboon for being great teacher of my life.

10. References

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