Ranking of Hazardous Highway Locations in Thailand

Ponjanat UBOLCHAY [a], Mongkut PIANTANAKULCHAI [b]

[a,b] *School of Civil Engineering and Technology, Sirindhorn International Institute of Technology, Thammasat University, P.O.Box 22, Pathum Thani 12121, Thailand.*
[a] *E-mail: clown.mummer@gmail.com*
[b] *E-mail: mongkutp@gmail.com*

Abstract: This study presents a technique to rank hazardous highway locations in Thailand by using available statistical data from the Department of Highways (DOH). Accident rate, death rate, and injury rate are calculated per length of highway and traffic volume. Two methods of ranking are applied in this study, weights given by DOH and weights derived from Principal Component Analysis (PCA). The results of study reveal hazardous highway locations in Thailand in two levels, district level and specific highway sections. Surprisingly, the results show that both methods give similar ranking results. The method of PCA provides an alternative ranking scheme which does not require subjective judgment of weights. The study suggests hazardous highway locations/areas where further investigations should be carried out by related authorities.

Keywords: Hazardous Highways, Ranking, Principal Component Analysis (PCA)

1. INTRODUCTION

About 1.24 million people die each year as a result of road traffic crashes. Road traffic injuries are the leading cause of death among young people, aged 15–29 years. 91% of the world's fatalities on the roads occur in low-income and middle-income countries, even though these countries have approximately half of the world's vehicles. Half of those dying on the world’s roads are “vulnerable road users”: pedestrians, cyclists and motorcyclists. Without action, road traffic crashes are predicted to result in the deaths of around 1.9 million people annually by 2020 (World Health Organization, 2013a).

Road accident causes huge losses to the economy in terms of the cost incurred in hospitalization and treatment and damages to vehicles and property etc. There is an urgent need to reduce the number and severity of road accidents by implementing remedial measures at hazardous locations in the road network. Further, it is generally not possible to implement all remedial measures identified due to limited budget available for road safety improvement. Hence it is needed to rank the hazardous locations so that depending on the available budget, the hazardous locations can be treated (Agarwal et al., 2013)

Up to 26,000 people are killed in road accidents every year in Thailand, which puts the country in the 6th spot in terms of road casualties. The Cabinet of Thailand and Ministry of Transportation and Communications during its meeting on June 29, 2010, announced 2011-2020 as the Decade of Road Safety. In line with the Moscow Declaration, the target is to reduce road traffic fatalities to less than 10 per 100,000 population in 2020.

In identifying hazardous highway areas, various indicators should be identified. Accident rate, death rate, and injury rate as above mentioned are used indicators for finding an accident location or hazardous location. Aside from accident related indicators, transportation indicators such as traffic volume is also considered as a significant indicator. The growing number of vehicles and traffic volume, besides a low culture of road users, enhances the risk of accident (Pakalnis et al., 2003). A large number of vehicles are involved in road accident each year, which cause many deaths and extensive property damage. The volume of passenger cars and light non-passenger car vehicles plays a significant role in the likelihood of no injury accidents, but the volume of heavy vehicles does not have much effect on the likelihood of no injury accidents on urban highways (Ayati and Abbasi, 2011).

The identification of hazardous highway locations is an important first step for highway safety improvement. The accident frequency, accident rate, accident severity, rate quality control, and a newly developed combination were applied as a methodology to determine the worst locations in a study – an evaluation of methods for identifying hazardous highway locations. The results of the accident frequency method and accident severity method are most similar. The result suggested that individual methods are not suitable to be used alone to identify hazardous highway locations (Utainarumol and Stammer, 1999).

Another study by Ratanavaraha and Watthanaklang (2013) studied the analysis of bus hazardous locations via data gathering using traffic accident statistics on National Highways in Thailand reported by Department of Highways in 2006 - 2011. The identification of black spots on Thai National Highways was incorporated in the study, then the study ranked by using the rate quality control. The results of the study showed that the most hazardous highway locations is in the central region, and the less hazardous highway location is in the south region.

Currently, in Thailand, the Department of Highways (DOH) uses accidents statistics to rank hazardous locations on national highways by assigning weights to accident rate, death rate, and injury rate (Statistical Information Group, 2013). Another methodology to find weights of each factors is Principal Component Analysis (PCA) which is used in this study. Eigenvalues in PCA show the majority weight of components, and eigenvectors show weight of each factors that is used for calculation. PCA is also an approach to identify significant indicators used for ranking (Xiaona and Qicheng, 2014; Al-Haji, 2007; Xiaoyi et al., 2010).

This study ranks the hazardous highway district areas and sections by using two methods. Moreover, two methods - weights given by DOH and weights derived from Principal Component Analysis (PCA) - are compared in this study.

2. RESEARCH METHODOLOGY

Weights given by DOH and weights derived from PCA were used to rank the hazardous highways districts and sections are presented in this section. The analysis is divided into two parts: the first part presents the results grouped by highway district administered by DOH while the second part presents the result grouped by highway sections. Accident rates, death rates, and injury rates were used in this study. Rates are calculated based on exposures of 100 million vehicle-kilometer and million vehicle-kilometer for the analysis at district level and highway section level respectively.

Data from 105 highway districts and 38 highway sections highlighted by DOH as top hazardous sections were obtained from Traffic Accident on National Highway annual report by DOH. Due to the limited data, the reports in 2011 – 2014 were used for hazardous highway district areas ranking, and the ranking of hazardous highway sections used the data form the report in 2013. The details of the methods are given in Section 2.1 and 2.2 below.

2.1 Department of Highways (DOH) Weights

Nowadays, DOH uses its own criteria to locate hazardous locations on National Highway for implementation of road safety measures by using the traffic accident statistics. The rankings of hazardous locations for road safety planning are presented by province, district and maintenance bureau (Statistical Information Group, 2013).

The criterion gives priority for each indicator as follows: accident rate is 20%, death rate is 50%, and injury rate is30%. The weighted score could be written in Equation 1:

$$Weighted\ Score = 0.2x_1 + 0.5x_2 + 0.3x_3 \tag{1}$$

where,

x_1 : normalized accident rate
x_2 : normalized death rate
x_3 : normalized injury rate

2.2 Principal Components Analysis (PCA)

Principal Components Analysis (PCA) is another technique that is applied for determining weights in this study. PCA is a multivariate technique used to find the best combination of indicators, which could describes the variation of the original data by means of a smaller set of dimensions. The advantage of the technique is that the weight of indicators is based on statistical method rather than subjective judgments. It lets simply the data itself to decide on the weighting issue, which is good from transparency point of view (Al-Haji, 2007). The general form of the principal components is presented in the linear combination of indicators as shown in Equation 2:

$$PC_j = \sum_{i=1}^{p} a_i x_i \tag{2}$$

where,

PC_j : weighted score obtained from principal component j
a_i : weight of indicator i
x_i : indicator i
p : number of indicators

Procedure of PCA in this study is as follows (Xiaoyi et al., 2010):

1) Defining the basic indicator matrix
Suppose are *n* highway districts/sections with 3 indicators (e.g. accident rate, death rate, and injury rate). The basic indicator matrix is defined as:

$$A' = \begin{bmatrix} x'_{11} & x'_{12} & x'_{13} \\ x'_{21} & x'_{22} & x'_{23} \\ x'_{31} & x'_{32} & x'_{33} \\ \vdots & \vdots & \vdots \\ x'_{n1} & x'_{n2} & x'_{n3} \end{bmatrix} \tag{3}$$

where,

x_{ij} : indicator j of highway district/section i

2) Normalizing the basic indicator matrix
In this step, each indicator x_{ij} is normalized by its mean and standard deviation (Smith, 2002) as presented in Equation 4.

$$x_{ij} = \frac{x'_{ij} - \left(\frac{\sum_i x'_{ij}}{n}\right)}{\sqrt{\frac{\sum\left(x'_{ij} - \left(\frac{\sum_i x'_{ij}}{n}\right)\right)^2}{n-1}}} \quad (4)$$

Which results in normalized indicator matrix *A*:

$$A = \begin{bmatrix} x_{11} & x_{12} & x_{13} \\ x_{21} & x_{22} & x_{23} \\ x_{31} & x_{32} & x_{33} \\ \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & x_{n3} \end{bmatrix} \quad (5)$$

3) Determining eigenvalues and eigenvectors
Eigenvalues are a special set of scalars associated with a linear system of equations that are also known as characteristic roots (Weisstein, 2014) which can be obtained by solving the following system of equations.

$$Av = \lambda v \quad (6)$$

where,

A : normalized indicator matrix
λ : eigenvalue
v : eigenvector

4) Calculation of scores

In this step, principal components that explain most of the variations (eigenvalues) are chosen. The proportion of explained variations varies by the magnitude of eigenvalue. Normally, the principal components are chosen such that total explained variation are summed up to 70% and 90% (Al-Haji, 2007). Then, the value of the normalized indicator in the formula of PCs is replaced. Subsequently, a single value (score) is calculated by using the formula below.

$$S = \sum_{K=1}^{K=K_{max}} W^{PC_K} \sum_{i=1}^{i=n} (V_i^{PC_K} X_i) \quad (7)$$

where,

S : score of highway district/section
W^{PC_K} : weight calculated by proportion of eigenvalue of the component to the total sum of eigenvectors considered
$V_i^{PC_K}$: component i of eigenvector of principal component K

X_i : normalized indicator i
K : index of the principal component
K_{max} : number of principal component used in the analysis which could explain more than 80% of total variance
i : index of indicator
N : number of indicators considered

5) The final step is to rank the scores.

In this study, MATLAB software was used in finding eigenvalues and eigenvectors in PCA.

3. RESULTS

This section presents the results of the study. The analyses were subdivided into two parts consisting of ranking of hazardous highway that was separated by district and section.

3.1 Hazardous Highway District Areas Ranking

This section provides the detailed results of the first part of the analyses were hazardous highway district areas ranked based on the score calculated using both approaches. The hazardous highway district area ranking used the data set of 105 highway districts.

The correlation matrix of indicators by district areas is shown in Table 1. For each highway district the average accident rate, the death rate, and the injury rate were compiled from most recent four years data (2011 – 2014). The correlation matrix shows that indicators used in the analysis are moderately to highly correlated.

Table 1. Correlation matrix of indicators by district areas

Indicator	Accident rate	Death rate	Injury rate
Accident rate	1	0.53	0.82
Death rate		1	0.79
Injury rate			1

Hazardous highway district areas ranking by using DOH criteria was calculated based on the weighted score formula shown in Equation 1. The results of the ranking based on the calculated weighted scores are given in Table 3. In part of the hazardous highway district areas ranking by using PCA were determined to calculate. The result as the analysis is shown in Table 2.

Table 2. Eigenvalue, proportion and eigenvector of each principal component (by district areas)

Principle components	Eigenvalue	Proportion (%)	Eigenvector		
			v1	v2	v3
PC1	2.43	81.07	0.56	0.55	0.62
PC2	0.47	15.68	-0.68	0.73	-0.40
PC3	0.09	3.26	-0.47	-0.40	0.78

Only the first principal component was considered from the result as could explain more than 80% (81.07%) of total variance. The score for the first principal component is shown in Equation 8.

$$PC1 = 0.56X_1 + 0.55X_2 + 0.62X_3 \quad (8)$$

From Equation 8, could adjusted to be the final equation of PCA. The equation is given as;

$$PCA = 0.32X_1 + 0.32\,X_2 + 0.36X_3 \quad (9)$$

The first ranking of hazardous highway district area ranking by using PCA is identical result with ranking by DOH criteria. Phatthalung being the top on the rank. Whereas, the second rank to the tenth rank were switched. The ranking is shown in Table 3.

Table 3. Comparison of Ranking Results for Hazardous Highway District Areas

District area	Ranking	
	DOH criteria	PCA
Phatthalung	1	1
Chanthaburi	2	3
Uthai Thani	3	2
Phrae	4	4
Tak 1	5	7
Loei 2	6	6
Prachin Buri	7	10
Uttaradit 1	8	9
Songkhla 2	9	8
Nakhon Sawan	10	11
Samut Sakhon	11	5

Surprisingly, Phatthalung being the top in the both rank. Moreover, the top ranking results from both methods are almost the same set of highway districts.

3.2 Hazardous Highway Sections Ranking

This section provides ranking of hazardous highway sections. The sections data consist of 38 hazardous highway sections reported by DOH.

The correlation matrix of indicators by highway sections is shown in Table 4. The result of correlation is similar to the result derived by using highway district data which indictors show moderate to high level of correlation.

Table 4. Correlation matrix of indicators by highway sections

Indicator	Accident rate	Death rate	Injury rate
Accident rate	1	0.48	0.80
Death rate		1	0.70
Injury rate			1

The result of ranking by using DOH criteria for highway sections is shown in Table 6. Wang Chao – Tak being on the top ranking for the hazardous highway section. In section of the hazardous highway section ranking by using PCA was estimated to calculate the eigenvalues, proportions and eigenvectors of each PC. The result of the analysis is shown in Table 5.

Table 5. Eigenvalue, proportion and eigenvector of each principal component (by sections)

Principle components	Eigenvalue	Proportion (%)	Eigenvector		
			v1	v2	v3
PC1	1.84	61.46	0.58	0.45	0.68
PC2	0.89	29.81	-0.57	0.82	-0.05
PC3	0.26	8.73	-0.58	-0.36	0.73

In this part, first and the second principal components are considered because they could explain more than 80% (95.33%) of total variance. In this case, the calculation of total scores should include two principal components.

$$PC1 = 0.58X_1 + 0.45X_2 + 0.68X_3 \quad (10)$$

$$PC2 = -0.57X_1 + 0.82X_2 - 0.36X_3 \quad (11)$$

From PC1 and PC2, the combined equation of PCA is given as;

$$PCA = 0.17X_1 + 0.47X_2 + 0.36X_3 \quad (12)$$

The first ranking of hazardous highway section ranking by using DOH criteria and PCA has identical results while the first rank switch place with the second rank. The comparison of hazardous highway section ranking by using DOH criteria and PCA is shown in Table 6.

Table 6. Comparison of Ranking Results for Hazardous Highway Sections

District area	Ranking	
	DOH criteria	PCA
Wang Chao - Tak	1	2
Huai Sai -Phru Pho	2	1
Pa Tian - Ban Sio	3	3
Samut Sakhon - Bang Bon	4	4
Samae Dam - Tha Chin Bridge (West)	5	5
Sra Phang - Khao Wang	6	7
Om Noi - Samut Sakhon	7	6
Krathum Lom - Phutthamonthon	8	8
Tan Diao - Sap Bon	9	9
Phra Nang Klao Bridge - Bang Yai Interchange	10	10

3.3 Comparison of Weighted Scores

3.3.1 Hazardous Highway District Areas Ranking

The two approaches indicated weight scores, which are summarized in Table 7. The ranking by using DOH criteria concerns about death rate as the first priority factor is 50%. Whereas, the ranking by using PCA concerns about injury rate as the first priority factor is 36%. Accident rate and death rate is the second priority factor, 32% in hazardous highway district areas by using PCA.

Table 7. Comparison of Results on Weight Scores for Hazardous Highway District Area

	Accident rate (x_1)	Death rate (x_2)	Injury rate (x_3)
DOH criteria	0.20	0.50	0.30
PCA	0.32	0.32	0.36

3.3.2 Hazardous Highway Section Ranking

The ranking of hazardous highway section was limited by data that input into model. Therefore, this model used only one-year statistical data to calculate. Both of two approaches concern about death rate as the first priority factor, hazardous highway section ranking by using DOH criteria is 50% and the ranking by using PCA is 47%. The last priority factor of the both approaches is accident rate, 20% and 17% by using DOH criteria and PCA respectively. The comparison of results for hazardous highway section is shown in Table 8.

Table 8. Comparison of Results on Weight Scores for Hazardous Highway Section

	Accident rate (x_1)	Death rate (x_2)	Injury rate (x_3)
DOH criteria	0.20	0.50	0.30
PCA	0.17	0.47	0.36

4. CONCLUSION

Thailand ranks second in the list of highest traffic fatality rate in the world. Hazardous road ranking is an approach for finding locations where are unsafety. The hazardous highway ranking could use to road prioritization for implementation or maintenance.

The weight scores by DOH and derived from PCA are different for the ranking hazardous highway district area, while the weight scores of the both approaches at hazardous highway section are similar. The results of implantation for ranking the hazardous highway district areas are resemble. The hazardous highway district areas ranking by the weights given from DOH and derived from PCA is resemble as Phatthalung is the top rank of the hazardous highway district areas.

It can be seen from the summary of results that the two approaches have given almost similar results and ranking on hazardous highway sections. Although, the weight of hazardous highway district area ranking by DOH criteria and PCA are different. Thus, PCA provides an alternative ranking scheme which does not require subjective judgment of weights aside from the state of practice that the DOH is currently using.

Because of limited data were used in this study, the ranking of hazardous highway section was calculated using only one year statistic. Moreover, investigating the significant factors that causes these highway areas/sections hazardous can be explored in the future.

ACKNOWLEDGEMENT

The research presented in this paper was partly funded by the Bangchak Petroleum Public Company Ltd, Scholarship. Thanks is also to Department of Highways (DOH) for provision of data in this study.

APPENDIX A: AVERAGE ACCIDENT STATISTIC OF TOP RANKED BY HIGHWAY DISTRICT IN 2011-2014

District area	Rate per 100 million vehicle-kilometer		
	Accident rate	Death rate	Injury rate
Phatthalung	22.83	2.89	27.54
Chanthaburi	9.99	3.29	11.47
Uthai Thani	18.42	1.86	14.66
Phrae	10.24	2.44	12.32
Tak 1	7.32	2.66	8.71
Loei 2	7.75	1.82	13.11
Prachin Buri	7.17	1.84	11.17
Uttaradit 1	8.94	1.85	9.59
Songkhla 2	9.60	1.66	10.14
Nakhon Sawan	11.01	1.47	9.44

APPENDIX B: AVERAGE ACCIDENT STATISTIC OF TOP RANKED BY HIGHWAY SECTION IN 2013

Highway Section	Rate per million vehicle-kilometer		
	Accident rate	Death rate	Injury rate
Wang Chao - Tak	74.57	31.40	45.14
Huai Sai -Phru Pho	92.90	20.32	116.13
Pa Tian - Ban Sio	83.35	15.54	107.36
Samut Sakhon - Bang Bon	244.40	0.00	144.02
Samae Dam - Tha Chin Bridge (West)	103.83	6.15	89.98
Sra Phang - Khao Wang	61.52	9.71	42.09
Om Noi - Samut Sakhon	137.68	1.26	73.26
Krathum Lom - Phutthamonthon	142.65	6.79	15.28
Tan Diao - Sap Bon	19.91	10.95	29.36
Phra Nang Klao Bridge - Bang Yai Interchange	49.21	7.24	26.05

REFERENCES

Agarwal, P. K., Patil, P. K., & Mehar, R. (2013). A Methodology for Ranking Road Safety Hazardous Locations Using Analytical Hierarchy Process. *Procedia - Social and Behavioral Sciences, 104*(0), 1030-1037.

Al-Haji, Ghazwan. (2003). *Road safety development index (RSDI).* Paper presented at the 16th ICTCT Workshop Amersfoort/Soesterberg, The Netherlands.

Al-Haji, G. (2007). *Road safety development index (RSDI).* (Ph.D.), Linköping University.

Ayati, E., & Abbasi, E. (2011). Investigation on the role of traffic volume in accidents on urban highways. *Journal of Safety Research, 42*(3), 209-214.

Pakalnis, A., Gužys, A., & Dimaitis, M. (2003). *Interactions between accident rate and traffic volume*. Paper presented at the 25th International Baltic Road Conference, Vilnius, Lithuania.

Peltola, H., Rajamäki, R., & Luoma, J. (2013). A tool for safety evaluations of road improvements. *Accident Analysis & Prevention*, 60, 277-288.

Ratanavaraha, V., & Watthanaklang, D. (2013). Road Safety Audit: Identification of Bus Hazardous Location in Thailand. Indian Journal of Science and Technology, Vol 6(8), 5126-5133.

Sadeghi, A., Ayati, E., & Neghab, M. P. (2013). Indentification and prioritazation of hazardous road locations by segmentatic and data environment analysis approach. *Journal PROMET - Traffic&Transportation*, 25.

Smith, L. I. (2002). A tutorial on Principal Components Analysis.

Statistical Information Group, B. o. H. S. (2013). *Traffic Accident on National Highways 2013*.

Utainarumol, S., & Stammer, Jr., Robert E. . (1999). An evaluation of methods for identifying hazardous highway locations. Journal of the Eastern Asia Society for Transportation Studies, 3, 287-309.

Weisstein, E. (2014). Eigenvalue. Retrieved 28/12/2014, 2014, from **http://mathworld.wolfram.com/Eigenvalue.html** [Last accessed on 2014 December 28]**.**

World Health Organization. Road Traffic Injuries Fact Sheet N 0 358, March 2013. Available from: **http://www.who.int/mediacentre/factsheets/fs358/en/** [Last accessed on 2015 February 28].

Xiaona, Z., & Qicheng, W. (2014). Chinese sports development status research based on SPSS principal component analysis and GM model. *Journal of Chemical & Pharmaceutical Research*, *6*(3), 272-277.

Xiaoyi, Z., Liying, Z., Xuemei, F., & Yinsheng, Y. (2010, 26-28 May 2010). *Research on evaluation of third-party logistics enterprises in agricultural product logistics based on PCA-priority-degree evaluation method.* Paper presented at the Control and Decision Conference (CCDC), 2010 Chinese.