# PRIORITIZATION OF TRAFFIC SIGN REPLACEMENT USING THE ANALYTIC NETWORK PROCESS

BY

PONJANAT UBOLCHAY

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (ENGINEERING AND TECHNOLOGY)

SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY

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A Thesis Presented

By

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## Abstract

PRIORITIZATION OF TRAFFIC SIGN REPLACEMENT
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by

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Traffic signs are used as safety tools to guide and control vehicles. Cleared traffic signs are essential to convey message to road users. Traffic signs should be maintained in good condition. A way to treat damaged signs is to replace them with new signs. However, several damaged traffic signs exist in road network, and it is impossible to replace them all. Therefore, prioritization is necessary for traffic sign replacement. In this research, to prioritize replacement of damaged signs, the Analytic Network Process (ANP) is applied. Prioritization of traffic sign replacement is considered by three factors such as location of traffic signs, level of damage of signs, and the context of traffic signs. The result shows that level of damage of signs is the first priority, especially the traffic signs which are fade away or unclear message. While, the physical location of traffic signs, where is roundabout, is the last priority.

Moreover, a technique to rank hazardous highway locations in Thailand by using available statistical data from the Department of Highways (DOH) is presented in this research. 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. 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.

Moreover, comprehension of traffic signs by drivers is studied in this research. This research proposes a method to rank importance of traffic signs by linking the context of traffic signs and potential causes of traffic accidents. Five categories of traffic accident causes which are related to traffic signs - speeding, road way channelization, overtaking, hazardous road conditions, and causes related to pedestrians and animals - are considered. The results show that drivers interpret the meaning of traffic signs by more than one meaning, and the importance of traffic signs depends on their meaning which drivers understand.

**Keywords**: Analytic Network Process (ANP), Prioritization, Traffic sign, Traffic sign replacement

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# Chapter 1
# Introduction

## 1.1 Background

About 1.24 million people die each year as a result of road traffic crashes. 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. Without action, road traffic crashes are predicted to result in the deaths of around 1.9 million people annually by 2020 (World Health Organization, 2016). In Thailand, up to 26,000 people are killed in road accidents every year. In 2014, Thailand's roads were ranked the second most dangerous worldwide. A study by the University of Michigan Transportation Research Institute showed that Thailand has the second-highest traffic fatality rate in the world, with 44 deaths per 100,000 populations (Hynes, 2014; DeGroat, 2014).

The elements in the road environment are important to support the safety. Traffic signs are one of the most important elements in road environment. Traffic signs are used as a traffic safety tool for guiding and controlling traffic, mostly developed to provide crucial information within a short time by words or symbols to support safe driving (Kirmizioglu and Tuydes-Yaman, 2012; Al-Madani and Al-Janahi(a), 2002; Al-Madani and Al-Janahi(b), 2002). Generally, traffic signs are grouped into three groups: regulatory signs, warning signs, and informatory or guidance signs. Regulatory signs give notice of requirements, prohibitions or restrictions. Warning signs provide warning of a hazard ahead. The last group of traffic signs is informatory signs or guidance signs. These signs give the information about routes, places, or facilities of particular value or interest to road users.

Traffic signs must give a clear message at the correct time to road users. Therefore, symbols are used rather than words to convey a message. The message must be unambiguous and speedily understood (Department for Transport, 2004). Symbols allow instant communication to road users, overcome language barriers, and have been a standard for traffic control devices worldwide. Familiarity with symbols on traffic signs is important for every drivers and road user in order to maintain the safety and efficiency of transportation facilities (United States Department of Transportation Federal Highway Administration, 2002).

Clear and effective traffic signs are an essential part of highways. The road with poorly maintained signs might be hazardous. After installation, traffic signs must be maintained to preserve the original effectiveness and general condition at all times. Traffic signs become less effective not only when characters or coloring are deteriorated, but also they are dirty, damaged, or displaced as a result of accidents or vandalisms (Department for Transport, 2004).

**1.2 Statement of Problem**

As mentioned above, traffic signs are important for road users. The main role of traffic signs is to give notice of requirements, prohibitions, restrictions, warnings, information, or directions for safe driving.

After installation, traffic signs are deteriorated in time, by weathering, vandalism, or being hit by vehicles. Traffic signs must be maintained to preserve their original effectiveness. A way to treat these deteriorated or damaged signs is replacement. When budget and time are limited, it is necessary to prioritize traffic sign replacements by considering their relative importance. Many factors must be considered such as location, level of damage, and potential of traffic accident caused by missing or damaged signs.

However, it is generally impossible to replace every damaged traffic sign due to financial and time limitations (Agarwal et al., 2013). Moreover, a large number of traffic signs which exist in practice cause difficulties in ranking them in terms of their relative importance. Therefore, a tool to aid the prioritization for traffic sign replacement is necessary.

**1.3 Objectives**

The main objective of this study is to ***prioritize traffic sign replacement in Thailand***. In general, traffic signs are installed on all national highways. Before replacing the new traffic signs, national highways should be prioritized or ranked a hazardous location. Therefore, this study generates a pre-screening step. The objective of this step is to *identify hazardous highway location in Thailand*.

Moreover, there are several traffic signs which are existed in practice. It is difficult in ranking or prioritizing traffic signs in terms of their importance. Therefore, to rank an importance of traffic signs, the context of traffic signs and potential causes of traffic accidents are linked. This process is to *identify an importance of traffic by linking their context and potential causes of traffic accidents*.

### 1.4 Scope and Limitation

General, traffic signs are classified into three groups; regulatory signs, warning signs, and informatory signs depend on their meaning. However, only regulatory signs and warning signs are considered in this study. Because there are many informatory signs in road networks. They can be created all times, depending on situations such as an informatory sign for guiding a direction. Therefore, informatory signs are not included in this study.

### 1.5 Significance of Study

This study will be useful for a replacement approach. Nowadays, there are many less effective or damaged signs must be maintained on road systems. However, agencies are limited capacity by budget and time. Therefore, a prioritization approach is an approach to prioritize traffic sign replacement.

### 1.5 Conceptual Framework

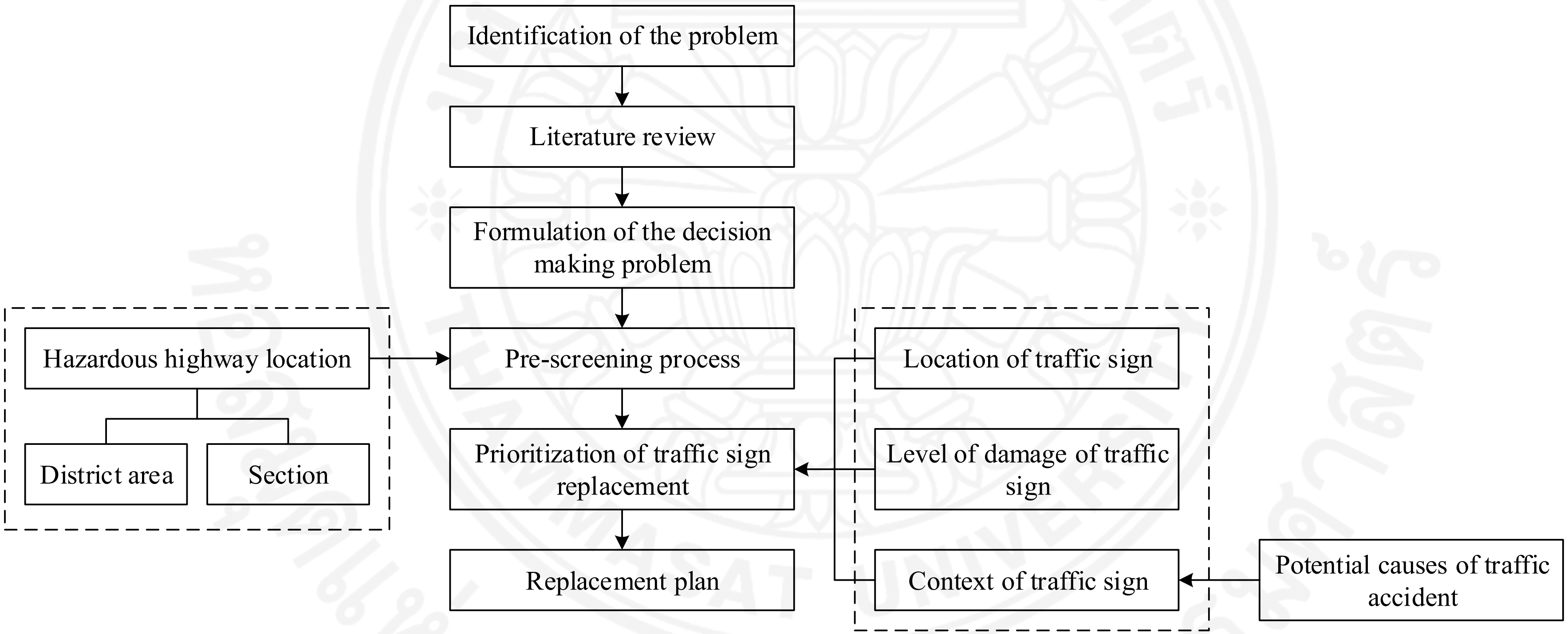



Figure 1.1 Conceptual framework

# Chapter 2
# Literature Review

This chapter presents a literature review related to the topic of *prioritization of traffic sign replacement using the analytic network process*. Related literatures of this study are divided into two parts: traffic signs, and prioritization techniques.

## 2.1 Traffic Signs

Traffic signs or road sings serve many functions such as regulating, warning, and giving directions and information to road users. The knowledge of traffic signs is essential, not just for new drivers, but for all road users including experienced drivers (Department for Transport, 2004).

### 2.1.1 Traffic sign classification

Traffic signs can be classified into two basic groups: ideogram based signs, and by text based signs. Ideogram based signs use simple ideographs (graphic symbol) to convey the meaning, while the text based signs texts or symbols (Paclík et al., 2000). Moreover, traffic signs can be also classified into three groups by their function or meaning: regulatory signs, warning signs, and informatory signs (Department for Transport, 2004; Office of transport and traffic policy and planning, 2004; Traffic Engineering and Safety Unit Design Branch, 1997).

#### 2.1.1.1 Regulatory signs

Regulatory signs are signs that present a notice of requirements, prohibitions, or restrictions. Shapes of regulatory signs include circular, octagonal, and invert equilateral triangular shape, and may be supplemented by plates beneath them augmenting the message given by the sign (Department for Transport, 2004).

In Thailand, regulatory signs are classified into three groups – priority sign, prohibitory or restrictive sign, and mandatory sign – by Office of Transportation and Traffic Policy and Planning, Ministry of Transport (2004). The regulatory signs in Thailand are shown in Appendix A. Examples of regulatory signs are shown in Figure 2.1.


(i) Priority for oncoming traffic | (ii) Cycle prohibited | (iii) Horn prohibited | (iv) Compulsory Pedestrian | (v) Minimum speed limit

Figure 2.1 Examples of regulatory signs

**2.1.1.2 Warning signs**

Warning signs are used to warn drivers about potential danger ahead. A Special group of warning signs is roadwork signs, which are used to alert road users the temporary traffic management in progress on the road ahead. The shape of warning signs is diamond. The signs may be supplemented by rectangular shape with additional information. Normally, warning signs have yellow background with black symbol. However, the background of roadwork signs that are special signs is orange with a black symbol (Department for Transport, 2004; Office of transport and traffic policy and planning, 2004). This study does not consider roadwork signs because they are temporary sign. After road maintenance is finished, roadwork signs are removed.

In Thailand, Department of Disaster Prevention and Mitigation, Ministry of Interior (2014), classified warning signs into four groups: curve warning signs, cross traffic warning signs, situation warning signs, and trailer warning signs. The warning signs that are considered are shown in Appendix A. Examples of warning signs are shown in Figure 2.2.

| (i) | (ii) | (iii) | (iv) | (v) |
|---|---|---|---|---|
| Turn left ahead | Dangerous dip | End of divided highway | Traffic signal ahead | Animal crossing |

Figure 2.2 Examples of warning signs

**2.1.1.3 Informatory signs**

The last group of traffic signs is informatory sign. These signs give information about routes, places, and facilities to road users. There are two principal types of informatory signs: directional information signs, and other information signs. Directional information signs show directions or distances to places, while other information signs give a variety of information to road users. The shape of informatory sign is rectangular, while directional information signs commonly have an arrow (Department for Transport, 2004; Office of transport and traffic policy and planning, 2004).

In Thailand, informatory signs are classified into three groups – guide signs, information signs, and support signs – by Department of Disaster Prevention and Mitigation, Ministry of Interior (2014). Because there are many informatory signs and they are generally less important in terms of safety, therefore, informatory signs are not be included in this study. However, Examples of informatory sign are shown in Figure 2.3.


| (i) | (ii) | (iii) | (iv) | (v) |
|---|---|---|---|---|
| Hospital | Parking | Restaurant | Gas station | Destination |

Figure 2.3 Examples of informatory signs

Summary of traffic sign classification is presented in Table 2.1. The detail in summary table will be referred to commonly used signs in Thailand. The purposes, characteristics, and colors of traffic signs are given by Office of Transport and Traffic Policy and Planning, Ministry of Transport, Thailand (2004).

Table 2.1 Summary of traffic sign classification in Thailand

| | **Regulatory Sign** | **Warning Sign** | **Informatory Sign** |
|---|---|---|---|
| **Purpose** | • Prohibition<br>• Restriction<br>• Mandatory | • Warning<br>o Danger<br>o Special caution<br>o Roadwork | • Guidance<br>o Direction<br>o Distance<br>o Place / Facility |
| **Shape** |  |  |  |
| **Background Color** | • White<br>• Blue<br>• Red | • Yellow<br>• Orange | • White<br>• Blue<br>• Green |

| | Regulatory Sign | Warning Sign | Informatory Sign |
|---|---|---|---|
| **Line Color** | • Red<br>• White<br>• Black | • Black | • Black<br>• White<br>• Brown |
| **Symbol / Character Color** | • Black<br>• White | • Black | • Black<br>• White<br>• Brown |

Source: Adapted from Office of Transport and Traffic Policy and Planning, Ministry of Transport, Thailand, 2004

### 2.1.2 Traffic sign positioning

Positioning of traffic signs is an importance within roadway networks. Standardization of traffic sign position is not always attainable, however, because of the changing roadway geometric conditions and environment (Government of Alberta: Transportation, 2010). Traffic signs siting along the road in relation to the junction, hazard, or other feature to which it applies. The placement in relation to the edge of the carriageway and other features of the cross section (Department for Transportation, 2004).

### 2.1.3 Traffic sign replacement

Traffic sign replacement is an approach to manage damaged sign. Because damaged signs effect on drivers' visibility, and visibility is a factor that is related to road fatalities. Retroreflectivity is considered as another important factor which relate to visibility of traffic signs. Retroreflectivity plays an important role to communicate with drivers during daytime and nighttime. The retroreflective sheeting deterioration depends on many factors such as materials of sheeting signs, colors of traffic signs, sheeting age, UV-radiation, pollutants, moisture, and temperature (Carlson and Lupes, 2007; Office of Transport and Traffic Policy and Planning, 2004; Hummer et al., 2013; Wen-hong et al., 2013; Black et al., 1992).

Moreover, Hummer et al. (2013) presented that the traffic sign replacement is the largest effect on budget. The authors suggested five methods for a traffic sign management system:

1) A nighttime visual inspection is to assess the retroreflective condition of traffic signs.

2) A daytime inspection is to investigate damaged signs.

3) Traffic sign prioritization for replacement by using safety aspect is to evaluate the important signs.

4) Replacing the old traffic signs with a higher quality traffic sign.

5) Record the information of traffic signs such as the installation date, type of traffic signs.

Nowadays, there is not specific guidance and practice to replace old traffic signs with new traffic signs. In practical, traffic signs with defects should be assessed the condition of the equipment. Office of Transport and Traffic Policy and Planning (2004) classified the temporary traffic signs (temporary warning signs) by their condition of the equipment. General, the classification of the conditions of traffic signs could be applied to use with all damaged traffic signs for assessment. The condition of traffic signs was classified into three levels: acceptable, marginal, and unacceptable. Table 2.2 represents the traffic sign assessment guideline.

Table 2.2 Sign condition assessment guide in Europe

| **Traffic sign illustration** | **Level** | **Definition** |
|---|---|---|
|  | • Acceptable | • There are some abrasions on the traffic signs but still understand the meaning. |
|  | • Marginal | • There are big abrasions on the traffic sign, but not large areas missing. |

| Traffic sign illustration | Level | Definition |
|---|---|---|
|  | • Unacceptable | • The colors of traffic signs fade/not clear and does not match the standard color. In addition sign are damaged by vehicle hit. |

Source: Adapted from Department for Transport/Highways Agency et al., 2009

In Thailand, traffic signs are assessed by trained official. There are five levels to classify the condition of traffic signs: no damage, low level, moderate level, high level, and extreme level. The guideline for traffic sign assessment in Thailand is represented in Table 2.3.

Table 2.3 Guideline for traffic sign assessment in Thailand

| Damaged level | Criteria (Definition) |
|---|---|
| No damage | • Normal |
| Low level | • Low damage of sign, no effects to road users. |
| Moderate level | • The sign will be damaged in the future but currently has no effect to road users. |
| High level | • Damaged sign, difficult to understand. |
| Extreme level | • Excessively damaged sign, road users almost cannot see and understand. |

Source: Adapted from Office of Transport and Traffic Policy and Planning, Ministry of Transport, Thailand, 2003

In addition, frequency of traffic sign assessment is suggested as every 1 month, every 3 months, and every 6 months. The frequency of traffic sign assessment is represented in Table 2.4.

Table 2.4 Guideline for frequency of traffic sign assessment in Thailand

| Period | Error of traffic sign |
|---|---|
| Every 1 month | • Dirty sign<br>• Proper direction of traffic sign installment<br>• Obscured the vision by the trees |
| Every 3 months | • Vandalism (Damaged sign)<br>• Retroreflectivity at night<br>• Deterioration of sign luminance |
| Every 6 months | • Dirty sign (Overhead signs)<br>• Proper direction (Overhead signs)<br>• Fade away or unclear message<br>• Rust on the sign |

Source: Adapted from Office of Transport and Traffic Policy and Planning, Ministry of Transport, Thailand, 2003

### 2.1.4 Traffic sign comprehension

Using symbols or words, traffic signs must provide critical information to drivers in short time. Therefore, comprehension of traffic sign is important to safe driving. Poor comprehension of traffic signs increases traffic accident risks. Confusable traffic signs give more than a meaning to drivers. Assess comprehension of traffic signs can be assessed by using questionnaires to drivers, which contained short-answer and multiple-choice questions. Several factors were found significant traffic sign comprehension such as education level, monthly income level, nationality, gender, age, urbanization of residence level, years with driving license, and daily driving practice of drivers (Al-Madani and Al-Janahi, 2002[a]; Al-Madani and Al-Janahi, 2002[b]; Ng and Chan, 2008; Ismali, 2012; Kirmizioglu and Tuydes-Yaman, 2012). The summary of related literatures of traffic sign comprehension is represented in Table 2.5 below.

Table 2.5 Summary of related literatures to traffic sign comprehension

| Author | Methodology | Result |
|---|---|---|
| Al-Madani and Al-Janahi (2002)a | • Survey questionnaires<br>  o Short answer<br>  o Multiple choices<br>• 28 types of traffic signs<br>  o 18 regulatory signs<br>  o 10 warning signs | • Significant variables<br>  o Nationality<br>  o Driving experience<br>  o Income<br>  o Education level<br>  o Gender |
| Al-Madani and Al-Janahi (2002)b | • Survey questionnaires<br>  o Short answer<br>  o Multiple choices<br>• 28 types of traffic signs<br>  o 18 regulatory signs<br>  o 10 warning signs | • 55% of drivers can correctly identify the regulatory signs, and 56% for the warning signs.<br>• European and American drivers have better understanding of traffic sign than Asian and Arab drivers.<br>• Major factors to traffic sign comprehension<br>  o Gender<br>  o Age<br>  o Education level<br>  o Income |
| Ng and Chan (2008) | • Survey questionnaires<br>• 21 types of traffic signs<br>• Sample size of 109 | • Significant variable<br>  o Driving experience<br>  o Education level<br>• Drivers are the highest understanding on *Pedestrians prohibited sign*. |
| Ismail (2012) | • Survey questionnaires<br>  o Short answer<br>  o Multiple choices<br>• 24 types of traffic signs<br>  o 8 regulatory signs<br>  o 8 warning signs | • Direct proportion<br>  o Level of education<br>  o Level of urbanization of the residential area<br>  o Driving experience<br>  o Gender |

| Author | Methodology | Result |
|---|---|---|
| | ○ 8 guide signs<br>• Sample size of 1,750 | (Male drivers are higher comprehension level than female drivers.)<br>○ Vehicle ownership (private car drivers have higher comprehension level than other drivers)<br>• Inverse proportion<br>○ Age<br>○ Number of accident |
| Kirmizioglu and Tuydes-Yaman (2012) | • Survey questionnaires<br>○ Open-ended questions<br>• 39 types of traffic signs<br>• Sample size of 1,478<br>○ The employees of public institutions<br>○ Local people<br>○ Driving professional | • *Pedestrian Crossing Ahead sign* was the most correctly identified sign.<br>• Traffic signs that mixed comprehension<br>○ *No through road in the direction indicated from junction ahead sign*<br>○ *Road narrow from left sign*<br>○ *Motor or non-motorized vehicles prohibited sign*<br>○ *End of motorway sign*<br>○ *Crossroad with a non-priority road sign*<br>○ *Dangerous shoulder sign*<br>○ *Give way sign*<br>○ *No standing or parking sign*<br>○ *Sharp deviation of route to the left sign*<br>• Overall of drivers did not well-known on traffic signs.<br>• To increase the traffic sign comprehension, education was suggested. |

## 2.2 Prioritization Techniques

Prioritization is the essential to make the best approach. It is important when time and financial are limited and demands are unlimited. Prioritization helps to manage the time where it is most needed and most wisely spent. A good priority reduce stress, and move towards a successful conclusion. There are several approaches to prioritize such as Paired Comparison Analysis, Decision Matrix Analysis, the Action Priority Matrix, Eisenhower Urgent / Important Principle, The Ansoff Matrix and the Boston Matrices, Pareto Analysis, and The Modified Borda Count (Mindtools, 2016).

In this study, the Analytic Network Process (ANP) technique was considered to be a main technique for prioritization the traffic signs. The priority of ANP technique derives from pairwise comparison matrices. The priority are entered as parts of the columns of a supermatrix. The supermatrix represents the influence priority of an element on the left of the matrix on an element at the top of the matrix with respect to a particular control criterion (Saaty, 2010). In addition for finding the top rank of hazardous highway location in Thailand, highway location was ranked by using statistical data from the Department of Highways (DOH) and Principal Component Analysis (PCA). Therefore, this part, Analytic Network Process (ANP) and Principal Component Analysis (PCA) will be presented.

### 2.2.1 Analytic Network Process (ANP)

The Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) have found useful applications in decision making. AHP and ANP are basically a way to measure intangible factors. Pairwise comparison with judgments is used in these techniques (Saaty, 2010).

The ANP is the generalization of the AHP developed by Saaty. The ANP is a multicriteria theory of measurement used to obtain relative priority scales from individual judgments or from actual measurement normalized to a relative form, that belong to a fundamental scale of absolute numbers. The judgments represent the relative influence, of one of two elements over the other in a pairwise comparison process on a third element in the system, with respect to an underlying control criterion. The ANP combines the result of dependence and feedback within and between clusters of elements, whereas the AHP combines the result with its independence upper levels from lower levels of elements (Saaty, 2005).

The ANP technique can be divided into four major steps as follows: (1) model construction of decision making problem, (2) pairwise comparison matrix, (3) supermatrix formation, and (4) the best alternative selection (Saaty, 2005; Yuksel and Dagdeviren, 2007; Shiue and Lin, 2012). In pairwise comparison step, Saaty (2010) suggested a fundamental scale for comparison two components which is presented in Table 2.6.

Table 2.6 Fundamental scale of relative importance

| Intensity of Importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective |
| 2 | Weak or slight | |
| 3 | Moderate importance | Experience and judgment slightly favor one activity over another |
| 4 | Moderate plus | |
| 5 | Strong importance | Experience and judgment strongly favor one activity over another |
| 6 | Strong plus | |
| 7 | Very strong or demonstrated importance | An activity is favored very strongly over another; its dominance demonstrated in practice |
| 8 | Very, very strong | |
| 9 | Extreme importance | The evidence favoring one activity over another is of the highest possible order of affirmation |

| Intensity of Importance | Definition | Explanation |
|---|---|---|
| 1.1 – 1.9 | When activities are very close a decimal is added to 1 to show their difference as appropriate | A better alternative way to assigning the small decimals is to compare two close activities with other widely contrasting ones, favoring the lager one a little over the smaller one when using the 1 – 9 values |

Source: Saaty, 2010

In many researches, ANP technique could be applied for prioritization in several field of study. As for example, in physical field, Neaupane and Piantanakulchai (2006) studied the landslide in Nepal. ANP was applied for landslide sensitivity, that priority weights for each indicator. Promentilla et al. (2013) applied ANP to rank the potential $CO_2$ sources and sinks in $CO_2$ capture and storage (CCS) system. The ranking could identify the best situations for the projects.

In economical field, moreover, Aragonés-Beltrán et al. (2014) applied both AHP and ANP to study the investment a solar-thermal power plant project. The study is to determine the order of priority of the projects.

Not only ANP was applied to utilize, but also AHP was utilized. In study related to road safety, Agarwal et al. (2013) used AHP for ranking the hazardous locations. The weight, which obtained from AHP, could identify safety factors for road safety.

### 2.2.2 Principal Component Analysis (PCA)

The Principal Component Analysis (PCA) is a technique which applied for determining weight of hazardous highway location in Thailand. PCA is a multivariate technique used to find the best combination of indicators, which could describe the variation of original data by means of a smaller set of dimension. The advantage of the technique is to the weight of indicators, which 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). 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 (Al-Haji, 2007; Xiaoyi et al., 2010; Xiaona and Qicheng, 2014).

The procedure of PCA could be divided into five procedures as follows (Xiaoyi et al., 2010): (1) defining the basic indicator matrix, (2) normalizing the basic indicator matrix, (3) determining eigenvalues and eigenvectors, (4) calculation of the scores, and (5) ranking the scores. The detail of procedure will be presented in the next chapter.

PCA technique was applied to evaluate indicators in many researches. For example, as PCA could be determined the weights, therefore, Al-Haji (2007) applied PCA technique to develop road safety development index (RSDI). Zang et al. (2010) evaluated third-party logistic enterprises in agricultural product logistic by using PCA technique. Liu and Xu (2011) applied PCA technique for selecting supplier in modern automotive industry.

# Chapter 3
# Research Methodology

This study developed a method to prioritize for traffic sign replacement in Thailand. There are three procedures for prioritization in this study: ranking hazardous highway locations, linking the context of traffic sings and traffic accident causes, and weighting the indicators.

## 3.1 Identification of Hazardous Highway Locations in Thailand

Ranking hazardous highway locations is the first step of this study. This step identifies the hazardous highway locations for safety improvement on highways. Historical statistics which included accident rates, death rates, and injury rates were used as indicators. Two weighting schemes by Department of Highway (DOH) criteria, and Principal Component Analysis (PCA) – were applied and compared. Rates were calculated based on exposures in vehicle-kilometers in the analysis.

### 3.1.1 Department of Highway (DOH) weighting scheme

Nowadays, Department of Highway (DOH) uses its own criteria to locate hazardous locations on national highway for implementation of road safety measures by using the traffic accident statistics (Statistical Information Group, 2013). The criterion gives priority for each indicator as follows: 20% for accident rate, 50% for death rate, and 30% for injury rate. The weighted score could be written in Equation 1:

$$Weighted\ Score = 0.2x_1 + 0.5x_2 + 0.3x_3 \qquad (1)$$

where,

$x_1$ : normalized accident rate

$x_2$ : normalized death rate

$x_3$ : normalized injury rate

### 3.1.2 Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is another technique to locate hazardous locations on national highway in this study. As mention in 2.2.2, the weight of indicators in PCA is based on statistical data. Hence, history of traffic accident – accident rates, death rates, and injury rates – could be applied. The general form of the principal components is presented in the linear combination of indicators as shown in Equation 2:

$$PC_j = \sum_{i=1}^{p} a_i x_i \qquad (2)$$

where,

$PC_j$ : weighted score obtained from principal component j

$a_i$ : weight of indicator i

$x_i$ : indicator i

$p$ : number of indicators

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

1. Defining the basic indicator matrix

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

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

where,

$x'_{ij}$ : indicator j of highway district/section i

2. Normalizing the basic indicators

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

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

Which results in the normalized indicator matrix *A*:

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

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.

$$Av = \lambda v \tag{6}$$

where,

*A* : normalized indicator matrix

$\lambda$ : eigenvalue

$v$ : eigenvector

4. Calculation of weighted score

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% to 90% (Al-Haji, 2007). Subsequently, a single value (score) is calculated by using the formula below.

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

where,

$S$ : score of highway district/section

$W^K$ : weight calculated by proportion of eigenvalue of the component to the total sum of eigenvectors considered

$V_i^K$ : 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. Rank the score in the final step

For this study, the calculations were programmed using MATLAB to find eigenvalues and eigenvectors in PCA.

### 3.2 Traffic Sign Classification by Linking the Context of Traffic Signs and Traffic Accident Causes

There are several causes of traffic accident on road networks. Five categories of traffic accident causes related to traffic signs - speeding, road way channelization, overtaking, hazardous road conditions, and causes related to pedestrians and animals - are considered in this study. This part presents a methodology to identify the importance of traffic signs by linking the context of traffic signs and traffic accident causes by drivers' comprehension.

### 3.2.1 Data collection

#### 3.2.1.1 Questionnaire preparation

Questionnaires were used in the data collection. These contain 40 regulatory signs and 51 warning signs commonly used in Thailand. The questionnaire consists of two main parts: multiple-choice and short-answer questions. The questionnaire is presented in Appendix B, and the example of the questionnaire is shown in Table 3.1.

1. Multiple-choice questions

The multiple-choice question part was designed to evaluate the linkage of the context of traffic signs and potential causes of traffic accident (if the sign is missing or damaged) perceived by drivers. There are five indicators for this part:

1) Speeding
2) Road way channelization
3) Overtaking
4) Hazardous road condition (Slippery road, narrow road, etc.)
5) Human and animal (School area, Animal area, etc.)

2. Short-answer questions

Personal information of respondent was asked in this part. The indicators of the questions are shown as following:

1) Gender
   - Male
   - Female
2) Age
3) Educational level
   - Middle school
   - High school or Vocational certificate
   - Vocational Diploma
   - Bachelor's Degree

- Master's Degree or above

4) Occupation
5) Driving license
    - Have
    - Do not have
6) Driving experience

Table 3.1 Example of questionnaire used in this study

Please check √ the potential cause(s) of traffic accident that involve missing/damaged of the specified traffic sign

| Traffic sign | Speeding (Sp.) | Road way channelization (Ch.) | Overtaking (Ov.) | Hazardous road conditions (Hr.) | Causes related to pedestrians and animals (Pa.) |
|---|---|---|---|---|---|
|   | | | | | |
|  | | | | | |
|  | | | | | |

**3.2.1.2 Sample size determination**

The questionnaires were completed by drivers who were selected by the stratified choice-based random sampling technique as applied in Al-Madani and Al-Janahi[a] (2002). In this study, the number of sample size was determined following Israel (2013). The table of sample size is shown in Table 3.2. Drivers or respondents are grouped according to their ages as new (age 18-25), young (age 26-35), middle aged (age 36-45), older (aged 46-60), and retirees (61 or older) (Kirmizioglu and Tuydes-Yaman, 2012).

Table 3.2 Sample size for ±3%, ±5%, ±7%, and ±10% precision levels where confidence level if 95% and P = 0.5

| **Size of population** | **Sample size (n) for precision (e) of** | | | |
|---|---|---|---|---|
| | **±3%** | **±5%** | **±7%** | **±10%** |
| 500 | a | 222 | 145 | 83 |
| 600 | a | 240 | 152 | 86 |
| 700 | a | 255 | 158 | 88 |
| 800 | a | 267 | 163 | 89 |
| 900 | a | 277 | 166 | 90 |
| 1,000 | a | 286 | 169 | 91 |
| 2,000 | 714 | 333 | 185 | 95 |
| 3,000 | 811 | 353 | 191 | 97 |
| 4,000 | 870 | 364 | 194 | 98 |
| 5,000 | 909 | 370 | 196 | 98 |
| 6,000 | 938 | 375 | 197 | 98 |
| 7,000 | 959 | 378 | 198 | 99 |
| 8,000 | 976 | 381 | 199 | 99 |
| 9,000 | 989 | 383 | 200 | 99 |
| 10,000 | 1,000 | 385 | 200 | 99 |
| 15,000 | 1,034 | 390 | 201 | 99 |
| 20,000 | 1,053 | 392 | 204 | 100 |
| 25,000 | 1,064 | 394 | 204 | 100 |
| 50,000 | 1,087 | 397 | 204 | 100 |
| 100,000 | 1,099 | 398 | 204 | 100 |
| >100,000 | 1,111 | 400 | 204 | 100 |

Source: Israel, 2013

In Thailand, October 2015, the number of driving licenses and transport personnel licenses is 29,997,028. 10% precision (e) levels was considered, therefore the sample size (n) is 100 in this study.

### 3.2.2 Relevance of traffic signs and causes of traffic accidents

The degree of relevancy between the context of traffic signs and causes of traffic accident are calculated by using Equation 8.

$$R_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \quad (8)$$

where,

$R_{ij}$ : degree of relevancy of missing/damaged of traffic sign j to the potential cause of traffic accident i

$x_{ij}$ : number of respondents who match the missing/damaged of traffic sign j to potential cause of accident i

$i$ : potential cause of traffic accident i (1 = speeding, 2 = channelization, 3 = overtaking, 4 = hazardous road condition, and 5 = causes related to pedestrians and animals)

$j$ : traffic sign type j

## 3.3 Traffic Sign Prioritization

The final step of this study is the prioritization of traffic sign replacement. Analytic Network Process (ANP) was used in the prioritizing process. Locations of traffic sign, levels of damaged sign, and traffic accident causes were considered as criteria.

### 3.3.1 Questionnaire preparation and data collection

Questionnaires were used as a research tool to collect data. The questionnaires were completed by three experts (two experts from the Department of Highway, and one expert from the university). Questionnaire consists of three parts: expert information, pairwise comparison of the clusters, and evaluation the level of elements of each cluster (Appendix C). The questionnaires were as followings:

1. Part I: Expert information
    1) Gender
        - Male
        - Female
    2) Age
    3) Educational level
        - High school
        - Bachelor’s Degree
        - Master’s Degree or above
    4) Organization and position
    5) Experience (years)
2. Part II and III: Evaluation the criterions and elements

The questionnaire of part II and III was designed for analysis the prioritization of traffic signs. To solve the problem, Analytic Network Process (ANP) was used in this step. A decision problem that is analyzed with the ANP is often through a control hierarchy or network. A decision network has clusters, elements, and links. A cluster is a collection of relevant elements within a network or sub-network. Each control criterion, the clusters of the system with their elements are determined. (Bayazit, 2002).

In this study, there are three clusters - physical locations of traffic sign, levels of damaged sign, and causes of traffic accident - and each of cluster consists of elements. Generally, ANP uses pairwise comparisons. However, to reduce the complexity of the interview, pairwise comparisons were used in the comparisons of criteria, while scorings using the Likert scale were used in the comparisons of elements.

ANP uses the fundamental scale (1-9), normally, the comparison scale enables the decision-maker to incorporate experience and knowledge and indicate how many times an element dominates another with respect to the criterion. It is a scale of absolute numbers (Bayazit, 2002). Never the less, in this study, the comparison scale of 1-5 were used. The definition of comparison scale used for decision-maker judgments is given in Table 3.3.

Table 3.3 The definition of comparison scale

| Intensity of Importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective |
| 2 | Moderate importance | Experience and judgement slightly favor one activity over another |
| 3 | Strong importance | Experience and judgement strongly favor one activity over another |
| 4 | Very strong or demonstrated importance | An activity is favored very strongly over another; its dominance demonstrated in practice |
| 5 | Extreme importance | The evidence favoring one activity over another is of the highest possible order of affirmation |

* Source: Adapted from Saaty, 2010

To compare elements in each cluster, the Likert scale was used in this step. The definition of the Likert scale used for judgments is given in Table 3.4.

Table 3.4 The definition of the Likert scale

| Very high | High | Moderate | Low | Very low |
|---|---|---|---|---|
| 5 | 4 | 3 | 2 | 1 |

### 3.3.2 Analytic Network Process (ANP) procedure

ANP is a methodology which applied to evaluate for prioritization traffic signs in this study. Refer to Saaty (2005), there are four main stages which were applied, described below:

1. Structuring of the decision-making problems

There are three clusters and each of clusters consists of elements: eight elements in physical locations of traffic sign, three elements of levels of damaged sign, and five elements of traffic accident causes. To easily understand, the criterions and their elements can be grouped as clusters, it is shown in Figure 3.1.

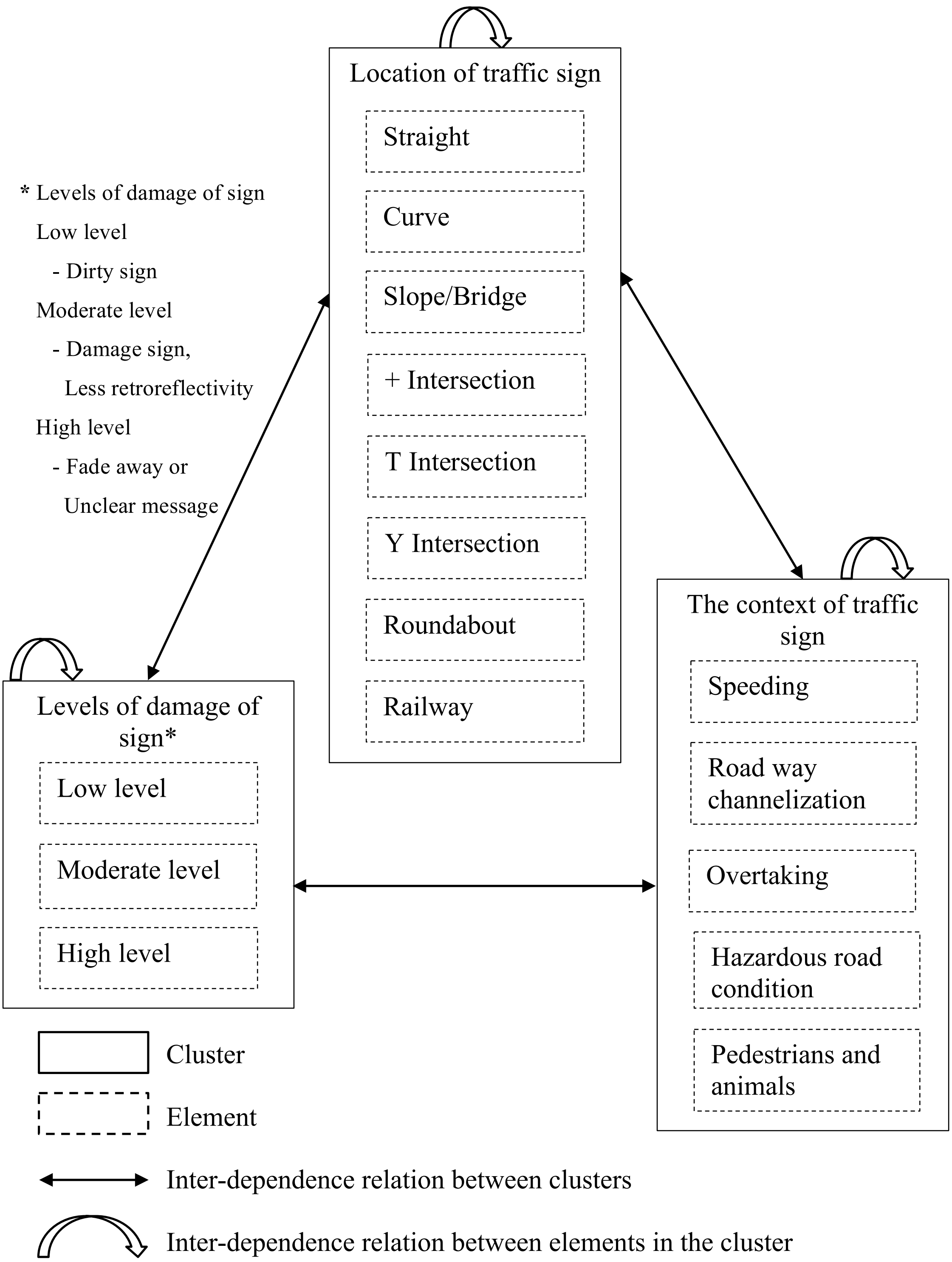



Figure 3.1 Structure of the ANP in this study

2. Making pairwise comparison and the Likert scale questionnaire

The series of pairwise comparison were made to find the relative importance of the elements with respect to a component of the network (Bottero et al., 2007). In this study, pairwise comparison of clusters (physical locations of traffic sign, levels of damaged sign, and causes of traffic accident) were used by using a ratio scale of 1 to 5 as given in Table 3.3. There are three series of cluster comparison:

- Physical locations of traffic sign – Levels of damaged sign
- Physical locations of traffic sign – Traffic accident causes
- Levels of damaged sign – Traffic accident causes

3. Supermatrix formation

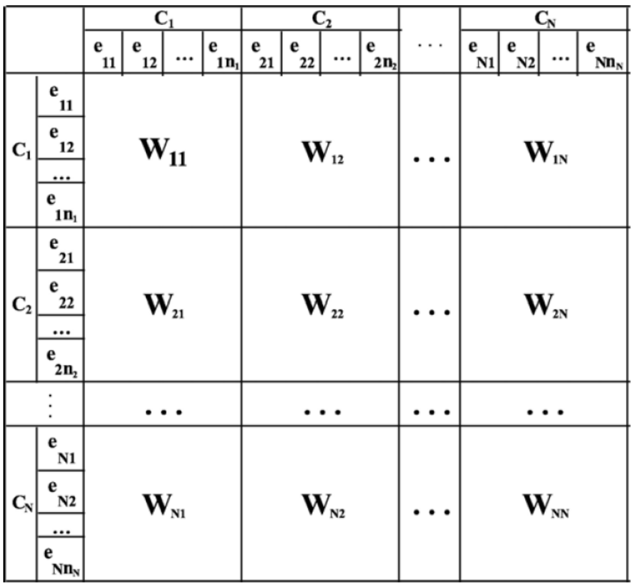



Figure 3.2 General structure of the supermatrix

where,

$C_i$ the $i$th cluster that has $j$ elements

$W_{ij}$ a priority vector calculated from the priority vector of the clusters multiple by the normalized priority vector of the elements, representing the importance of the elements in the $i$th cluster on an element in the $j$th cluster.

* If there is no relationship between clusters, the corresponding matrix segment is a zero.

* Source: Neaupane and Piantanakulchai, 2006

The priority vectors derived from the questionnaire part II and III were entered into columns of a supermatrix. The general stricter of a supermatrix is shown in Figure 3.2. In this study, there are two types of the technique for data collection (pairwise comparison, and the Likert scale). Therefore, the priority vector of the element which obtained in part III of the questionnaire must be normalized. The supermatrix is transformed into weighted which the sum of each column is one.

4. Final priority

The last step, the weighted supermatrix ($W_{ij}$) is transformed into the limiting supermatrix. The calculation of the limit supermatrix is given in equation (9).

$$\lim_{k \to \infty} W^k \tag{9}$$

If the supermatrix has the effect of cyclicity, there may be two or more N limiting supermatrices. In this case, the Cesaro sum is calculated as in Eq. (10) to get the average priority weights as follows (Neaupane and Piantanakulchai, 2006):

$$\lim_{k \to \infty} \left(\frac{1}{N}\right) \sum_{i=1}^{N} W_i^k \tag{10}$$

For this study, the calculations were programmed using MATLAB to find the limit supermatrix.

# Chapter 4
# Prioritization of Traffic Sign Replacement

Due to time and budget limitation, prioritization of traffic sign replacement is necessary. In this study, physical locations of traffic signs, levels of damaged signs, and traffic sign classifications (the context of traffic sign) are considered as indicators for prioritization. Because the prioritization of all traffic signs in the country is not practical due to excessive number of traffic signs to be considered. Identification hazardous locations by ranking is the first important step. This chapter presents the results of ranking of hazardous highway location/section and the results of ANP weights.

## 4.1 Hazardous Highway Location Ranking

History of traffic accidents on national highway in Thailand - accident rates, death rates, and injury rates - were used as indicators to identify 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).

Currently, in Thailand, the Department of Highways (DOH) uses accident 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). 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).

The identification of hazardous highway locations is the important first step for highway safety improvement. The accident rate, accident severity, and a newly developed combination are applied as a methodology - weights given by DOH and weights derived from Principal Component Analysis (PCA) - to determine the worst locations in this chapter. Moreover, two methods are compared in this part.

### 4.1.1 Hazardous highway district area ranking

The data set of 105 highway districts which highlighted by DOH as top hazardous location are obtained from Traffic Accident on National Highway annual report by DOH in 2011 – 2014.

The correlation matrix of indicators by district areas is shown in Table 4.1. For each highway district the average accident rate, the death rate, and the injury rate were compiled from most recent four years data. The correlation matrix shows that indicators used in the analysis are moderately to highly correlated.

Table 4.1 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 is 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 4.3. 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 4.2.

Table 4.2 Eigenvalue, proportion and eigenvector of each principal component (district area)

| 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 1.

$$PC1 = 0.56X_1 + 0.55X_2 + 0.62X_3 \quad (1)$$

From Equation 1, could adjusted to be the final equation of PCA. The equation is given as;

$$PCA = 0.32X_1 + 0.32\,X_2 + 0.36X_3 \quad (2)$$

The results of ranking of hazardous highway district area ranking by using PCA is identical with ranking by DOH criteria. From 105 highway districts, Phatthalung is the top on the rank. Whereas, the second rank to the tenth rank were switched. The ranking is shown in Table 4.3. Moreover, the top ranking results from both methods are almost the same set of highway districts.

Table 4.3 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 |

### 4.1.2 Hazardous highway section ranking

This section data consist of 38 hazardous highway sections reported by DOH. Due to the limited data, the reports in 2011 – 2014 are used for hazardous highway district areas ranking, and the ranking of hazardous highway sections used the data form the report in 2013.

The correlation matrix of indicators by highway sections is shown in Table 4.4. 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 4.4 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 3.6. Wang Chao – Tak being on the top ranking for the hazardous highway section. In section of the hazardous highway section ranking by using PCA is estimated to calculate the eigenvalues, proportions and eigenvectors of each PC. The result of the analysis is shown in Table 4.5.

Table 4.5 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.

$$PC1 = 0.58X_1 + 0.45X_2 + 0.68X_3 \quad (3)$$

$$PC2 = - 0.57X_1 + 0.82X_2 – 0.36X_3 \quad (4)$$

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

$$PCA = 0.17X_1 + 0.47X_2 + 0.36X_3 \quad (5)$$

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 4.6.

Table 4.6 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 |

### 4.1.3 Weighted score comparison

To identify hazardous highway locations in Thailand, both DOH criteria and PCA techniques are applied. The results of two techniques would be compared and shown as below.

#### 4.1.3.1 District area location

The two techniques indicated weight scores, which are summarized in Table 4.7. 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 4.7 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 |

#### 4.1.3.2 Section location

The ranking of hazardous highway section is 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 4.8.

Table 4.8 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 |

## 4.2 Linking the Context of Traffic Signs and Potential Causes of Traffic Accidents

This part proposes a method to classify importance of traffic signs by linking the context of traffic signs and potential causes of traffic accidents by drivers' perception. Five categories of traffic accident causes which related to traffic signs -

speeding, road way channelization, overtaking, hazardous road conditions, and causes related to pedestrians and animals - are considered. Results of study show distribution of related causes of traffic accidents which are relevant to each sign.

### 4.2.1 Background

Traffic sign comprehension is critical for effective driving. The driver comprehension process will have increased by level of education, level of urbanization of the residence, and driving daily practice of drivers (Ismali, 2012). The majority of causes of traffic accidents are due to driver mistakes and traffic violations. One major factor affecting safe driving is the comprehensibility of traffic signs by drivers (Kirmizioglu and Tuydes-Yaman, 2012).

The drivers' comprehension of traffic sings are able to understand and correctly identify 50 - 60% of the signs. Education, gender, income, and nationality have significant effect to understanding (Al-Madani and Al-Janahia, 2002). Furthermore, another study by Al-Madani and Al-Janahib (2002), role of drivers' personal characteristic in understanding traffic sign symbols. The study showed that percentage of correctly response to the signs by drivers is low. Middle-aged drivers (35 - 44 years) understand the signs significantly well than other groups.

### 4.2.2 Descriptive statistics

Questionnaires (Appendix B) were distributed to 124 drivers. The gender distribution is 53.23% female and 46.77% male, and the young age group (26-35) is the majority of respondents.

Table 4.9 Summary of driver characteristics (%)

| Age Group | Educational Background | | | Driving Experience | | | |
|---|---|---|---|---|---|---|---|
| | Secondary School | Bachelor's Degree | Master's Degree or Higher | 1-5 years | 6-10 years | 11-15 years | Over 16 years |
| 18-25 | 0.81 | 21.77 | 6.45 | 22.58 | 6.45 | - | - |
| 26-35 | 0.00 | 12.90 | 8.06 | 12.10 | 6.45 | 2.42 | - |
| 36-45 | 0.81 | 20.16 | 8.06 | 1.61 | 7.26 | 12.90 | 7.26 |
| 46-60 | 2.42 | 10.48 | 4.03 | 0.00 | 0.00 | 5.65 | 11.29 |
| 61 and over | 0.81 | 3.23 | 0.00 | 0.00 | 0.00 | 0.00 | 4.03 |

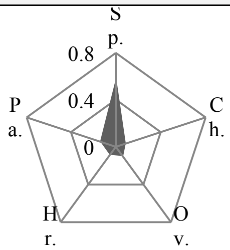
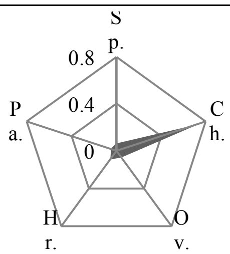
### 4.2.3 Relevance of traffic signs and potential causes of traffic accident

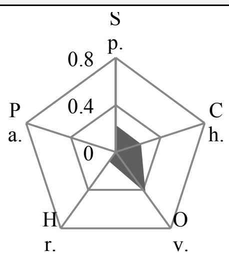
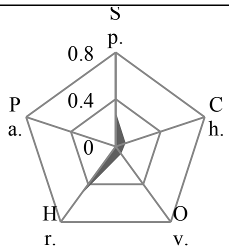
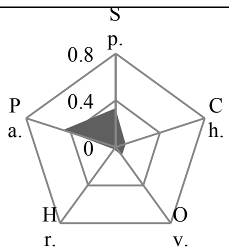
The results present drivers' comprehension of relevancies between traffic signs and traffic accident causes. In this study, only regulatory signs and warning signs were selected for analysis. Five potential causes of traffic accident are considered – speeding (Sp.), road way channelization (Ch.), Overtaking (Ov.), Hazardous road condition (Hr.), and causes related to pedestrians and animals (Pa.).

Selected 91 traffic signs consist of 40 regulatory signs and 51 warning signs. Examples of results selected from the highest relevancies in each potential cause of traffic accident are shown in Table 4.10, and whole results are shown in Appendix A.

The results can be interpreted as, for example, missing/damaged minimum speed limit sign has the highest degree of relevancy to the speeding. Interpretation in case of other signs can be done in similar way.

Table 4.10 Examples of results:
potential causes of traffic accident when the traffic sign is missing/damaged

| Traffic sign | Degree of relevancy | Potential cause of traffic accident | | | | |
|---|---|---|---|---|---|---|
| | | **Sp.** | **Ch.** | **Ov.** | **Hr.** | **Pa.** |
| <br><br>Minimum speed limit | <br> | 0.60* | 0.09 | 0.10 | 0.09 | 0.14 |
| <br>Left/Right turn prohibited | <br> | 0.06 | 0.73* | 0.07 | 0.09 | 0.05 |

| Traffic sign | Degree of relevancy | Potential cause of traffic accident | | | | |
|---|---|---|---|---|---|---|
| | | **Sp.** | **Ch.** | **Ov.** | **Hr.** | **Pa.** |
|  Overtaking prohibited |   | 0.23 | 0.23 | 0.43* | 0.10 | 0.01 |
|  Beware of fallen rocks |   | 0.30 | 0.09 | 0.08 | 0.53* | 0.00 |
|  Animal crossing |   | 0.33 | 0.09 | 0.09 | 0.02 | 0.47* |

* The highest degree of relevancy

Further analysis shows that the context of regulatory signs are mostly related to channelization, while the context of warning signs are mostly related to speeding.

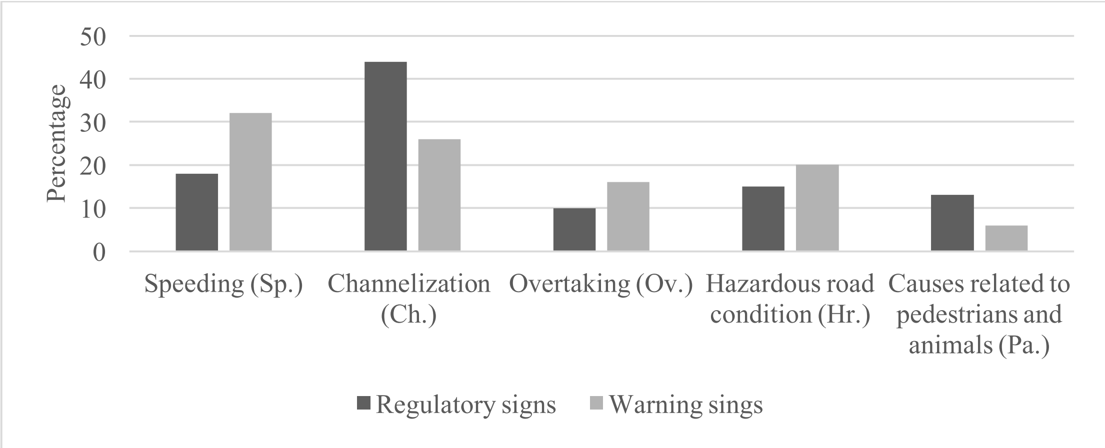



Figure 4.1 Comparison of the context of regulatory signs and warning signs related to potential causes of traffic accident

### 4.3 Prioritization of Traffic Sign Replacement

In this section, an approach to priority traffic signs for replacement will be presented. Data analysis were followed the ANP technique. Physical locations of traffic signs, levels of damaged signs, and traffic accident causes that related with the context of traffic sign (classification of traffic sign) are considered as indicators.

In order to data collection, face-to-face interviews were conducted by three selected experts with a transportation background. Their personal profiles are shown in Table 4.11.

Table 4.11 Personal profile of experts

| Expert | Educational level | Experience (years) | Career and Organization |
|---|---|---|---|
| 1 | Bachelor's Degree | 29 | Government officer<br>Department of Highway, Thailand |
| 2 | Bachelor's Degree | 5 | Government officer<br>Department of Highway, Thailand |
| 3 | Master's Degree or above | 15 | Lecturer/Researcher<br>University |

As earlier mentioned in section 3.3, pairwise comparison method was selected to evaluate criteria, and ranking by the Likert scale was selected for elements. In making paired comparisons of clusters, ratios were evaluated by using a 1 to 5 fundamental scale as given in Table 3.3 to compare two criteria with respect to an attribute. The paired comparisons for every pair are shown in Table 4.12 to 4.20 – criteria judgments with respect to physical location of traffic sign, level of damage of sign, and the context of traffic sign.

The pairwise comparisons with respect to location of traffic sign criteria are shown in Table 4.12 – 4.14. The first and the third experts considered that level of damage of sign criteria and the context of traffic sign criteria are equal importance. While, the second expert considered that the context of traffic sign criteria is very stronger or demonstrated important than level of damage of sign criteria.

Table 4.12 Pairwise comparison of the first expert: location of traffic sign

| **Location of traffic sign** | **Level of damage of sign** | **The context of traffic sign** | **Priorities** |
|---|---|---|---|
| Level of damage of sign | 1/1 | 1/1 | 0.50 |
| The context of traffic sign | 1/1 | 1/1 | 0.50 |

Table 4.13 Pairwise comparison of the second expert: location of traffic sign

| **Location of traffic sign** | **Level of damage of sign** | **The context of traffic sign** | **Priorities** |
|---|---|---|---|
| Level of damage of sign | 1/1 | 1/4 | 0.20 |
| The context of traffic sign | 4/1 | 1/1 | 0.80 |

Table 4.14 Pairwise comparison of the third expert: location of traffic sign

| **Location of traffic sign** | **Level of damage of sign** | **The context of traffic sign** | **Priorities** |
|---|---|---|---|
| Level of damage of sign | 1/1 | 1/1 | 0.50 |
| The context of traffic sign | 1/1 | 1/1 | 0.50 |

The paired comparisons with respect to level of damage of sign are shown in Table 4.15 – 4.17. The considering of the first expert, the context of traffic sign criteria is more extremely important than physical location of traffic sign. The second expert the context of traffic sign criteria is stronger important than physical location of traffic sign. Nevertheless, the third expert considered that the both criteria are equal importance.

Table 4.15 Pairwise comparison of the first expert: Level of damage of sign

| **Level of damage of sign** | **Location of traffic sign** | **The context of traffic sign** | **Priorities** |
|---|---|---|---|
| Location of traffic sign | 1/1 | 1/5 | 0.17 |
| The context of traffic sign | 5/1 | 1/1 | 0.83 |

Table 4.16 Pairwise comparison of the second expert: Level of damage of sign

| **Level of damage of sign** | **Location of traffic sign** | **The context of traffic sign** | **Priorities** |
|---|---|---|---|
| Location of traffic sign | 1/1 | 1/4 | 0.20 |
| The context of traffic sign | 4/1 | 1/1 | 0.80 |

Table 4.17 Pairwise comparison of the third expert: Level of damage of sign

| **Level of damage of sign** | **Location of traffic sign** | **The context of traffic sign** | **Priorities** |
|---|---|---|---|
| Location of traffic sign | 1/1 | 1/1 | 0.50 |
| The context of traffic sign | 1/1 | 1/1 | 0.50 |

The comparisons with respect to the context of traffic sign (traffic accident causes related with the context of traffic sign) are shown in Table 4.18 – 4.20. Considering of the first and the third expert is different, which the first expert considered level of damage of sign criteria as the first priority while the second expert considered physical location of traffic sign as the first priority. Nevertheless, the third expert still considered that the both criteria are equal importance.

Table 4.18 Pairwise comparison of the first expert: The context of traffic sign

| **The context of traffic sign** | **Location of traffic sign** | **Level of damage of sign** | **Priorities** |
|---|---|---|---|
| Location of traffic sign | 1/1 | 1/3 | 0.25 |
| Level of damage of sign | 3/1 | 1/1 | 0.75 |

Table 4.19 Pairwise comparison of the second expert: The context of traffic sign

| The context of traffic sign | Location of traffic sign | Level of damage of sign | Priorities |
|---|---|---|---|
| Location of traffic sign | 1/1 | 3/1 | 0.75 |
| Level of damage of sign | 1/3 | 1/1 | 0.25 |

Table 4.20 Pairwise comparison of the third expert: The context of traffic sign

| The context of traffic sign | Location of traffic sign | Level of damage of sign | Priorities |
|---|---|---|---|
| Location of traffic sign | 1/1 | 1/1 | 0.50 |
| Level of damage of sign | 1/1 | 1/1 | 0.50 |

The Linkert scale method were used to evaluate the elements with each respect cluster. The priority vectors that are normalized from the Linkert scale method present in the appropriate column of the initial supermatrix (Table 4.21 to 4.23). Then, the priority weights obtained from the ANP model were multiplied with the cell attributes (weighted score of elements in each cluster multiply by priority of each criteria which respect to each attribute). The weighted supermatrix are presented in Table 4.24 to 4.26. Generated the limiting supermatrix presented in Table 4.27 to 4.29.

Table 4.21 Initial supermatrix: The first expert

| Initial | | Physical location of traffic sign | | | | | | | | Level of damage of sign | | | The context of traffic sign | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **P1** | **P2** | **P3** | **P4** | **P5** | **P6** | **P7** | **P8** | **L1** | **L2** | **L3** | **C1** | **C2** | **C3** | **C4** | **C5** |
| **Physical location of traffic sign** | **P1** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1250 | 0.1304 | 0.1333 | 0.1316 | 0.0345 | 0.0789 | 0.1000 | 0.1515 |
| | **P2** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1875 | 0.1739 | 0.1667 | 0.1053 | 0.0690 | 0.1316 | 0.1333 | 0.1212 |
| | **P3** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1875 | 0.1739 | 0.1667 | 0.1053 | 0.0345 | 0.1316 | 0.1000 | 0.1515 |
| | **P4** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1250 | 0.1304 | 0.1333 | 0.1316 | 0.1724 | 0.1316 | 0.1333 | 0.1515 |
| | **P5** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1250 | 0.1304 | 0.1333 | 0.1316 | 0.1724 | 0.1316 | 0.1333 | 0.1515 |
| | **P6** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1250 | 0.1304 | 0.1333 | 0.1316 | 0.1724 | 0.1316 | 0.1333 | 0.1515 |
| | **P7** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0625 | 0.0870 | 0.1000 | 0.1316 | 0.1724 | 0.1316 | 0.1333 | 0.0606 |
| | **P8** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0625 | 0.0435 | 0.0333 | 0.1316 | 0.1724 | 0.1316 | 0.1333 | 0.0606 |
| **Level of damage of sign** | **L1** | 0.2222 | 0.2500 | 0.2500 | 0.2222 | 0.2222 | 0.2222 | 0.1667 | 0.3333 | 0.0000 | 0.0000 | 0.0000 | 0.2222 | 0.2222 | 0.2500 | 0.2222 | 0.2222 |
| | **L2** | 0.3333 | 0.3333 | 0.3333 | 0.3333 | 0.3333 | 0.3333 | 0.3333 | 0.3333 | 0.0000 | 0.0000 | 0.0000 | 0.3333 | 0.3333 | 0.3333 | 0.3333 | 0.3333 |
| | **L3** | 0.4444 | 0.4167 | 0.4167 | 0.4444 | 0.4444 | 0.4444 | 0.5000 | 0.3333 | 0.0000 | 0.0000 | 0.0000 | 0.4444 | 0.4444 | 0.4167 | 0.4444 | 0.4444 |
| **The context of traffic sign** | **C1** | 0.2941 | 0.2105 | 0.2222 | 0.2083 | 0.2083 | 0.2083 | 0.2381 | 0.2381 | 0.1818 | 0.1875 | 0.1905 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | **C2** | 0.0588 | 0.1053 | 0.0556 | 0.2083 | 0.2083 | 0.2083 | 0.2381 | 0.2381 | 0.1818 | 0.1875 | 0.1905 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | **C3** | 0.1765 | 0.2632 | 0.2778 | 0.2083 | 0.2083 | 0.2083 | 0.2381 | 0.2381 | 0.2727 | 0.2500 | 0.2381 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | **C4** | 0.1765 | 0.2105 | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1905 | 0.1905 | 0.1818 | 0.1875 | 0.1905 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | **C5** | 0.2941 | 0.2105 | 0.2778 | 0.2083 | 0.2083 | 0.2083 | 0.0952 | 0.0952 | 0.1818 | 0.1875 | 0.1905 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Table 4.22 Initial supermatrix: The second expert

| Initial | | Physical location of traffic sign | | | | | | | | Level of damage of sign | | | The context of traffic sign | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | L1 | L2 | L3 | C1 | C2 | C3 | C4 | C5 |
| Physical location of traffic sign | P1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1250 | 0.1600 | 0.1600 | 0.1923 | 0.1250 | 0.1923 | 0.1316 | 0.1786 |
| | P2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1875 | 0.1600 | 0.1600 | 0.1154 | 0.0833 | 0.1154 | 0.1316 | 0.1071 |
| | P3 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1250 | 0.0800 | 0.0800 | 0.1154 | 0.1250 | 0.1154 | 0.1316 | 0.1071 |
| | P4 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1250 | 0.1200 | 0.1200 | 0.1154 | 0.1250 | 0.1154 | 0.1316 | 0.1429 |
| | P5 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1250 | 0.1200 | 0.1200 | 0.1154 | 0.1250 | 0.1154 | 0.1316 | 0.1429 |
| | P6 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1250 | 0.1200 | 0.1200 | 0.1154 | 0.1250 | 0.1154 | 0.1316 | 0.1429 |
| | P7 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1250 | 0.1200 | 0.1200 | 0.1154 | 0.1250 | 0.1154 | 0.0789 | 0.0714 |
| | P8 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0625 | 0.1200 | 0.1200 | 0.1154 | 0.1667 | 0.1154 | 0.1316 | 0.1071 |
| Level of damage of sign | L1 | 0.2000 | 0.2727 | 0.3333 | 0.2500 | 0.2500 | 0.2500 | 0.2500 | 0.1429 | 0.0000 | 0.0000 | 0.0000 | 0.2222 | 0.1667 | 0.1667 | 0.2222 | 0.2500 |
| | L2 | 0.4000 | 0.3636 | 0.3333 | 0.3750 | 0.3750 | 0.3750 | 0.3750 | 0.4286 | 0.0000 | 0.0000 | 0.0000 | 0.3333 | 0.3333 | 0.3333 | 0.3333 | 0.3333 |
| | L3 | 0.4000 | 0.3636 | 0.3333 | 0.3750 | 0.3750 | 0.3750 | 0.3750 | 0.4286 | 0.0000 | 0.0000 | 0.0000 | 0.4444 | 0.5000 | 0.5000 | 0.4444 | 0.4167 |
| The context of traffic sign | C1 | 0.2174 | 0.1875 | 0.1765 | 0.1667 | 0.1667 | 0.1667 | 0.2143 | 0.1364 | 0.2222 | 0.2143 | 0.2105 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | C2 | 0.1304 | 0.1250 | 0.1765 | 0.1667 | 0.1667 | 0.1667 | 0.2143 | 0.1818 | 0.1111 | 0.1429 | 0.1579 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | C3 | 0.2174 | 0.1875 | 0.1765 | 0.1667 | 0.1667 | 0.1667 | 0.2143 | 0.2273 | 0.1111 | 0.1429 | 0.1579 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | C4 | 0.2174 | 0.3125 | 0.2941 | 0.2778 | 0.2778 | 0.2778 | 0.2143 | 0.2273 | 0.2222 | 0.2143 | 0.2105 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | C5 | 0.2174 | 0.1875 | 0.1765 | 0.2222 | 0.2222 | 0.2222 | 0.1429 | 0.2273 | 0.3333 | 0.2857 | 0.2632 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Table 4.23 Initial supermatrix: The third expert

| Initial | | Physical location of traffic sign | | | | | | | | Level of damage of sign | | | The context of traffic sign | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | L1 | L2 | L3 | C1 | C2 | C3 | C4 | C5 |
| Physical location of traffic sign | P1 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0800 | 0.0909 | 0.0909 | 0.1250 | 0.1000 | 0.0909 | 0.1111 | 0.1250 |
| | P2 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1600 | 0.1515 | 0.1515 | 0.1563 | 0.1000 | 0.1515 | 0.1852 | 0.1250 |
| | P3 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1600 | 0.1515 | 0.1515 | 0.1563 | 0.1667 | 0.1515 | 0.1481 | 0.1250 |
| | P4 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1200 | 0.1212 | 0.1212 | 0.1250 | 0.1333 | 0.1212 | 0.1111 | 0.1250 |
| | P5 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1200 | 0.1212 | 0.1212 | 0.1250 | 0.1333 | 0.1212 | 0.1111 | 0.1250 |
| | P6 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1200 | 0.1212 | 0.1212 | 0.1250 | 0.1333 | 0.1212 | 0.1111 | 0.1250 |
| | P7 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0800 | 0.0909 | 0.0909 | 0.0938 | 0.1333 | 0.1212 | 0.1111 | 0.1250 |
| | P8 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1600 | 0.1515 | 0.1515 | 0.0938 | 0.1000 | 0.1212 | 0.1111 | 0.1250 |
| Level of damage of sign | L1 | 0.2222 | 0.2500 | 0.2500 | 0.2500 | 0.2500 | 0.2500 | 0.2222 | 0.2500 | 0.0000 | 0.0000 | 0.0000 | 0.2500 | 0.2500 | 0.2308 | 0.2500 | 0.2727 |
| | L2 | 0.3333 | 0.3333 | 0.3333 | 0.3333 | 0.3333 | 0.3333 | 0.3333 | 0.3333 | 0.0000 | 0.0000 | 0.0000 | 0.3333 | 0.3333 | 0.3846 | 0.3333 | 0.2727 |
| | L3 | 0.4444 | 0.4167 | 0.4167 | 0.4167 | 0.4167 | 0.4167 | 0.4444 | 0.4167 | 0.0000 | 0.0000 | 0.0000 | 0.4167 | 0.4167 | 0.3846 | 0.4167 | 0.4545 |
| The context of traffic sign | C1 | 0.2500 | 0.2174 | 0.1905 | 0.2500 | 0.2500 | 0.2500 | 0.2000 | 0.2667 | 0.1875 | 0.2000 | 0.2000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | C2 | 0.2000 | 0.2174 | 0.1905 | 0.2000 | 0.2000 | 0.2000 | 0.2667 | 0.2000 | 0.1875 | 0.2000 | 0.2000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | C3 | 0.2000 | 0.2174 | 0.2381 | 0.2000 | 0.2000 | 0.2000 | 0.2000 | 0.2000 | 0.2500 | 0.2000 | 0.2000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | C4 | 0.2000 | 0.2174 | 0.2381 | 0.2000 | 0.2000 | 0.2000 | 0.2000 | 0.2000 | 0.2500 | 0.2500 | 0.2500 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | C5 | 0.1500 | 0.1304 | 0.1429 | 0.1500 | 0.1500 | 0.1500 | 0.1333 | 0.1333 | 0.1250 | 0.1500 | 0.1500 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Table 4.24 Weighted supermatrix: The first expert

| Weighted | | Physical location of traffic sign | | | | | | | | Level of damage of sign | | | The context of traffic sign | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **P1** | **P2** | **P3** | **P4** | **P5** | **P6** | **P7** | **P8** | **L1** | **L2** | **L3** | **C1** | **C2** | **C3** | **C4** | **C5** |
| **Physical location of traffic sign** | **P1** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0213 | 0.0222 | 0.0227 | 0.0329 | 0.0086 | 0.0197 | 0.0250 | 0.0379 |
| | **P2** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0319 | 0.0296 | 0.0283 | 0.0263 | 0.0172 | 0.0329 | 0.0333 | 0.0303 |
| | **P3** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0319 | 0.0296 | 0.0283 | 0.0263 | 0.0086 | 0.0329 | 0.0250 | 0.0379 |
| | **P4** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0213 | 0.0222 | 0.0227 | 0.0329 | 0.0431 | 0.0329 | 0.0333 | 0.0379 |
| | **P5** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0213 | 0.0222 | 0.0227 | 0.0329 | 0.0431 | 0.0329 | 0.0333 | 0.0379 |
| | **P6** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0213 | 0.0222 | 0.0227 | 0.0329 | 0.0431 | 0.0329 | 0.0333 | 0.0379 |
| | **P7** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0106 | 0.0148 | 0.0170 | 0.0329 | 0.0431 | 0.0329 | 0.0333 | 0.0152 |
| | **P8** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0106 | 0.0074 | 0.0057 | 0.0329 | 0.0431 | 0.0329 | 0.0333 | 0.0152 |
| **Level of damage of sign** | **L1** | 0.1111 | 0.1250 | 0.1250 | 0.1111 | 0.1111 | 0.1111 | 0.0833 | 0.1667 | 0.0000 | 0.0000 | 0.0000 | 0.1667 | 0.1667 | 0.1875 | 0.1667 | 0.1667 |
| | **L2** | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.0000 | 0.0000 | 0.0000 | 0.2500 | 0.2500 | 0.2500 | 0.2500 | 0.2500 |
| | **L3** | 0.2222 | 0.2083 | 0.2083 | 0.2222 | 0.2222 | 0.2222 | 0.2500 | 0.1667 | 0.0000 | 0.0000 | 0.0000 | 0.3333 | 0.3333 | 0.3125 | 0.3333 | 0.3333 |
| **The context of traffic sign** | **C1** | 0.1471 | 0.1053 | 0.1111 | 0.1042 | 0.1042 | 0.1042 | 0.1190 | 0.1190 | 0.1509 | 0.1556 | 0.1581 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | **C2** | 0.0294 | 0.0526 | 0.0278 | 0.1042 | 0.1042 | 0.1042 | 0.1190 | 0.1190 | 0.1509 | 0.1556 | 0.1581 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | **C3** | 0.0882 | 0.1316 | 0.1389 | 0.1042 | 0.1042 | 0.1042 | 0.1190 | 0.1190 | 0.2264 | 0.2075 | 0.1976 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | **C4** | 0.0882 | 0.1053 | 0.0833 | 0.0833 | 0.0833 | 0.0833 | 0.0952 | 0.0952 | 0.1509 | 0.1556 | 0.1581 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | **C5** | 0.1471 | 0.1053 | 0.1389 | 0.1042 | 0.1042 | 0.1042 | 0.0476 | 0.0476 | 0.1509 | 0.1556 | 0.1581 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Table 4.25 Weighted supermatrix: The second expert

| Weighted | | Physical location of traffic sign | | | | | | | | Level of damage of sign | | | The context of traffic sign | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **P1** | **P2** | **P3** | **P4** | **P5** | **P6** | **P7** | **P8** | **L1** | **L2** | **L3** | **C1** | **C2** | **C3** | **C4** | **C5** |
| **Physical location of traffic sign** | **P1** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0250 | 0.0320 | 0.0320 | 0.1442 | 0.0938 | 0.1442 | 0.0987 | 0.1339 |
| | **P2** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0375 | 0.0320 | 0.0320 | 0.0865 | 0.0625 | 0.0865 | 0.0987 | 0.0804 |
| | **P3** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0250 | 0.0160 | 0.0160 | 0.0865 | 0.0938 | 0.0865 | 0.0987 | 0.0804 |
| | **P4** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0250 | 0.0240 | 0.0240 | 0.0865 | 0.0938 | 0.0865 | 0.0987 | 0.1071 |
| | **P5** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0250 | 0.0240 | 0.0240 | 0.0865 | 0.0938 | 0.0865 | 0.0987 | 0.1071 |
| | **P6** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0250 | 0.0240 | 0.0240 | 0.0865 | 0.0938 | 0.0865 | 0.0987 | 0.1071 |
| | **P7** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0250 | 0.0240 | 0.0240 | 0.0865 | 0.0938 | 0.0865 | 0.0592 | 0.0536 |
| | **P8** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0125 | 0.0240 | 0.0240 | 0.0865 | 0.1250 | 0.0865 | 0.0987 | 0.0804 |
| **Level of damage of sign** | **L1** | 0.0400 | 0.0545 | 0.0667 | 0.0500 | 0.0500 | 0.0500 | 0.0500 | 0.0286 | 0.0000 | 0.0000 | 0.0000 | 0.0556 | 0.0417 | 0.0417 | 0.0556 | 0.0625 |
| | **L2** | 0.0800 | 0.0727 | 0.0667 | 0.0750 | 0.0750 | 0.0750 | 0.0750 | 0.0857 | 0.0000 | 0.0000 | 0.0000 | 0.0833 | 0.0833 | 0.0833 | 0.0833 | 0.0833 |
| | **L3** | 0.0800 | 0.0727 | 0.0667 | 0.0750 | 0.0750 | 0.0750 | 0.0750 | 0.0857 | 0.0000 | 0.0000 | 0.0000 | 0.1111 | 0.1250 | 0.1250 | 0.1111 | 0.1042 |
| **The context of traffic sign** | **C1** | 0.1739 | 0.1500 | 0.1412 | 0.1333 | 0.1333 | 0.1333 | 0.1714 | 0.1091 | 0.1778 | 0.1714 | 0.1684 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | **C2** | 0.1043 | 0.1000 | 0.1412 | 0.1333 | 0.1333 | 0.1333 | 0.1714 | 0.1455 | 0.0889 | 0.1143 | 0.1263 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | **C3** | 0.1739 | 0.1500 | 0.1412 | 0.1333 | 0.1333 | 0.1333 | 0.1714 | 0.1818 | 0.0889 | 0.1143 | 0.1263 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | **C4** | 0.1739 | 0.2500 | 0.2353 | 0.2222 | 0.2222 | 0.2222 | 0.1714 | 0.1818 | 0.1778 | 0.1714 | 0.1684 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | **C5** | 0.1739 | 0.1500 | 0.1412 | 0.1778 | 0.1778 | 0.1778 | 0.1143 | 0.1818 | 0.2667 | 0.2286 | 0.2105 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Table 4.26 Weighted supermatrix: The third expert

| Weighted | | Physical location of traffic sign | | | | | | | | Level of damage of sign | | | The context of traffic sign | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **P1** | **P2** | **P3** | **P4** | **P5** | **P6** | **P7** | **P8** | **L1** | **L2** | **L3** | **C1** | **C2** | **C3** | **C4** | **C5** |
| **Physical location of traffic sign** | **P1** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0400 | 0.0455 | 0.0455 | 0.0625 | 0.0500 | 0.0455 | 0.0556 | 0.0625 |
| | **P2** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0800 | 0.0758 | 0.0758 | 0.0781 | 0.0500 | 0.0758 | 0.0926 | 0.0625 |
| | **P3** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0800 | 0.0758 | 0.0758 | 0.0781 | 0.0833 | 0.0758 | 0.0741 | 0.0625 |
| | **P4** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0600 | 0.0606 | 0.0606 | 0.0625 | 0.0667 | 0.0606 | 0.0556 | 0.0625 |
| | **P5** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0600 | 0.0606 | 0.0606 | 0.0625 | 0.0667 | 0.0606 | 0.0556 | 0.0625 |
| | **P6** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0600 | 0.0606 | 0.0606 | 0.0625 | 0.0667 | 0.0606 | 0.0556 | 0.0625 |
| | **P7** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0400 | 0.0455 | 0.0455 | 0.0469 | 0.0667 | 0.0606 | 0.0556 | 0.0625 |
| | **P8** | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0800 | 0.0758 | 0.0758 | 0.0469 | 0.0500 | 0.0606 | 0.0556 | 0.0625 |
| **Level of damage of sign** | **L1** | 0.1111 | 0.1250 | 0.1250 | 0.1250 | 0.1250 | 0.1250 | 0.1111 | 0.1250 | 0.0000 | 0.0000 | 0.0000 | 0.1250 | 0.1250 | 0.1154 | 0.1250 | 0.1364 |
| | **L2** | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.1667 | 0.0000 | 0.0000 | 0.0000 | 0.1667 | 0.1667 | 0.1923 | 0.1667 | 0.1364 |
| | **L3** | 0.2222 | 0.2083 | 0.2083 | 0.2083 | 0.2083 | 0.2083 | 0.2222 | 0.2083 | 0.0000 | 0.0000 | 0.0000 | 0.2083 | 0.2083 | 0.1923 | 0.2083 | 0.2273 |
| **The context of traffic sign** | **C1** | 0.1250 | 0.1087 | 0.0952 | 0.1250 | 0.1250 | 0.1250 | 0.1000 | 0.1333 | 0.0938 | 0.1000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | **C2** | 0.1000 | 0.1087 | 0.0952 | 0.1000 | 0.1000 | 0.1000 | 0.1333 | 0.1000 | 0.0938 | 0.1000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | **C3** | 0.1000 | 0.1087 | 0.1190 | 0.1000 | 0.1000 | 0.1000 | 0.1000 | 0.1000 | 0.1250 | 0.1000 | 0.1000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | **C4** | 0.1000 | 0.1087 | 0.1190 | 0.1000 | 0.1000 | 0.1000 | 0.1000 | 0.1000 | 0.1250 | 0.1250 | 0.1250 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | **C5** | 0.0750 | 0.0652 | 0.0714 | 0.0750 | 0.0750 | 0.0750 | 0.0667 | 0.0667 | 0.0625 | 0.0750 | 0.0750 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Table 4.27 Limiting supermatrix: The first expert

| Limiting | | Physical location of traffic sign | | | | | | | | Level of damage of sign | | | The context of traffic sign | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **P1** | **P2** | **P3** | **P4** | **P5** | **P6** | **P7** | **P8** | **L1** | **L2** | **L3** | **C1** | **C2** | **C3** | **C4** | **C5** |
| **Physical location of traffic sign** | **P1** | 0.0194 | 0.0194 | 0.0194 | 0.0194 | 0.0194 | 0.0194 | 0.0194 | 0.0194 | 0.0194 | 0.0194 | 0.0194 | 0.0194 | 0.0194 | 0.0194 | 0.0194 | 0.0194 |
| | **P2** | 0.0239 | 0.0239 | 0.0239 | 0.0239 | 0.0239 | 0.0239 | 0.0239 | 0.0239 | 0.0239 | 0.0239 | 0.0239 | 0.0239 | 0.0239 | 0.0239 | 0.0239 | 0.0239 |
| | **P3** | 0.0232 | 0.0232 | 0.0232 | 0.0232 | 0.0232 | 0.0232 | 0.0232 | 0.0232 | 0.0232 | 0.0232 | 0.0232 | 0.0232 | 0.0232 | 0.0232 | 0.0232 | 0.0232 |
| | **P4** | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 |
| | **P5** | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 |
| | **P6** | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 | 0.0241 |
| | **P7** | 0.0192 | 0.0192 | 0.0192 | 0.0192 | 0.0192 | 0.0192 | 0.0192 | 0.0192 | 0.0192 | 0.0192 | 0.0192 | 0.0192 | 0.0192 | 0.0192 | 0.0192 | 0.0192 |
| | **P8** | 0.0163 | 0.0163 | 0.0163 | 0.0163 | 0.0163 | 0.0163 | 0.0163 | 0.0163 | 0.0163 | 0.0163 | 0.0163 | 0.0163 | 0.0163 | 0.0163 | 0.0163 | 0.0163 |
| **Level of damage of sign** | **L1** | 0.0929 | 0.0929 | 0.0929 | 0.0929 | 0.0929 | 0.0929 | 0.0929 | 0.0929 | 0.0929 | 0.0929 | 0.0929 | 0.0929 | 0.0929 | 0.0929 | 0.0929 | 0.0929 |
| | **L2** | 0.1346 | 0.1346 | 0.1346 | 0.1346 | 0.1346 | 0.1346 | 0.1346 | 0.1346 | 0.1346 | 0.1346 | 0.1346 | 0.1346 | 0.1346 | 0.1346 | 0.1346 | 0.1346 |
| | **L3** | 0.1762 | 0.1762 | 0.1762 | 0.1762 | 0.1762 | 0.1762 | 0.1762 | 0.1762 | 0.1763 | 0.1763 | 0.1763 | 0.1762 | 0.1762 | 0.1762 | 0.1762 | 0.1762 |
| **The context of traffic sign** | **C1** | 0.0825 | 0.0825 | 0.0825 | 0.0825 | 0.0825 | 0.0825 | 0.0825 | 0.0825 | 0.0825 | 0.0825 | 0.0825 | 0.0825 | 0.0825 | 0.0825 | 0.0825 | 0.0825 |
| | **C2** | 0.0770 | 0.0770 | 0.0770 | 0.0770 | 0.0770 | 0.0770 | 0.0770 | 0.0770 | 0.0770 | 0.0770 | 0.0770 | 0.0770 | 0.0770 | 0.0770 | 0.0770 | 0.0770 |
| | **C3** | 0.1036 | 0.1036 | 0.1036 | 0.1036 | 0.1036 | 0.1036 | 0.1036 | 0.1036 | 0.1036 | 0.1036 | 0.1036 | 0.1036 | 0.1036 | 0.1036 | 0.1036 | 0.1036 |
| | **C4** | 0.0784 | 0.0784 | 0.0784 | 0.0784 | 0.0784 | 0.0784 | 0.0784 | 0.0784 | 0.0784 | 0.0784 | 0.0784 | 0.0784 | 0.0784 | 0.0784 | 0.0784 | 0.0784 |
| | **C5** | 0.0806 | 0.0806 | 0.0806 | 0.0806 | 0.0806 | 0.0806 | 0.0806 | 0.0806 | 0.0806 | 0.0806 | 0.0806 | 0.0806 | 0.0806 | 0.0806 | 0.0806 | 0.0806 |

Table 4.28 Limiting supermatrix: The second expert

| Limiting | | Physical location of traffic sign | | | | | | | | Level of damage of sign | | | The context of traffic sign | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **P1** | **P2** | **P3** | **P4** | **P5** | **P6** | **P7** | **P8** | **L1** | **L2** | **L3** | **C1** | **C2** | **C3** | **C4** | **C5** |
| **Physical location of traffic sign** | **P1** | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 | 0.0602 |
| | **P2** | 0.0436 | 0.0436 | 0.0436 | 0.0436 | 0.0436 | 0.0436 | 0.0436 | 0.0436 | 0.0436 | 0.0436 | 0.0436 | 0.0436 | 0.0436 | 0.0436 | 0.0436 | 0.0436 |
| | **P3** | 0.0430 | 0.0430 | 0.0430 | 0.0430 | 0.0430 | 0.0430 | 0.0430 | 0.0430 | 0.0430 | 0.0430 | 0.0430 | 0.0430 | 0.0430 | 0.0430 | 0.0430 | 0.0430 |
| | **P4** | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 |
| | **P5** | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 |
| | **P6** | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 | 0.0469 |
| | **P7** | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 | 0.0371 |
| | **P8** | 0.0458 | 0.0458 | 0.0458 | 0.0458 | 0.0458 | 0.0458 | 0.0458 | 0.0458 | 0.0458 | 0.0458 | 0.0458 | 0.0458 | 0.0458 | 0.0458 | 0.0458 | 0.0458 |
| **Level of damage of sign** | **L1** | 0.0412 | 0.0412 | 0.0412 | 0.0412 | 0.0412 | 0.0412 | 0.0412 | 0.0412 | 0.0412 | 0.0412 | 0.0412 | 0.0412 | 0.0412 | 0.0412 | 0.0412 | 0.0412 |
| | **L2** | 0.0651 | 0.0651 | 0.0651 | 0.0651 | 0.0651 | 0.0651 | 0.0651 | 0.0651 | 0.0651 | 0.0651 | 0.0651 | 0.0651 | 0.0651 | 0.0651 | 0.0651 | 0.0651 |
| | **L3** | 0.0788 | 0.0788 | 0.0788 | 0.0788 | 0.0788 | 0.0788 | 0.0788 | 0.0788 | 0.0788 | 0.0788 | 0.0788 | 0.0788 | 0.0788 | 0.0788 | 0.0788 | 0.0788 |
| **The context of traffic sign** | **C1** | 0.0850 | 0.0850 | 0.0850 | 0.0850 | 0.0850 | 0.0850 | 0.0850 | 0.0850 | 0.0850 | 0.0850 | 0.0850 | 0.0850 | 0.0850 | 0.0850 | 0.0850 | 0.0850 |
| | **C2** | 0.0696 | 0.0696 | 0.0696 | 0.0696 | 0.0696 | 0.0696 | 0.0696 | 0.0696 | 0.0696 | 0.0696 | 0.0696 | 0.0696 | 0.0696 | 0.0696 | 0.0696 | 0.0696 |
| | **C3** | 0.0776 | 0.0776 | 0.0776 | 0.0776 | 0.0776 | 0.0776 | 0.0776 | 0.0776 | 0.0776 | 0.0776 | 0.0776 | 0.0776 | 0.0776 | 0.0776 | 0.0776 | 0.0776 |
| | **C4** | 0.1092 | 0.1092 | 0.1092 | 0.1092 | 0.1092 | 0.1092 | 0.1092 | 0.1092 | 0.1092 | 0.1092 | 0.1092 | 0.1092 | 0.1092 | 0.1092 | 0.1092 | 0.1092 |
| | **C5** | 0.1031 | 0.1031 | 0.1031 | 0.1031 | 0.1031 | 0.1031 | 0.1031 | 0.1031 | 0.1031 | 0.1031 | 0.1031 | 0.1031 | 0.1031 | 0.1031 | 0.1031 | 0.1031 |

Table 4.29 Limiting supermatrix: The third expert

| Limiting | | Physical location of traffic sign | | | | | | | | Level of damage of sign | | | The context of traffic sign | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | L1 | L2 | L3 | C1 | C2 | C3 | C4 | C5 |
| Physical location of traffic sign | P1 | 0.0330 | 0.0330 | 0.0330 | 0.0330 | 0.0330 | 0.0330 | 0.0330 | 0.0330 | 0.0330 | 0.0330 | 0.0330 | 0.0330 | 0.0330 | 0.0330 | 0.0330 | 0.0330 |
| | P2 | 0.0499 | 0.0499 | 0.0499 | 0.0499 | 0.0499 | 0.0499 | 0.0499 | 0.0499 | 0.0499 | 0.0499 | 0.0499 | 0.0499 | 0.0499 | 0.0499 | 0.0499 | 0.0499 |
| | P3 | 0.0508 | 0.0508 | 0.0508 | 0.0508 | 0.0508 | 0.0508 | 0.0508 | 0.0508 | 0.0508 | 0.0508 | 0.0508 | 0.0508 | 0.0508 | 0.0508 | 0.0508 | 0.0508 |
| | P4 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 |
| | P5 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 |
| | P6 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 | 0.0406 |
| | P7 | 0.0340 | 0.0340 | 0.0340 | 0.0340 | 0.0340 | 0.0340 | 0.0340 | 0.0340 | 0.0340 | 0.0340 | 0.0340 | 0.0340 | 0.0340 | 0.0340 | 0.0340 | 0.0340 |
| | P8 | 0.0438 | 0.0438 | 0.0438 | 0.0438 | 0.0438 | 0.0438 | 0.0438 | 0.0438 | 0.0438 | 0.0438 | 0.0438 | 0.0438 | 0.0438 | 0.0438 | 0.0438 | 0.0438 |
| Level of damage of sign | L1 | 0.0823 | 0.0823 | 0.0823 | 0.0823 | 0.0823 | 0.0823 | 0.0823 | 0.0823 | 0.0823 | 0.0823 | 0.0823 | 0.0823 | 0.0823 | 0.0823 | 0.0823 | 0.0823 |
| | L2 | 0.1115 | 0.1115 | 0.1115 | 0.1115 | 0.1115 | 0.1115 | 0.1115 | 0.1115 | 0.1115 | 0.1115 | 0.1115 | 0.1115 | 0.1115 | 0.1115 | 0.1115 | 0.1115 |
| | L3 | 0.1396 | 0.1396 | 0.1396 | 0.1396 | 0.1396 | 0.1396 | 0.1396 | 0.1396 | 0.1396 | 0.1396 | 0.1396 | 0.1396 | 0.1396 | 0.1396 | 0.1396 | 0.1396 |
| The context of traffic sign | C1 | 0.0717 | 0.0717 | 0.0717 | 0.0717 | 0.0717 | 0.0717 | 0.0717 | 0.0717 | 0.0717 | 0.0717 | 0.0717 | 0.0717 | 0.0717 | 0.0717 | 0.0717 | 0.0717 |
| | C2 | 0.0675 | 0.0675 | 0.0675 | 0.0675 | 0.0675 | 0.0675 | 0.0675 | 0.0675 | 0.0675 | 0.0675 | 0.0675 | 0.0675 | 0.0675 | 0.0675 | 0.0675 | 0.0675 |
| | C3 | 0.0701 | 0.0701 | 0.0701 | 0.0701 | 0.0701 | 0.0701 | 0.0701 | 0.0701 | 0.0701 | 0.0701 | 0.0701 | 0.0701 | 0.0701 | 0.0701 | 0.0701 | 0.0701 |
| | C4 | 0.0764 | 0.0764 | 0.0764 | 0.0764 | 0.0764 | 0.0764 | 0.0764 | 0.0764 | 0.0764 | 0.0764 | 0.0764 | 0.0764 | 0.0764 | 0.0764 | 0.0764 | 0.0764 |
| | C5 | 0.0477 | 0.0477 | 0.0477 | 0.0477 | 0.0477 | 0.0477 | 0.0477 | 0.0477 | 0.0477 | 0.0477 | 0.0477 | 0.0477 | 0.0477 | 0.0477 | 0.0477 | 0.0477 |

The results of the priorities of elements with represent to each criteria are shown in Table 4.30 and Figure 4.2.

Table 4.30 Average of weighted scores of elements for traffic sign replacement

| Criteria | Element | Expert | | | Average |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | |
| Physical location of traffic sign | P1 – Straight | 0.0194 | 0.0602 | 0.0330 | 0.0375 |
| | P2 – Curve | 0.0239 | 0.0436 | 0.0499 | 0.0392 |
| | P3 – Slope/Bridge | 0.0232 | 0.0430 | 0.0508 | 0.0390 |
| | P4 – + Intersection | 0.0241 | 0.0469 | 0.0406 | 0.0372 |
| | P5 – T Intersection | 0.0241 | 0.0469 | 0.0406 | 0.0372 |
| | P6 – Y Intersection | 0.0241 | 0.0469 | 0.0406 | 0.0372 |
| | P7 – Roundabout | 0.0192 | 0.0371 | 0.0340 | 0.0301 |
| | P8 – Railway | 0.0163 | 0.0458 | 0.0438 | 0.0353 |
| Level of damage of sign | L1 – Low | 0.0929 | 0.0412 | 0.0823 | 0.0721 |
| | L2 – Moderate | 0.1346 | 0.0651 | 0.1115 | 0.1037 |
| | L3 – High | 0.1762 | 0.0788 | 0.1396 | 0.1315 |
| The context of traffic sign | C1 – Speeding | 0.0825 | 0.0850 | 0.0717 | 0.0797 |
| | C2 – Road way channelization | 0.0770 | 0.0696 | 0.0675 | 0.0714 |
| | C3 – Overtaking | 0.1036 | 0.0776 | 0.0701 | 0.0838 |
| | C4 – Hazardous road condition | 0.0784 | 0.1092 | 0.0764 | 0.0880 |
| | C5 – Pedestrians and animals (related traffic accident causes) | 0.0806 | 0.1031 | 0.0477 | 0.0771 |

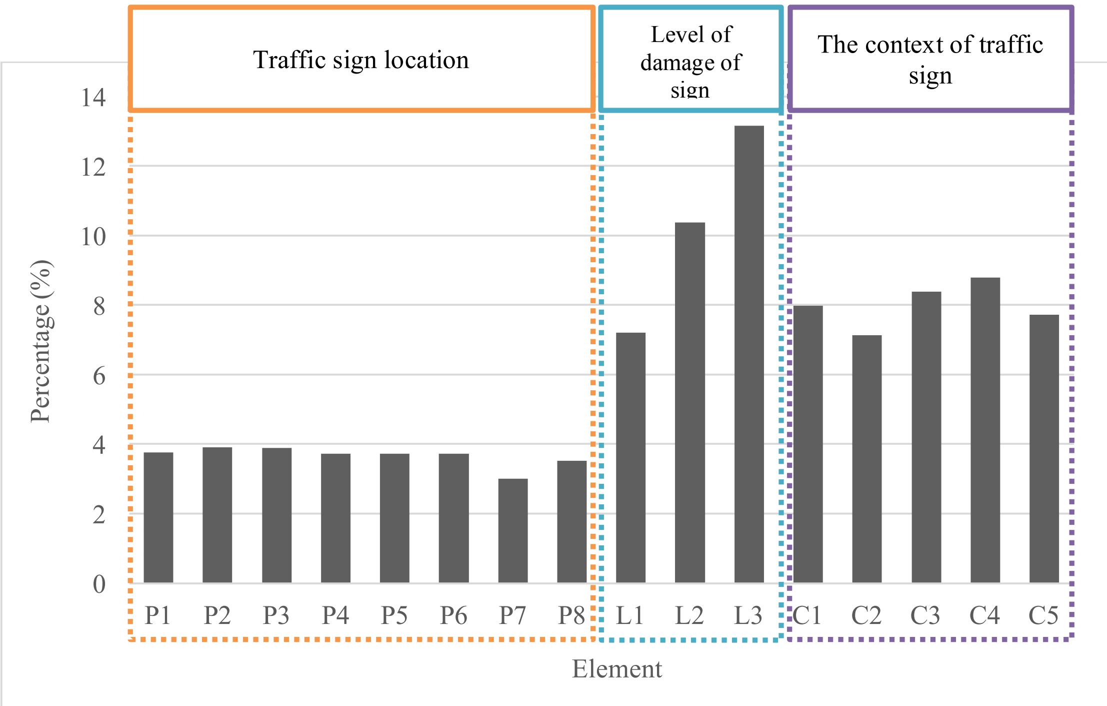



Figure 4.2 Weighted scores of priority of traffic sign replacement

The results show traffic signs that of high damaged level is the first priority (13.15%). The second priority is traffic signs that are moderate damaged level (10.37%). The third priority is physical location of traffic sign where is roundabout (3.01%). For 12$^{th}$ ranking, physical location of traffic sign at + intersection, T intersection, and Y intersection are same ranking and priority (3.72%).

## 4.4 Application for traffic sign replacement prioritization

This hypothetical example shows to how the method can be used to prioritize the replacement of traffic signs in various situations. In this example, minimum speed limit sign and no right turn sign are to be replaced. For the sake of illustration, only locations of traffic signs and potential causes of traffic accident are considered as related factors in the decision making. The criteria and its weight are supposed to be provided as shown in Table 4.10 and 4.30.

Suppose a minimum speed limit sign was installed at the vicinity of a highway's curve (0.3920) and no right turn sign was installed at the vicinity of an intersection (0.0372). In addition, a minimum speed limit sign is dirty sign (0.0721), and a no right turn sign is fade away (0.1315). What sign should be given more priority? Example of calculation is shown below by using weighted scores.

$$P_1 = (0.3920) + (0.0721) + (0.0797 * 0.6000) + (0.0714 * 0.1100) + (0.0838 * 0.0800) + (0.0880 * 0.0900) + (0.0771 * 0.1300)$$
$$= 0.1916$$
$$P_2 = (0.0372) + (0.1315) + (0.0797 * 0.0400) + (0.0714 * 0.7400) + (0.0838 * 0.0700) + (0.0880 * 0.0900) + (0.0771 * 0.0600)$$
$$= 0.2431$$

It is noted that, in this situation, the priority of replacing a no right turn sign (24.31%) is higher than a minimum speed limit sign (19.16%).

# Chapter 5
# Conclusion and Recommendations

## 5.1 Conclusion and Discussion

The first part of analysis to rank hazardous highway locations in Thailand. The hazardous highway ranking could be used to road prioritization for implementation or maintenance. Nowadays, Department of Highway (DOH) assigns weights to evaluate hazardous highway locations. Death rate (50%) is the highest priority in DOH criteria. Second priority of weighted score by DOH criteria is injury rate (30%). The least priority of weights by DOH criteria is accident rate (20%).

In practice, highways where there are more traffic accidents (high accident rate) but less death rate is difficult to compare with highways where less accident rate and less death rate are. Therefore, the author applied PCA technique to find weighted scores of each factors (accident rate, injury rate, and death rate). The results found that the weighted scores by DOH criteria and derived from PCA technique are different for the ranking hazardous highway district area. But, the weighted scores of the both approaches at hazardous highway section are similar. The results of implantation for ranking the hazardous highway district areas are similar. The hazardous highway district areas were ranked by the weights given from DOH criteria and derived from PCA technique is resemble as Phatthalung is the top rank of the hazardous highway district areas. From the traffic accident report, Phatthalung has high accident rate and injury rate, although death rate is lower than other districts. Moreover, during New Year in 2016, the statistic of accident rate and injury rate in Patthalung are decreased but death rate is increased. It shows that the severity of traffic accident has been increasing in the district. The main factor that cause traffic accidents is speeding (Provincial Public Relations Office, Phatthalung, 2016).

Two approaches have given almost similar results and ranking on hazardous highway sections. Although, the weighted scores of hazardous highway district area were ranked by DOH criteria and PCA technique are different. Thus, PCA technique provides an alternative ranking scheme which does not require subjective judgment of weights aside from the state of practice that the DOH criteria is currently using.

To identify the importance of traffic signs, linking between the context of traffic signs and potential causes of traffic accident by drivers' perception was applied. Not only a traffic accident cause relates pre a traffic sign, but a traffic sign can be related to several traffic accident causes, which depended on road users' comprehension. The results found that drivers comprehend more than one meaning of traffic signs. The context of traffic signs can be related to potential causes of traffic accidents (speeding, roadway channelization, overtaking, hazardous road condition, and causes related to pedestrian and animal). However, the importance of traffic signs does not only depend on type of their meaning, but also their surrounding conditions.

In order to prioritize traffic signs replacement in Thailand, Analytic Network Process (ANP) technique was applied in this study. Three criteria – physical locations of traffic signs, level of damage of signs, and the context of traffic signs – were considered as a control criterion for prioritization. At cluster level, the level of damage of sign reveals the highest priority. The second priority is the context of traffic signs, and the lowest priority is locations of traffic signs. While the element level, a fade away or unclear message sign is the most important factor for traffic sign replacement.

In practice, nowadays, an agency who is response to replace traffic signs does not priority traffic signs. Moreover, there is no guideline for prioritization of traffic sign replacement. Therefore, weighted scores of element or criteria can be applied to be a replacement plan for priority the importance of traffic signs by considering the relative elements surrounding damaged signs.

The prioritization of traffic sign replacement, it should be noted that, not only importance of traffic signs but also other criteria such as traffic sign location, history of traffic accidents, level of damage of traffic sign, etc. should be considered too. Assessment of importance of traffic sign using the concept proposed in this study can be applied as a part of the prioritization process of traffic sign replacement.

### 5.2 Recommendations

This study applied statistical data from traffic accident report to identify ranking of hazardous highway location. Because of limited data were used in this study, the ranking of hazardous highway section was calculated using only one year statistics. Moreover, investigating the significant factors that causes these highway areas and sections hazardous can be explored in the future.

In this study only damaged signs were considered which related factors such as location of traffic signs, level of damage of signs, and the context of traffic signs. However, deterioration of coloring and character of traffic signs was not considered and it is recommended for future studies.

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# Appendices

# Appendix A

## Traffic Signs in Thailand (Regulatory Signs and Warning Signs) and Scores Related to Potential Causes of Traffic Accident

| Traffic sign | Potential cause of traffic accident | | | | |
|---|---|---|---|---|---|
| | Sp. | Ch. | Ov. | Hr. | Pa. |
| ***Regulatory sign*** | | | | | |
|  STOP | 0.39 | 0.06 | 0.10 | 0.14 | 0.32 |
|  Give way | 0.22 | 0.24 | 0.22 | 0.07 | 0.25 |
|  Priority for oncoming traffic | 0.16 | 0.36 | 0.31 | 0.13 | 0.05 |
|  Overtaking prohibited | 0.23 | 0.23 | 0.43 | 0.10 | 0.01 |
|  No entry | 0.07 | 0.37 | 0.02 | 0.35 | 0.20 |
|  U-turns prohibited | 0.09 | 0.71 | 0.07 | 0.07 | 0.05 |

* Sp. – Speeding Ch. – Roadway chanelization Ov. – Overtaking Hr. –Hazardous road condition

Pa. – Causes related to pedestrians and animals

| Traffic sign | Potential cause of traffic accident | | | | |
|---|---|---|---|---|---|
| | Sp. | Ch. | Ov. | Hr. | Pa. |
|  Left/Right turn prohibited | 0.06 | 0.73 | 0.07 | 0.09 | 0.05 |
|  Lane change prohibited | 0.13 | 0.49 | 0.25 | 0.11 | 0.03 |
|  Left/Right or U-turn prohibited | 0.10 | 0.69 | 0.10 | 0.07 | 0.03 |
|  Motor vehicles except solo motor cycles prohibited | 0.09 | 0.34 | 0.01 | 0.29 | 0.27 |
|  Truck prohibited | 0.10 | 0.36 | 0.01 | 0.32 | 0.20 |
|  Solo motor cycles prohibited | 0.13 | 0.42 | 0.04 | 0.22 | 0.19 |
|  Caravan prohibited | 0.07 | 0.41 | 0.04 | 0.32 | 0.17 |
|  Three-wheel motor vehicles prohibited | 0.12 | 0.43 | 0.03 | 0.28 | 0.14 |

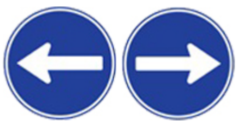
* Sp. – Speeding  Ch. – Roadway chanelization  Ov. – Overtaking  Hr. –Hazardous road condition

Pa. – Causes related to pedestrians and animals

| Traffic sign | Potential cause of traffic accident | | | | |
|---|---|---|---|---|---|
| | Sp. | Ch. | Ov. | Hr. | Pa. |
|  Three-wheel prohibited | 0.15 | 0.45 | 0.02 | 0.24 | 0.14 |
|  Cycles prohibited | 0.20 | 0.41 | 0.02 | 0.23 | 0.14 |
|  Hand carts direction prohibited | 0.21 | 0.43 | 0.06 | 0.19 | 0.11 |
|  Bullock carts prohibited | 0.18 | 0.40 | 0.06 | 0.25 | 0.11 |
|  Animal-drawn vehicles prohibited | 0.17 | 0.42 | 0.02 | 0.23 | 0.16 |
|  Motor vehicles prohibited | 0.15 | 0.32 | 0.07 | 0.24 | 0.22 |
|  Cycles, three-wheeler, and hand carts direction prohibited | 0.18 | 0.44 | 0.02 | 0.21 | 0.16 |
|  Solo motor cycles and three-wheel motor vehicles prohibited | 0.16 | 0.42 | 0.05 | 0.21 | 0.16 |

* Sp. – Speeding    Ch. – Roadway chanelization    Ov. – Overtaking    Hr. –Hazardous road condition

Pa. – Causes related to pedestrians and animals

| Traffic sign | Potential cause of traffic accident | | | | |
| --- | --- | --- | --- | --- | --- |
| | **Sp.** | **Ch.** | **Ov.** | **Hr.** | **Pa.** |
|  Horn prohibited | 0.09 | 0.14 | 0.07 | 0.00 | 0.71 |
|  Pedestrian prohibited | 0.19 | 0.17 | 0.02 | 0.22 | 0.41 |
|  Restricted zone | 0.10 | 0.48 | 0.03 | 0.18 | 0.21 |
|  No stopping or standing | 0.21 | 0.45 | 0.07 | 0.14 | 0.13 |
|   STOP Police | 0.40 | 0.29 | 0.10 | 0.07 | 0.14 |
|  Left/right turn | 0.14 | 0.59 | 0.17 | 0.08 | 0.03 |
|  Keep left/right | 0.16 | 0.59 | 0.16 | 0.07 | 0.01 |
|  Pass either side | 0.17 | 0.60 | 0.16 | 0.04 | 0.03 |

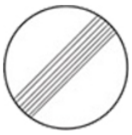
* Sp. – Speeding Ch. – Roadway chanelization Ov. – Overtaking Hr. –Hazardous road condition

Pa. – Causes related to pedestrians and animals

| Traffic sign | Potential cause of traffic accident | | | | |
|---|---|---|---|---|---|
| | Sp. | Ch. | Ov. | Hr. | Pa. |
|  Turn left/right | 0.17 | 0.62 | 0.14 | 0.05 | 0.03 |
|  Left/Right optional lane | 0.17 | 0.63 | 0.12 | 0.06 | 0.02 |
|  Left/Right straight optional lane | 0.17 | 0.59 | 0.17 | 0.06 | 0.02 |
|  Roundabout | 0.25 | 0.49 | 0.18 | 0.03 | 0.05 |
|  Compulsory bus lane | 0.16 | 0.72 | 0.00 | 0.00 | 0.12 |
|  Compulsory mass transit lane | 0.15 | 0.68 | 0.08 | 0.06 | 0.04 |
|  Compulsory solo motor cycles | 0.17 | 0.65 | 0.08 | 0.05 | 0.05 |
|  Compulsory cycles | 0.15 | 0.64 | 0.08 | 0.03 | 0.10 |

* Sp. – Speeding Ch. – Roadway chanelization Ov. – Overtaking Hr. –Hazardous road condition

Pa. – Causes related to pedestrians and animals

| Traffic sign | Potential cause of traffic accident | | | | |
| --- | --- | --- | --- | --- | --- |
| | Sp. | Ch. | Ov. | Hr. | Pa. |
|  Compulsory pedestrian | 0.16 | 0.46 | 0.05 | 0.00 | 0.34 |
|   Minimum speed limit | 0.59 | 0.09 | 0.10 | 0.09 | 0.14 |
|  Restriction ends sign | 0.32 | 0.33 | 0.17 | 0.10 | 0.09 |
| ***Warning sign*** | | | | | |
|  Bend ahead | 0.35 | 0.25 | 0.24 | 0.14 | 0.01 |
|  Turn left/right ahead | 0.33 | 0.23 | 0.24 | 0.19 | 0.00 |
|  Bend ahead | 0.32 | 0.26 | 0.23 | 0.18 | 0.01 |
|  Bend ahead | 0.33 | 0.23 | 0.23 | 0.20 | 0.00 |
|  Double bend ahead | 0.32 | 0.22 | 0.24 | 0.22 | 0.00 |

* Sp. – Speeding  Ch. – Roadway chanelization  Ov. – Overtaking  Hr. –Hazardous road condition

Pa. – Causes related to pedestrians and animals

| Traffic sign | Potential cause of traffic accident | | | | |
|---|---|---|---|---|---|
| | Sp. | Ch. | Ov. | Hr. | Pa. |
|  Crossroads ahead | 0.31 | 0.32 | 0.20 | 0.10 | 0.07 |
|  Y-intersection ahead | 0.33 | 0.33 | 0.22 | 0.11 | 0.01 |
|  Side road left/right ahead | 0.34 | 0.33 | 0.21 | 0.10 | 0.01 |
|  Staggered intersection ahead | 0.34 | 0.35 | 0.20 | 0.10 | 0.01 |
|  Traffic merges ahead from the left/right | 0.36 | 0.33 | 0.19 | 0.10 | 0.03 |
|  Escape lane ahead | 0.36 | 0.35 | 0.18 | 0.09 | 0.01 |
|  Roundabout ahead | 0.33 | 0.35 | 0.17 | 0.12 | 0.02 |
|  Road narrow on both sides ahead | 0.28 | 0.27 | 0.22 | 0.22 | 0.00 |

* Sp. – Speeding Ch. – Roadway chanelization Ov. – Overtaking Hr. –Hazardous road condition

Pa. – Causes related to pedestrians and animals

| Traffic sign | Potential cause of traffic accident | | | | |
|---|---|---|---|---|---|
| | **Sp.** | **Ch.** | **Ov.** | **Hr.** | **Pa.** |
|  Road narrow on left/right sides ahead | 0.29 | 0.28 | 0.22 | 0.22 | 0.00 |
|  Narrow bridge | 0.30 | 0.22 | 0.20 | 0.26 | 0.02 |
|  Left/Right lane end | 0.23 | 0.36 | 0.20 | 0.21 | 0.00 |
|  Level crossing without barriers | 0.35 | 0.16 | 0.13 | 0.18 | 0.18 |
|  Level crossing with barriers | 0.33 | 0.19 | 0.14 | 0.20 | 0.15 |
|  Highway-Rail Grade crossing closed to junction | 0.32 | 0.21 | 0.13 | 0.20 | 0.14 |
|   Road narrows | 0.20 | 0.28 | 0.15 | 0.37 | 0.00 |
|   Low clearance | 0.23 | 0.28 | 0.10 | 0.39 | 0.00 |

* Sp. – Speeding  Ch. – Roadway chanelization  Ov. – Overtaking  Hr. –Hazardous road condition

Pa. – Causes related to pedestrians and animals

| Traffic sign | Potential cause of traffic accident | | | | |
| --- | --- | --- | --- | --- | --- |
| | Sp. | Ch. | Ov. | Hr. | Pa. |
|   Dangerous descent / Steep ascent | 0.31 | 0.13 | 0.17 | 0.39 | 0.00 |
|  Road hump or series of road ahead | 0.36 | 0.09 | 0.10 | 0.40 | 0.05 |
|  Uneven road | 0.35 | 0.08 | 0.07 | 0.44 | 0.05 |
|  Dangerous dip | 0.37 | 0.06 | 0.09 | 0.46 | 0.01 |
|  Slippery road | 0.36 | 0.06 | 0.12 | 0.45 | 0.01 |
|  Loose chipping | 0.36 | 0.04 | 0.11 | 0.49 | 0.00 |
|  Falling rocks | 0.30 | 0.09 | 0.08 | 0.52 | 0.00 |
|  Opening bridge ahead | 0.28 | 0.20 | 0.07 | 0.44 | 0.01 |

* Sp. – Speeding Ch. – Roadway chanelization Ov. – Overtaking Hr. –Hazardous road condition

Pa. – Causes related to pedestrians and animals

| Traffic sign | Potential cause of traffic accident | | | | |
|---|---|---|---|---|---|
| | Sp. | Ch. | Ov. | Hr. | Pa. |
|  Lane cross over | 0.27 | 0.34 | 0.22 | 0.16 | 0.00 |
|  Exit to frontage road | 0.31 | 0.39 | 0.19 | 0.10 | 0.00 |
|  Main road entry | 0.31 | 0.39 | 0.19 | 0.11 | 0.00 |
|  Merging traffic | 0.29 | 0.39 | 0.24 | 0.08 | 0.00 |
|  Divided highway | 0.28 | 0.39 | 0.19 | 0.15 | 0.00 |
|  End of divided highway | 0.30 | 0.37 | 0.21 | 0.12 | 0.00 |
|  U-Turn ahead | 0.25 | 0.48 | 0.19 | 0.07 | 0.00 |
|  Two-way traffic ahead | 0.29 | 0.41 | 0.23 | 0.07 | 0.00 |

* Sp. – Speeding Ch. – Roadway chanelization Ov. – Overtaking Hr. –Hazardous road condition

Pa. – Causes related to pedestrians and animals

| Traffic sign | Potential cause of traffic accident | | | | |
|---|---|---|---|---|---|
| | Sp. | Ch. | Ov. | Hr. | Pa. |
|  Traffic signal ahead | 0.51 | 0.19 | 0.18 | 0.04 | 0.09 |
|   Stop sign ahead | 0.55 | 0.16 | 0.16 | 0.05 | 0.08 |
|   Yield sign ahead | 0.56 | 0.16 | 0.16 | 0.04 | 0.07 |
|  Pedestrian crossing | 0.33 | 0.11 | 0.12 | 0.02 | 0.41 |
|  School | 0.33 | 0.13 | 0.10 | 0.01 | 0.43 |
|  Animal crossing | 0.33 | 0.09 | 0.09 | 0.02 | 0.47 |
|  Low flying aircraft | 0.37 | 0.19 | 0.05 | 0.10 | 0.29 |
|   Other danger ahead | 0.30 | 0.12 | 0.13 | 0.25 | 0.20 |

* Sp. – Speeding    Ch. – Roadway chanelization    Ov. – Overtaking    Hr. –Hazardous road condition

Pa. – Causes related to pedestrians and animals

| Traffic sign | Potential cause of traffic accident | | | | |
|---|---|---|---|---|---|
| | Sp. | Ch. | Ov. | Hr. | Pa. |
|  No passing zone | 0.26 | 0.16 | 0.35 | 0.13 | 0.09 |
|  Double arrow | 0.25 | 0.36 | 0.18 | 0.19 | 0.02 |
|  Transition alignment | 0.30 | 0.46 | 0.17 | 0.07 | 0.00 |
|  Transition alignment | 0.30 | 0.46 | 0.17 | 0.07 | 0.00 |
|  Transition alignment | 0.33 | 0.43 | 0.16 | 0.08 | 0.00 |
|  Transition alignment | 0.33 | 0.31 | 0.12 | 0.22 | 0.03 |
|  Alternate Merging | 0.29 | 0.38 | 0.21 | 0.11 | 0.00 |

* Sp. – Speeding Ch. – Roadway chanelization Ov. – Overtaking Hr. –Hazardous road condition

Pa. – Causes related to pedestrians and animals

# Appendix B

## Questionnaire – Linking the Context of Traffic Signs and Potential Causes of Traffic Accident

| | |
|---|---|
| Sirindhorn International Institute of Technology | **Linking the context of traffic sign and traffic accident causes questionnaire** |

The questionnaire is to survey a linking the context of traffic signs and potential causes of traffic accident for prioritization of replacement of traffic signs in Thailand.

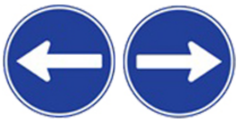
Direction Please check ✓ the potential cause(s) of traffic accident that involve missing/damaged of the specified traffic sign.

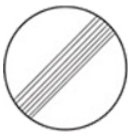
| Traffic sign | Speeding | Road way channelization | Overtaking | Hazardous road conditions | Causes related to pedestrians and animals |
|---|---|---|---|---|---|
| 1. STOP   | | | | | |
| 2. Give way   | | | | | |
| 3. Priority for oncoming traffic  | | | | | |
| 4. Overtaking prohibited  | | | | | |

| Traffic sign | Speeding | Road way channelization | Overtaking | Hazardous road conditions | Causes related to pedestrians and animals |
|---|---|---|---|---|---|
| 5. No entry  | | | | | |
| 6. U-turns prohibited  | | | | | |
| 7. Left/Right turn prohibited  | | | | | |
| 8. Lane change prohibited  | | | | | |
| 9. Left/Right or U-turn prohibited  | | | | | |
| 10. Motor vehicles except solo motor cycles prohibited  | | | | | |
| 11. Truck prohibited  | | | | | |

| Traffic sign | Speeding | Road way channelization | Overtaking | Hazardous road conditions | Causes related to pedestrians and animals |
|---|---|---|---|---|---|
| 12. Solo motor cycles prohibited  | | | | | |
| 13. Caravan prohibited  | | | | | |
| 14. Three-wheel motor vehicles prohibited  | | | | | |
| 15. Three-wheel prohibited  | | | | | |
| 16. Cycles prohibited  | | | | | |
| 17. Hand carts direction prohibited  | | | | | |
| 18. Bullock carts prohibited  | | | | | |

| Traffic sign | Speeding | Road way channelization | Overtaking | Hazardous road conditions | Causes related to pedestrians and animals |
|---|---|---|---|---|---|
| 19. Animal-drawn vehicles prohibited<br> | | | | | |
| 20. Motor vehicles prohibited<br> | | | | | |
| 21. Cycles, three-wheeler, and hand carts direction prohibited<br> | | | | | |
| 22. Solo motor cycles and three-wheel motor vehicles prohibited<br> | | | | | |
| 23. Horn prohibited<br> | | | | | |
| 24. Pedestrian prohibited<br> | | | | | |
| 25. Restricted zone<br> | | | | | |

| Traffic sign | Speeding | Road way channelization | Overtaking | Hazardous road conditions | Causes related to pedestrians and animals |
|---|---|---|---|---|---|
| 26. No stopping or standing  | | | | | |
| 27. STOP Check  | | | | | |
| 28. Left/right turn  | | | | | |
| 29. Keep left/right  | | | | | |
| 30. Pass either side  | | | | | |
| 31. Turn left/right  | | | | | |
| 32. Left/Right optional lane  | | | | | |
| 33. Left/Right straight optional lane  | | | | | |

| Traffic sign | Speeding | Road way channelization | Overtaking | Hazardous road conditions | Causes related to pedestrians and animals |
|---|---|---|---|---|---|
| 34. Roundabout  | | | | | |
| 35. Compulsory bus lane  | | | | | |
| 36. Compulsory mass transit lane  | | | | | |
| 37. Compulsory solo motor cycles  | | | | | |
| 38. Compulsory cycles  | | | | | |
| 39. Compulsory pedestrian  | | | | | |
| 40. Minimum speed limit  | | | | | |
| 41. Restriction ends sign  | | | | | |

| Traffic sign | Speeding | Road way channelization | Overtaking | Hazardous road conditions | Causes related to pedestrians and animals |
|---|---|---|---|---|---|
| 42. Bend ahead  | | | | | |
| 43. Turn left/right ahead  | | | | | |
| 44. Bend ahead  | | | | | |
| 45. Bend ahead  | | | | | |
| 46. Double bend ahead  | | | | | |
| 47. Crossroads ahead  | | | | | |
| 48. Y-intersection ahead  | | | | | |
| 49. Side road left/right ahead  | | | | | |

| Traffic sign | Speeding | Road way channelization | Overtaking | Hazardous road conditions | Causes related to pedestrians and animals |
|---|---|---|---|---|---|
| 50. Staggered intersection ahead  | | | | | |
| 51. Traffic merges ahead from the left/right  | | | | | |
| 52. Escape lane ahead  | | | | | |
| 53. Roundabout ahead  | | | | | |
| 54. Road narrow on both sides ahead  | | | | | |
| 55. Road narrow on left/right sides ahead  | | | | | |
| 56. Narrow bridge  | | | | | |

| Traffic sign | Speeding | Road way channelization | Overtaking | Hazardous road conditions | Causes related to pedestrians and animals |
|---|---|---|---|---|---|
| 57. Left/Right lane end  | | | | | |
| 58. Level crossing without barriers  | | | | | |
| 59. Level crossing with barriers  | | | | | |
| 60. Highway-Rail Grade crossing closed to junction  | | | | | |
| 61. Road narrows   | | | | | |
| 62. Low clearance   | | | | | |
| 63. Dangerous descent / Steep ascent   | | | | | |

| Traffic sign | Speeding | Road way channelization | Overtaking | Hazardous road conditions | Causes related to pedestrians and animals |
|---|---|---|---|---|---|
| 64. Road hump or series of road ahead  | | | | | |
| 65. Uneven road  | | | | | |
| 66. Dangerous dip  | | | | | |
| 67. Slippery road  | | | | | |
| 68. Loose chipping  | | | | | |
| 69. Falling rocks  | | | | | |
| 70. Opening bridge ahead  | | | | | |

| Traffic sign | Speeding | Road way channelization | Overtaking | Hazardous road conditions | Causes related to pedestrians and animals |
|---|---|---|---|---|---|
| 71. Lane cross over ahead  | | | | | |
| 72. Exit to frontage road ahead  | | | | | |
| 73. Main road entry ahead  | | | | | |
| 74. Merging traffic  | | | | | |
| 75. Divided highway  | | | | | |
| 76. End of divided highway  | | | | | |
| 77. U-Turn ahead  | | | | | |
| 78. Two-way traffic ahead  | | | | | |

| Traffic sign | Speeding | Road way channelization | Overtaking | Hazardous road conditions | Causes related to pedestrians and animals |
|---|---|---|---|---|---|
| 79. Traffic signal ahead  | | | | | |
| 80. Stop sign ahead   | | | | | |
| 81. Yield sign ahead   | | | | | |
| 82. Pedestrian crossing  | | | | | |
| 83. School  | | | | | |
| 84. Animal crossing  | | | | | |
| 85. Low flying aircraft  | | | | | |
| 86. Other danger ahead   | | | | | |

| Traffic sign | Speeding | Road way channelization | Overtaking | Hazardous road conditions | Causes related to pedestrians and animals |
|---|---|---|---|---|---|
| 87. No passing zone   | | | | | |
| 88. Double arrow  | | | | | |
| 89. Transition alignment  | | | | | |
| 90. Transition alignment  | | | | | |
| 91. Transition alignment  | | | | | |
| 92. Transition alignment  | | | | | |
| 93. Alternate Merging  | | | | | |

***Personal information***

| | | |
|---|---|---|
| Gender | □ Male | □ Female |
| Age | __________ years | |
| Education | □ Master's Degree or Higher | □ Bachelor's Degree |
| | □ Secondary School | |
| Occupation | _________________ | |
| Driving License | □ Have | □ Do not have |
| Driving Experience | __________ years | |

# Appendix C
# Questionnaire – Analytic Network Process

| | **Prioritization of traffic sign replacement in Thailand using Analytic Network Process** |
|---|---|

The questionnaire is to identify the priority of criteria and elements of prioritization for traffic sign replacement in Thailand. There are three parts in this questionnaire including Part I Expert information, Part II Pairwise comparison of the criteria, and Part III Evaluation the level of elements.

## ***Part I Expert information***

Gender ☐ Male ☐ Female

Age ___________ years

Education ☐ Master's Degree or Higher ☐ Bachelor's Degree

☐ Secondary School

Occupation/Position ______________________________________________

Working Experience ___________ years

## ***Part II Pairwise comparison of the criteria***

Direction Comparing the criteria in different context will be required. The definition of comparison scale will be shown in the table below.

| *Intensity of Importance* | *Definition* | *Explanation* |
|---|---|---|
| 1 | Equal importance | Two criteria contribute equally to the objective |
| 2 | Moderate importance | Experience and judgement slightly favor one criteria over another |
| 3 | Strong importance | Experience and judgement strongly favor one criteria over another |
| 4 | Very strong or demonstrated importance | A criteria is favored very strongly over another; its dominance demonstrated in practice |
| 5 | Extreme importance | The evidence favoring one criteria over another is of the highest possible order of affirmation |

Example for answering the question

| Criteria | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | Criteria |
|---|---|---|---|---|---|---|---|---|---|---|
| $X_1$ | | | ✓ | | | | | | | $X_2$ |

"Criteria $X_1$ is more ***strong importance*** than criteria $X_2$ (level 3)"

1) Comparing the criteria will be required, if knowing the traffic sign location.

| Criteria | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | Criteria |
|---|---|---|---|---|---|---|---|---|---|---|
| Level of damage of traffic sign* | | | | | | | | | | Context of traffic sign |

2) Comparing the criteria will be required, if knowing the level of damage of traffic sign.*

| Criteria | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | Criteria |
|---|---|---|---|---|---|---|---|---|---|---|
| Traffic sign location | | | | | | | | | | Context of traffic sign |

3) Comparing the criteria will be required, if knowing the the context of traffic sign.

| Criteria | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | Criteria |
|---|---|---|---|---|---|---|---|---|---|---|
| Traffic sign location | | | | | | | | | | Level of damage of traffic sign* |

** Level of damage of traffic sign*

| | |
|---|---|
| *Low effectiveness* | *- Dirty sign* |
| *Moderate effectiveness* | *- Damage sign,* |
| | *- Less retroreflectivity* |
| *High effectiveness* | *- Fade away* |
| | *- Unclear message* |

***Part III Evaluation the level of elements***

| ***Very high*** | ***High*** | ***Moderate*** | ***Low*** | ***Very low*** |
|---|---|---|---|---|
| 5 | 4 | 3 | 2 | 1 |

Example for answering the question

| Element | Factor 1 | Factor 2 |
|---|---|---|
| A | 4 | 2 |

*"Element A has high effect in Factor 1, and low effect in Factor 2"*

1) Traffic sign location

| Element | Straight | Curve | Slope/Bridge | + Intersection | T Intersection | Y intersection | Roundabout | Railway |
|---|---|---|---|---|---|---|---|---|
| Low level of damage of traffic sign | | | | | | | | |
| Moderate level of damage of traffic sign | | | | | | | | |
| High level of damage of traffic sign | | | | | | | | |

| Element | Straight | Curve | Slope/Bridge | + Intersection | T Intersection | Y intersection | Roundabout | Railway |
|---|---|---|---|---|---|---|---|---|
| Speeding | | | | | | | | |
| Road way channelization | | | | | | | | |
| Overtaking | | | | | | | | |
| Hazardous road condition | | | | | | | | |
| Causes related to pedestrians and animals | | | | | | | | |

2) Level of damage of traffic sign

| Element | Low level of damage of traffic sign | Moderate level of damage of traffic sign | High level of damage of traffic sign |
|---|---|---|---|
| Straight | | | |
| Curve | | | |
| Slope/Bridge | | | |
| + Intersection | | | |
| T Intersection | | | |
| Y Intersection | | | |
| Roundabout | | | |
| Railway | | | |

| Element | Low level of damage of traffic sign | Moderate level of damage of traffic sign | High level of damage of traffic sign |
|---|---|---|---|
| Speeding | | | |
| Road way channelization | | | |
| Overtaking | | | |
| Hazardous road condition | | | |
| Causes related to pedestrians and animals | | | |

3) The context of traffic sign

| Element | Speeding | Road way channelization | Overtaking | Hazardous road condition | Causes related to pedestrians and animals |
|---|---|---|---|---|---|
| Straight | | | | | |
| Curve | | | | | |
| Slope/Bridge | | | | | |
| + Intersection | | | | | |
| T Intersection | | | | | |
| Y Intersection | | | | | |
| Roundabout | | | | | |
| Railway | | | | | |

| Element | Speeding | Road way channelization | Overtaking | Hazardous road condition | Causes related to pedestrians and animals |
|---|---|---|---|---|---|
| Low level of damage of traffic sign | | | | | |
| Moderate level of damage of traffic sign | | | | | |
| High level of damage of traffic sign | | | | | |