# THE DEVELOPMENT OF CHEMICAL EMERGENCY RESPONSE SYSTEM FOR THAILAND EXPRESSWAY

BY

WIPAPORN KITTHIPHOVANONTH

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY IN
OCCUPATIONAL AND ENVIRONMENTAL HEALTH
FACULTY OF PUBLIC HEALTH
THAMMASAT UNIVERSITY
ACADEMIC YEAR 2024

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DISSERTATION

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# ABSTRACT

The transportation of hazardous materials (Hazmat) plays a vital role in Thailand's industrial, agricultural, and public health sectors. Due to Bangkok's high traffic congestion and volume of Hazmat vehicles, chemical incidents on expressways pose significant risks. The Expressway Authority of Thailand (EXAT) has developed an extensive expressway system, yet emergency responses are often hindered by human errors such as miscommunication and inaccurate data. This study aims to reduce such errors by creating a decision-support system for chemical spill responses on expressways.

The research used a multi-stage methodology. A Delphi method with 17 experts identified key factors influencing emergency route selection, categorized into five main components: Travel Time, Chemical Information, Social Impact, Traffic Data, and Fire Station Effectiveness. These were weighted using Analytic Hierarchy Process (AHP) and Fuzzy AHP to address uncertainty in expert opinions. A computer program integrating real-time traffic, GPS data, weather conditions, and chemical hazard

modeling (via ALOHA and CAMEO software) was developed to simulate spill scenarios on the Chaloem Mahanakhon Expressway. The cost function was calculated using normalized weights to identify the most suitable emergency response route.
Results showed that the Bon Kai route consistently had the lowest total cost in both daytime (0.484) and nighttime (0.4785) scenarios, due primarily to its high fire station readiness. This indicates that the system successfully supports emergency planning by optimizing route selection. The study recommends integrating such a model into EXAT's real-time response protocols to enhance safety and reduce impact during chemical incidents.

**Keyword : Emergency Response,** Hazardous Materials (Hazmat), Expressway Incident Management, ALOHA & CAMEO Software, Fuzzy Analytic Hierarchy Process (FAHP), Route Optimization, Cost Function Analysis

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Wipaporn Kitthiphovanonth

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# CHAPTER 1
# INTRODUCTION

## 1.1 Background

The effective chemicals emergency response system is considerably for the hazardous substance transportation accident. Hazardous substance or hazardous material (Hazmat) are vital to Thailand's industry, agriculture and public health (J. et al., 2012) More than 23,000 trucks loaded with more than 1,000 liters of hazardous chemical trucks and trailers in Thailand on December 31, 2019. Top 5 provinces Bangkok, Chon Buri, Saraburi, Rayong, and. Bangkok, Thailand's most congested province (Transportation statistics sub-division, 2019) has the largest number of chemical trucks (P. Kanchit et al., 1994) (K. Puntumapon et al., 2009) Hence the highways managed by the Expressway Authority of Thailand are built to reduce congestion in Thailand (P. Kanchit et al., 1994) Currently, the expressway consists of 9 routes, Udonratthaya, Srirat, Chalermmahanakorn, Chalongrat, 3rd stage (S1 Section), Buraphavithi, Bangpli Suksawas, Srirat-outer ring road and Ramindra-outer ring road, as shown in Figure 1.1 The route involves EXAT Hazmat Chemical Trucking Regulations 4 routes including Chalermmahanakorn, Srirat, Chalongrat and Srirat-outer ring road in Figure 1.1. The EXAT Hazmat truck regulations have time limitations on the rush hour. The hazardous chemical truck cannot transport between 5.00-9.00 am and 3.00-9.00 pm. The Chaloem Maha Nakhon Expressway routes serve as a critical link to Bangkok's Central Business District (CBD), an area characterized by high population density and intense commercial activity. Consequently, this region frequently experiences significant traffic congestion. Indeed, Bangkok is consistently identified among the most congested cities in both Thailand and globally by the TomTom Traffic Index (index, 2024). This pervasive challenge of severe traffic congestion unequivocally highlights the paramount importance of developing optimized routing strategies, particularly for critical services such as emergency response, which are also linked to the Hazmat truck regulation's route, as depicted in Figure 1.2. The highest risk in the hazmat group is the flammable substance category. The physical properties of these hazardous chemicals are liquid and solid (Transportation statistics sub-division, 2019). Data reporting on Hazmat EXAT sticker request between 2019 – 2022 allows 9,248 hazardous trucks to journey on the EXAT. Hazardous substance type 3 (flammable liquid) is the largest number of hazardous truck on EXAT route. The fusel oil (UN number 1201) and LPG (UN number 1051) ranked first and second respectively. When a chemical accident occurs, a fire or explosion can develop into a catastrophic or cascading disaster (Yu & Guan, 2016). The Federal Emergency Management Agency (FMEA) divides emergency management into four categories, including mitigation, preparedness, response, and recovery (COVA, 1999). Although they have an effective emergency response plan, its effectiveness is troublesome. The Emergency Response Team (ERT) must communicate with the Emergency Operations Center (EOC) to ensure their decisions are correct and respond in a timely manner (Vaez & Nourai, 2013). Because of the many factors involved and depending on the nature of the accident, it is difficult to respond effectively. They react in stressful situations and have to reduce the severity of an accident in a timely manner (Woodcock & Au, 2013). Communication failures and misinformation can occur through coordination within the team (Yu & Guan, 2016). Despite their training, they have limited experience with unreal scenarios. Therefore, their decision-making in emergency situations fails due to human error, which is a weakness of emergency management (Woodcock & Au, 2013). Mathematics for calculating the total value of the human error probability score by the Delphi method (Laboratory, 2009) (Rujipun Phangchandha & Arron Ketsakorn, 2018). The factors of concern, namely quantitative and qualitative factors, were analyzed using Fuzzy Analytic Hierarchy Process (FAHP), which was developed from Analytic Hierarchy Process (AHP) to solve the multi-criteria decision-making (MCDM) problem. Fuzzy logic is a tool that supports decision-making based on fluctuating data. This method is better than Boonlean logic. Partial truth is somewhere between completely right and completely wrong. It can calculate and weight the factor score (Thanyarat Tiya-apisit & Uttapol Smutkupt, 2017). The influencing factors are the results and input data of the scenario simulation program. The computer programs support predicts the risk and manage the chemical emergency response. ALOHA software is a hazard model widely used in chemical emergencies. ALOHA threat zone exported to MARPLOT can be viewed and integrated with Google Map or Google Earth and displayed on the map in KML format. This map shows threat areas from Google's database alongside the real environment and used to exclude the risk location and predict the route ((EPA), 2016). Used to calculate chemical concentration levels, can be separated by a safe distance (Chakrabarti & Parikh, 2012). Google Maps has a hidden map feature style that contains many features. Points of Interest (POI) filtering can be customized to hide or show POI categories such as Medical Services, Government, Gas Stations, etc. Illustrated landmark POI markers can show specific landmarks and raised places and give them a unique appearance (Google, 2022). The chemical emergency response map integrated between ALOHA, CAMEO, MARPLOT and Google Map, used for simulation modelling. EXAT has an Aimsun software license and is capable of simulating chemical emergency response (Grigorev et al., 2022). Mathematical programs and computer programs can address human error when the ERT responds to emergencies. The method can categorize the influencing factor. The program can simulate the appropriate route and make a valid decision for the effective emergency response. Therefore, this study focuses on identifying factors related to emergency response through Delphi techniques and the Fuzzy Analytic Hierarchy Process (FAHP) and developing appropriate emergency response models (Laboratory, 2009) (COVA, 1999) ((EPA), 2016) (Chakrabarti & Parikh, 2012)

## 1.2 State of problem

Human error activities are the part of human error operations that are more likely to occur in emergency situations than in normal situations. It can progress to failure and serious situations. Although Emergency Response Teams (ERTs) train for drills or emergencies, their training experience is limited by practical experience. In the initial stages of an emergency, failure messages are generated by disorganized teams. When ERTs work in emergency situations, they have a short time to evaluate accurate data. They cannot recheck the validity of their operations. Incorrect information and wrong commands can lead to catastrophic events (Woodcock & Au, 2013). Bangkok is the highest risk area for chemical accidents. Accidents can be classified into three severities, as shown in Table 1.1

Table 1.1 Accident severity classification

| Severities | Financial Loss | Injury | Goods Damage |
|---|---|---|---|
| **Minor** | Less than THB 5,000 | Minor Injury but does not required Medical Doctor (MD) examination | Less than 50 kg. |
| **Medium** | Between THB 5,001 – 50,000 | Injury, Required Medical Doctor (MD) examination but does not required leave from work | Between 51-500 kg. |
| **Major** | More than THB 50,0001 | Injury, Required Medical Doctor (MD) examination and leave from work required<br>- Organ loss<br>- Death | More than 500 kg. |

## 1.3 Study objective

The general objective of this research is to solve the human error with computer model's framework. The specific objectives are

1. To determine the factors relating to the emergency response system by applying Delphi and Fuzzy Analytic Hierarchy Process techniques.

2. To simulate the situation of emergency chemical spill on the Chalerm Mahanakorn route by applying a map API.

3. To develop an appropriate emergency response route for the Chalerm Mahanakorn expressway.

**1.4 Study area**

Hazardous chemicals shipped by ship will be delivered to Klong Toei port. Close to the port in Bangkok's Central Business District (CBD) area, which is congested with traffic, densely populated and densely commercialized as shown in

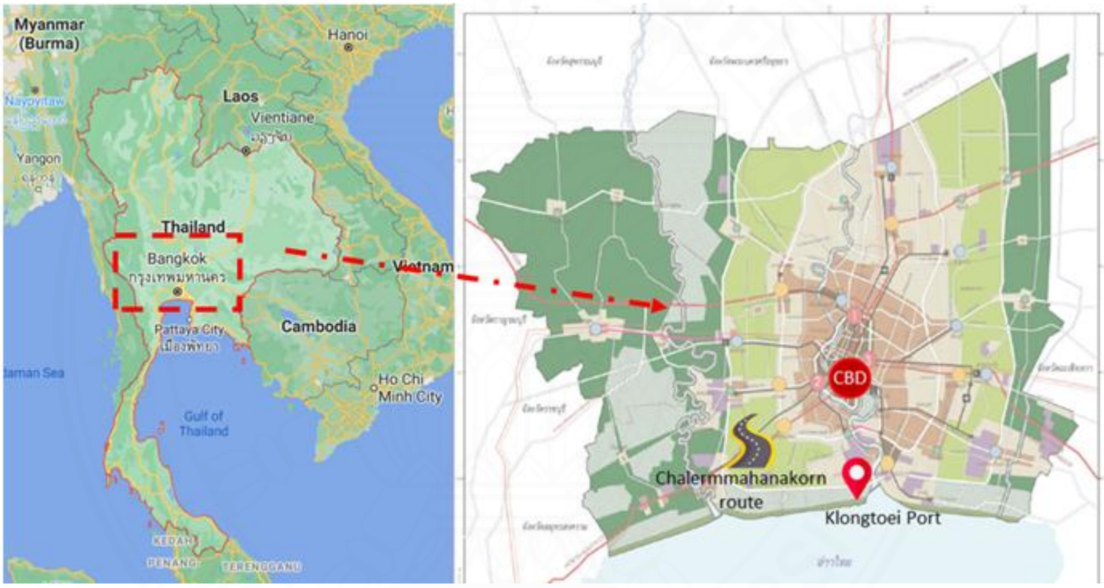



Figure 1.3. Hazmat transport from Klong toei port via highway to many provinces in each region. The Chalerm Mahanakorn route is the main route that connects other routes and supports the transport of Hazmat to their destination safely and easily. The weather data comes from EXAT environmental monitoring measurements at the RAMA 4 toll plaza port near the on-ramp near Klong Toei on this route. Hence, this route is the highest risk of Hazmat transport accidents, with high commercial and population impacts.


Figure 1.1 The routes of the expressway


Figure 1.2 The routes concerned the EXAT Hazmat chemical truck transportation regulations

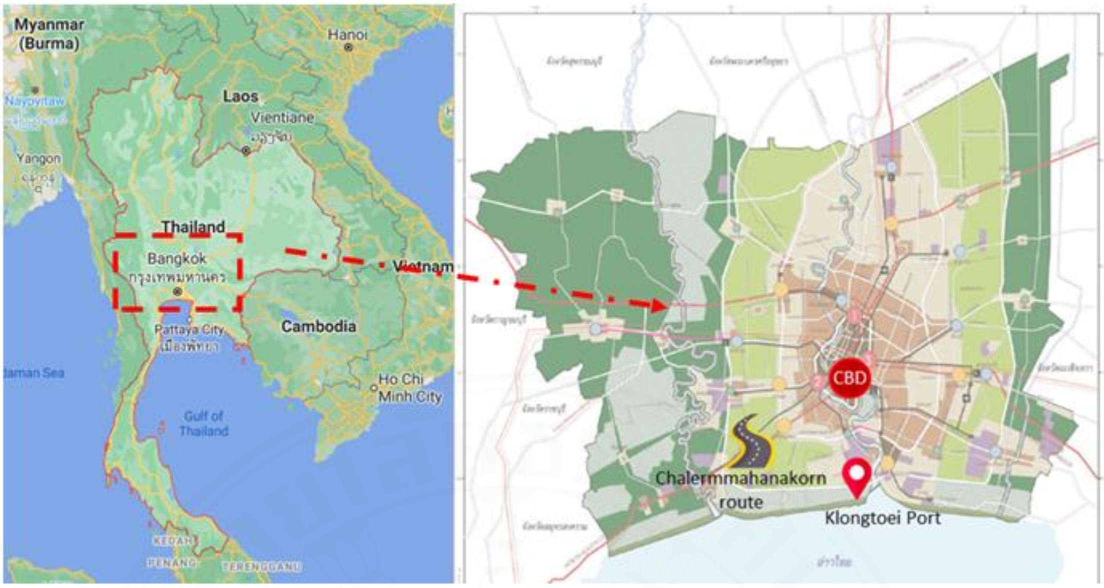



Figure 1.3 The location of Bangkok, CBD, Chalermmahanakorn route and Klongtoei port

**1.5 Operation definition**

- Chemical spill on the expressway refers to type 3 hazmat truck accident only fuel oil and LPG spilled on Chalerm Mahanakorn route. An incident origin at latitude 13.724894, longitude 100.552500 on the Chalerm Mahanakorn Expressway.

- The Emergency Response Team (ERT) comprises individuals who play a crucial role in responding to emergency situations. In the context of this study, ERTs specifically refer to those affiliated with Bangkok Metropolitan Administration (BMA) fire stations located within a 3.5 km radius of the incident site.

- The safest route for ERT refers to The safest route refers to the route that yields the lowest result from the cost function calculation.

- Safety program refers to the integration of ALOHA, CAMEO and MARPLOT program

- Impact refers to the impact of a chemical spill on population, business and the environment

- Population density refers to the number of people per square meter (persons/sq.m.).

- Travel time refers to the estimated duration it takes to travel from a starting point to a destination, calculated using real-time traffic data.

## 1.6 Conceptual framework

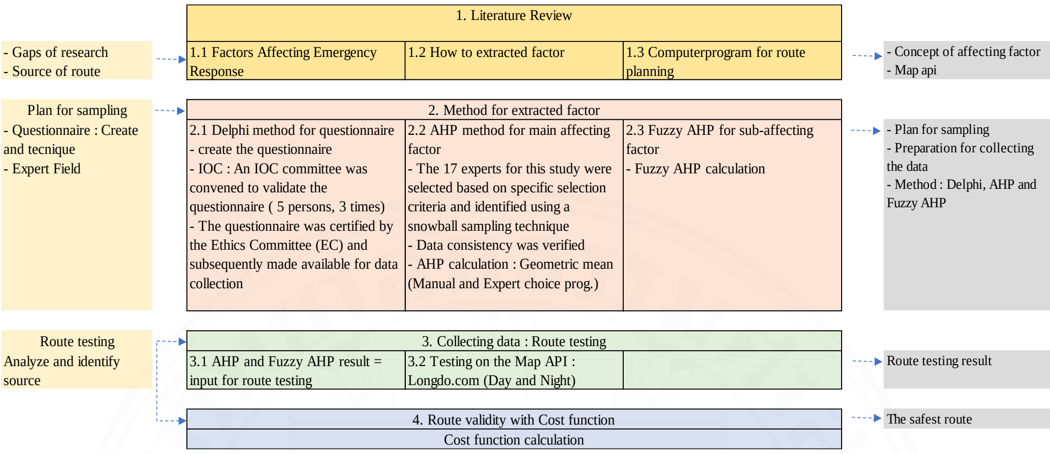



Figure 1.4 Conceptual framework

## 1.7 Practical Model

Emergency Response System (ERS) model address human error. It should support the proper and safe route of EXAT personnel and outsourced personnel. The practical model is

1. Incidents, which occurred from fuel and LPG, do not develop into disasters. This model should demonstrate the suitable route to support the team operation on time on the Chalerm Mahanakorn route.

2. Outsourced or public teams serving as key emergency responders can follow the safest route to the scene in time to contain and mitigate the incident.

3. This model can demonstrate the safe zone and route. The ERT can respond safely.

4. Human error can occur when teams work in stressful situations. Therefore, as the program assesses the situation, the model can effectively manage the emergency response.

5. Principles of this model can be contributed to other EXAT routes or public roads to support ERT

# CHAPTER 2
# REVIEW OF LITERATURE

## 2.1 Hazmat Transport in Thailand

### 2.1.1 Situation

The industry in Thailand depends on the transportation of Hazardous Materials (Hazmat). Industrial, public health, and agricultural industries all apply hazmat (J. et al., 2012) (Warakorn Decha, 2005) On June 30, 2020, there were 24,091 Hazmat trucks, which included hazardous material trucks (Type 4) and semi-trailers (Type 7), which was an increase of roughly 1.02% from June 30, 2019 (23,642). Every year, hazmat trucks will become increasingly popular. The top 6 Hazmat truck-producing provinces are Bangkok, Chon Buri, Nakhon Ratchasima, Saraburi, Rayong, and Samut Sakhon, in that order. Bangkok occupies the top of the list, and it hasn't altered over the 2019-2020 period. (Transportation statistics sub-division, 2019) Hazmat truck accidents are more probable to occur in Bangkok. (J. et al., 2012)

### 2.1.2 Accident

According to the 2017 Hazmat accident statistics report, a total of 38 accidents occurred in 24 provinces across the country. Two out of every nine Hazmat truck accidents happened on the Motorway with the same EXAT highway business, and the reason of the accident was someone losing their balance and toppling over. It has had an impact on citizens, created victims, and caused property damage. Between January 1 and June 30, 2019, there were 12 Hazmat truck accident cases, of which 5 involved fire, 3 involved chemical leaks, and 2 involved explosives. Although the Hazmat truck management, such as the laws or a system of road safety, help to control the Hazmat transport failure and to lessen the possibility of accidents. However, the Hazmat truck driver's aberrant actions, such as disregarding safety rules or being unaware of them, contributed to cause the tragedy. According to the information above, there is an insufficient integration of the Hazmat truck accident information between other government departments, and the data reported erratically. The lack of accurate data and information makes it difficult to identify the problem's real issues and construct a Hazmat transport management system (J. et al., 2012)

**2.1.3 Management**

The Design and Development of HAZMAT Trucks System for the Expressway Authority of Thailand (EXAT) (Krit Jedwanna et al., 2014) and The Studying and Developing Tracking Systems and Defining Hazmat Transport Standard for the Expressway Authority of Thailand (EXAT) (Ladkrabang, 2014) are two of the projects that the Ministry of Transport attempted to develop the management of hazardous materials. The purpose of the study was to examine the Hazmat transport route project through GISPORTAL and through the MOT's reporting system and database. Combined with the traffic system, accident system, route evaluation system, and chemical data evaluation system is the traffic reporting system. The state agency responsible used the system's database to determine the most suitable route for transporting hazardous materials and to develop administrative procedures and preventive measures. The system consists of the Hazmat transport route database, the risk evaluated of the Hazmat transport route system and the risk of the Hazmat transport route report system with Geographic Information System (GIS) (Ladkrabang, 2014). The Hazmat transport route database uses factors such as transport accidents, cargo type or trucking type to assess the risk of hazmat routes. The Hazmat transport route system's risk evaluation utilizes the system's Hazmat transport route database to evaluate the risks using the existing factors in the Ministry of Transport database. Management of transport emergency response relies on Hazardous Goods and Chemical Data (Thai-FRID). The German government, the Deutsche Gesellschaft für International Zusammenarbeit (GIZ) GmbH , which administers the Thai-German Dangerous Goods Project (TG-DGP), contributes greatly for sustainable development as part of global collaboration. More than 120 countries are members of the GIZ. GIZ Thailand is a German-Thailand cooperation. The TG-DGP study attempts to assist the developing disaster management system in order to protect and control hazardous materials at Bangpoo, Thailand's industrial estate authority, from February 1998 to April 2004. This project can reduce the Hazmat incidence about 5-10%, was functional in progress and establish of the national information system for hazardous materials

The Hazardous Material Handling, Storage and Transportation System for Bangpoo Industrial Estate and the Safety Management Planning Project for hazardous materials (Thai First Response Information Database: Thai-FRID) was monitoring this project, which can reduce the incidence of hazardous materials by 5 to 10%, was operational and establishing up the national information system for hazardous materials. The project expected to make a significant impact on the whole of Southeast Asia. (GIZ, 2004) (GIZ, 2019). This project is currently outdated and has not yet been integrated with the database of the Department of Land Transport (DLT) or any other organization within the Thai Ministry of Transport (GIZ, 2019). The Bangkok port's import-export Hazmat database, the only Thai organization with a complete Hazmat database to be utilized in assessing Hazmat risk routes, will assist in accelerating the development of Hazmat transport in the future. As a result of this study, Samut Prakan Province and Public Road Number 9 are the most dangerous because of the number of factories in Samut Prakan and the high volume of hazardous material transport on this road, which travels to the east of the port. The data collection method collecting should be improved because it only collected expert recommendations that had an impact on risk assessment. The recommendation is that, in order to ensure an efficient emergency response, the Hazmat transport route data should integrate with other safety systems of government, and the Hazmat emergency response should communicate with local authorities and the general population.

## 2.2 Support for emergency management

### 2.2.1 HAMS-GPS software

The pasquill stability is the most commonly turbulent atmosphere categories which has 7 classes. D class is Neutral condition and should be chosen to use irrespective of wind speed (NOAA, 2025) LPG BLEVE follow the BLEVE model and damage distance of unconfined VCE (Vapor Cloud Explosion) is evaluated by TNT (the trinitrotoluene) equivalent method. HAMS-GPS software use TNT method to calculate the distance of the effect overpressure explosion. ALOHA software is used to form the worst-case scenario ammonia releasing assessment and toxic endpoints (Chakrabarti & Parikh, 2012).

### 2.2.2 Geographical Information System (GIS)

The four phases of Comprehensive Emergency Management (CEM) include mitigation, preparedness, response, and recovery. The utilization of GIS can combine the phases of preparation and response. In the mitigation phase, risk mapping and damage assessment can be created using GIS applications that concentrate on spatial layers and spatial modeling. GIS focuses on long-term forecasting or forecasting using analytical models during the mitigation phase. The three main components of this phase are risk, hazard, and vulnerability. The risk mapping category contains vulnerability, risk, and natural hazard mapping. Natural disasters and vulnerabilities are associated with physical and human potential for technological hazards and vulnerabilities. For the preparedness and response phases, GIS applications facilitate the delivery and implementation of emergency response plans, which are extremely important for emergency response managers. GIS applications can support accurate spatial information thus managers' commands are correct and timely (COVA, 1999). It is critical that emergency medical services (EMS) are on the scene for patients to be rescued quickly. Traffic accidents and congestion are route response problems, but are solved by GIS. Rescue time is the key factor for emergency response. GIS can choose the best route for the ERT. GIS can integrate data from disparate sources to support chemical spill modeling, mapping, and spatial decision support in a short period of time. Chemical spill in USA, HAZMAT team uses the CAMEO to assess the risk and applies the GIS to gain the essential information (Abayomi, 2021) but GIS can only be used with computer programs and cannot operate in real time (Puttinaovarat et al., 2019)

### 2.2.3 Map API

Efficient freight transportation is fundamental to the vitality and smooth operation of urban economies. However, devising optimal planning methods faces significant challenges, primarily stemming from the inherent variability in travel speeds influenced by dynamic factors like traffic congestion. While conventional approaches often rely on GPS technologies and associated routing services for planning, these can be costly and necessitate frequent re-optimization due to continuously evolving traffic conditions. To address these limitations, a novel solution integrates real-time traffic data into daily vehicle route planning. This methodology specifically incorporates the Google Maps API for precise traffic congestion estimation and utilizes a Mixed Integer Linear Programming (MILP) model to determine optimal routes for an entire operational day. The efficacy of this approach was demonstrated through testing in a major U.S. city. Results indicated that the proposed methodology outperforms conventional routing approaches by up to 18% in terms of routing time, thereby underscoring its practical relevance and potential for significantly enhancing urban freight efficiency (Muñoz-Villamizar et al., 2024).

#### 2.2.3.1 Google map

Google Maps API holds a prominent position in the global market for mapping and route-finding services, characterized by its continuous development and introduction of new functionalities (Market Research Firm, Year). A key feature is the Compute Routes method, part of the Routes API service, which allows for the efficient generation of optimal paths. This method processes HTTPS requests to provide detailed directions between specified locations, incorporating real-time traffic data for a range of transportation modes, including transit, cycling, driving, two-wheeled motorized vehicles, and walking, and supports routing through multiple waypoints. The Route Optimization feature within the Google Maps Platform API is designed to generate highly optimized route plans for individual or multiple vehicles and their respective stops. This capability directly contributes to enhancing the operational efficiency of transportation fleets by providing optimized travel paths (Google, 2024).

**2.2.3.2 Longdo map**

Longdo Map stands as a leading online mapping service in Thailand, developed by a local company specifically to address the unique demands of the domestic market. This platform supports various development environments, including JavaScript API and Mobile SDK, and offers a range of functionalities designed to be cost-effective, with options for free initial usage. Key features include the Geocoding API for converting addresses to geographical coordinates, the Route API for efficient route searching, and the Search API for locating specific places. The Route API provided by Longdo Map is designed to identify optimal routes specifically tailored for Thailand's intricate road network. It offers support for various modes of transportation, contributing to its versatility across different travel requirements. Notably, the Longdo Map Routing API demonstrates particular utility in scenarios requiring customizable route adjustments, such as accommodating road closures in designated areas. This inherent flexibility is especially valuable for dynamic planning within Thailand's complex transportation infrastructure (Longdo, 2024).

**2.2.3.3 OpenStreet Map**

OpenStreetMap (OSM) is a collaborative, open-source mapping project that generates a freely accessible geographic database, serving as a foundational resource for various routing services. One notable example is openrouteservice, which offers a diverse set of free-to-use, open-source Geo-services through a unified API. In Thailand, the OpenStreetMap community actively contributes to the continuous development and maintenance of geographic data. Nevertheless, it is important to acknowledge that data coverage may still present limitations in certain areas, potentially impacting the comprehensiveness of routing information.(OpenStreet-Map, 2024)

**2.2.4 Route selection**

The influencing factor of optimal route consist of surrounding information, map information, geographic map and building and location of community. Surrounding information focuses on environmental, weather, location of community and chemical accident information. Map information focuses on nodes or edges in road networks, location of the accident and traffic information. These factors influence the optimal route, the one with the lowest risk of emergency response (Seo et al., 2022) (Scerri et al., 2012).

#### 2.2.5 Hazadous material (Hazmat) management : CAMEO, ALOHA, MARPLOT

Figure 2.1 represents the components of the CAMEO program, which include CAMEO Data Manager, CAMEO Chemical, MARPLOT, and ALOHA. It can operate together or independently. Substantial chemical datasheets from CAMEO Chemical are crucial for responding to spills, fighting fires, and providing first aid. MARPLOT is an application for mapping. Based on toxicology, climate, chemical datasheets, and the actual circumstances surrounding the chemical spill, ALOHA evaluates the chemical hazard that spreads in the atmosphere. ALOHA can describe the potential release of chemical hazards and estimate dangerous zones for flammable and poisonous materials. The export of the ALOHA zoning to MARPLOT allows for grid-based grid-plotting and map-plotting. The orange and yellow areas are the hazard reduction areas, respectively, and are adjacent to the red area, which is the most dangerous location ((EPA), 2016). ALOHA software estimates the toxicity, and the distance for ammonia leak accident. Applying the worst-case of ammonia release model evaluates the site-specific meteorological and health effects. The hazard footprint can demonstrate where a danger started and where it ended up becoming poisonous (Chakrabarti & Parikh, 2012). MARPLOT can export the different files (kml, .kmz, and .xlsx file types) to draw the virtual map on Google Earths and Google map ((NOAA), 2022)

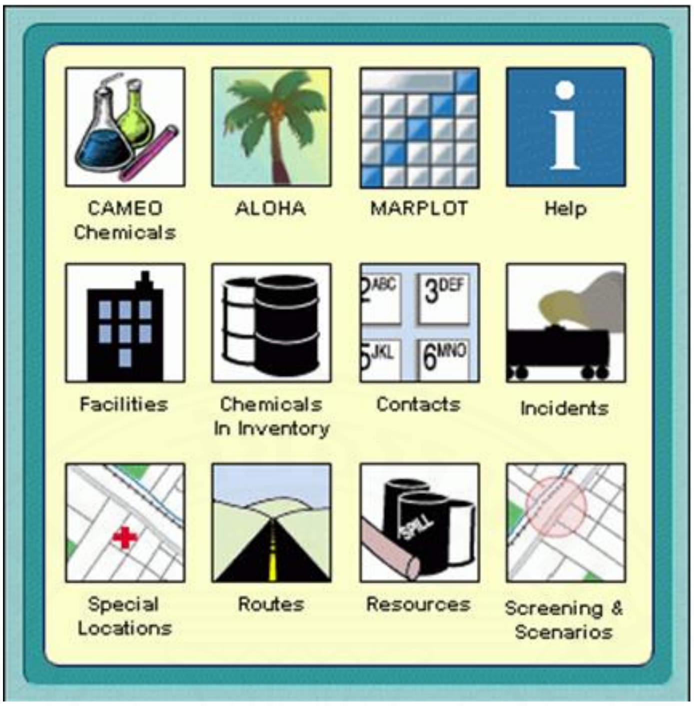



Figure 2.1 CAMEO ALOHA MARPLOT Software

### 2.3 Instrument development

The effective techniques to analyze the influencing factors and provide input to the developed emergency response model are the Delphi technique, Analytic Hierarchy Process (AHP), and Fuzzy Analytic Hierarchy Process (FAHP).

#### 2.3.1 Delphi technique

Norman Dalkey and Olaf Helmer of the Rand Corporation developed Delphi technology in the early 1950s, which is a systematic group judgement. Delphi is a method of organizing the communication process of groups in order to deal effectively with complex problems (Loukaitou-Sideris, 2000) Using this method, through the way of questionnaire, the researcher can find out the unclear answers in the focus point from the expert opinion. The decision of the expert criteria affects the correctness consensus of the specialist's opinion. The expert wasn't cognizant of the other experts' opinions or who was in the group. As a result, the results are impartial and confidential to avoid antagonizing anyone. The expert replied the questionnaire three times to ensure the greatest level of accuracy. In order to verify the results in the subsequent round, the researcher will make judgments that are consistent with the expert opinions in each question and provide them back to the expert team. The option to affirm or modify their response with a justification is available. The fundamental statistics assessed the consensus of the professional opinions. The Delphi technique's success factors are as follows: 1) The researcher must have enough time to interview the experts and follow up with the feedback questionnaire because they are always busy; 2) The Delphi technique's expert criteria selection is essential because it affects the validity of the results. It requires to consider a specialist who has a genuine interested in the research topic. There should be between 5 and 20 experts (Crawford et al., 2004), but the 90% confidence level indicates more than 13, although this affects the accuracy, correctness and clarity of the questionnaire responses.(Dalkey, 1969) (Dobbins & Camp, 2003). The expert should not get the questionnaire for too prolonged because they can forget their previous response. 4) In order to gather and evaluate data effectively, the researcher must completely comprehend this technique. The Delphi technique process as shown in Figure 2.2 (Namphung, 2016)

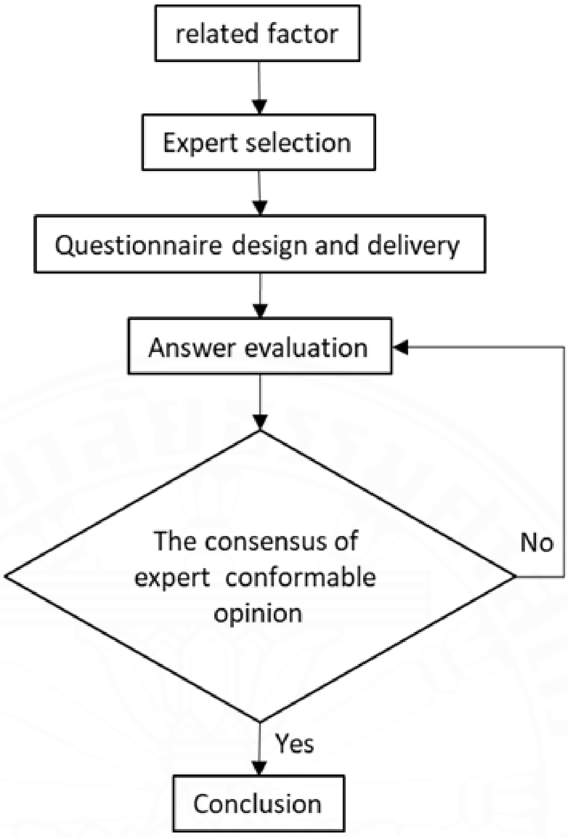



Figure 2.2 The Delphi technique process

**2.3.2 Analytic Hierarchy Process (AHP)**

One of the most effective multi-criteria evaluation techniques and multi-criteria decision-making (MCDM) techniques for determining the best option is the Analytic Hierarchy Process (AHP) created by Saaty. The Analytic Hierarchy Process (AHP) is a straightforward principle that categorizes problems into various classifications. The three components that AHP considers as essential are (Vudhivanich, 2003) (Murat et al., 2016)

(1) The evaluation of the hierarchy is divided into three levels: goals, criteria, sub-criteria, and alternatives, as shown in Figure 2.3 (Dalalah et al., 2010)

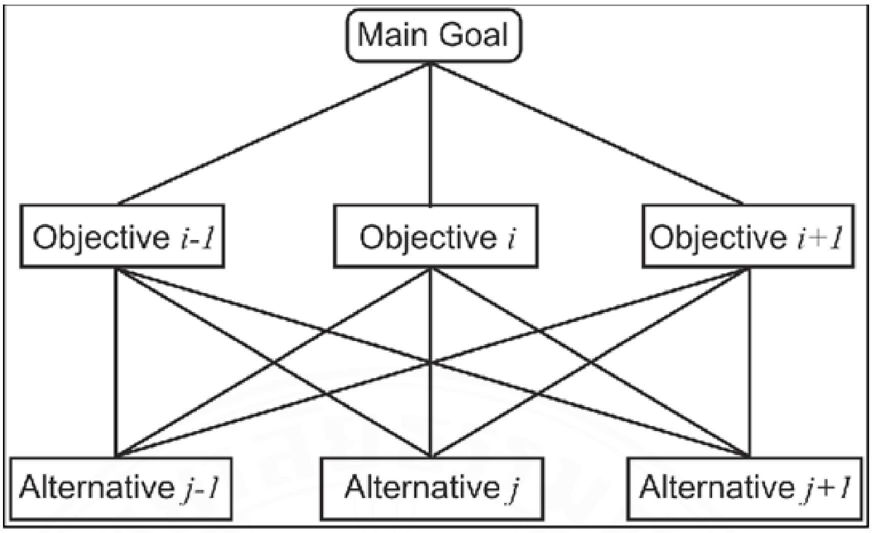



Figure 2.3 AHP hierarchy of goals, objectives and alternatives

(2) Calculation of relative priority: When performing pairwise comparisons, the expert selected the best alternative. Each problem compared one by one and weighted them to obtain the more important alternative. The AHP measurement scale as showed in Table 2.1(Afshari et al., 2010)

Table 2.1 Saaty's 1-9 scale of pairwise comparisons

| Intensity of importance | Definition | Explanation |
|---|---|---|
| 1 | Equal Importance | Two activities contribute equally to the objective |
| 2 | Weak of 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 | An activity is favored very strongly over another |

| Intensity of importance | Definition | Explanation |
|---|---|---|
| 8 | Very very Strong | |
| 9 | Extreme Importance | The evidence favoring one activity over another is of the highest possible order of affirmation |

$$\mathbf{A}^k = \begin{matrix} & A_1 & \cdots & A_n \\ A_1 & a^k_{11} & \cdots & a^k_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ A_n & a^k_{n1} & \cdots & a^k_{nn} \end{matrix}$$

Figure 2.4 Matrix A explains to the strength of choice

There are n different options. In the matrix ($a_{ij}$), A explains that the decision-maker accepts that alternatives I is more powerful than alternative j in terms of choice strength.

The number of alternatives is n. In the matrix A explains to the strength of choice that the decision maker accepts that the alternative i is powerful more than alternative j. Vargas created a model based on the following axioms (Vargas, 1990).

1) Reciprocal comparison axiom; if Ai dominates $A_j$ $\chi$ times then $A_j$ dominates $A_i$ $1/\chi$ times.

2) Homogeneity axiom; the dominance judgments are represented by means of a bounded scale.

3) Independence axiom; the weights of criteria are independent of the stimuli in a multi-criteria situation.

4) Expectation axiom; the hierarchic structure is assumed to be complete regarding the purpose of decision-making

### 2.3.3 Fuzzy Analytic Hierarchy Process (FAHP)

Fuzzy set and AHP developed to Fuzzy Analytic Hierarchy Process (FAHP) for the human's opinion improvement. The step of FAHP method as below

- Step 1: Changing the number to fuzzy number (Fuzzification)
- Step 2: Putting the fuzzy number into the matrix table to pairwise comparison
- Step 3: Calculating comply with the Analytical process
- Step 4: Calculating the alternatives follow the step 1-3
- Step 5: Changing the fuzzy number to the real number (Defuzzification), finding the alternatives by fuzzy set weighting multiply with the alternatives weighting

## 2.4 Research Review

2.4.1 Kamthorn Puntumapon, Taksin Punyararj, Wasan Pattara-atikom (K. Puntumapon et al., 2009)

They studied important traffic congestion factors in Bangkok to alleviate the problem. Within 7 months, study on Bangkok's traffic congestion occurred at the 328 Main Road. There are two times during rush hour: from 7.00 to 7.59 in the morning and from 6.00 to 6.59 in the evening. The worst weekly congestion is on Friday between 6 and 6.59 p.m. It is possible to forecast future directions using the database on traffic congestion

2.4.2 Kanchit Pianuan, Mingsarn Santikarn Kaosa-ard and Piyanuch Pienchob (P. Kanchit et al., 1994)

They researched many options for reducing Bangkok's traffic congestion, including the sky train, the metro system, expressways, etc. The Expressway and Rapid Transit Authority (ERTA) was established in 1972 to reduce congestion. This resolution was successful only with private cars and deteriorating traffic.

2.4.3 Mahaboon J., Grzebieta R.H., Friswell R., and Mooren L. (J. et al., 2012)

They examined the gaps brought up by the Hazmat manager's perceptions and determined the legally required point. The survey results should not only be based on the manager's assessment of hazmat operations, but also take into account practical hazmat operations performance. And the correlation between the safety performance and the implementation, which has a sample size larger than this study (32 carriers), validates this relationship.

2.4.4 Zuo-fu Yua,b, Jia-lin Guan (Yu & Guan, 2016)

Setting up the emergency fire and rescue dangerous chemical accident team is essential because if they respond incorrectly in emergencies, they will become the victims. The studies showed that China's emergency training system lacked the capacity to prepare its personnel for operating in emergency scenarios. Avoiding scattered repetitions of emergency situations should be the goal of training exercises.

2.4.5 Ben Woodcock, Zachary Au (Woodcock & Au, 2013)

The purpose of this study is to comprehend how to deal with human error in a dangerous environment when in an emergency. HAZOP and Task analysis techniques are suitable for identifying and eliminating hazards in emergency response situations.

2.4.6 Najmeh Vaez, Farshad Nourai (Vaez & Nourai, 2013)

Operators in the control room and automatic process control are very important in hazardous industries during emergency situations. Detailed Action Plan (DAPs) include automatic processes and operations. This study DAPs applies emergency response analysis in actual settings to verify and improve the applicability. DAP is an integral part of an emergency management plan that reduces human and machine errors. DAPs lack actual information in emergency situations, making it unreliable and unrealistic. This study doesn't account for wasted time during the recovery period.

2.4.7 Thomas Cova (COVA, 1999)

The geographic information system (GIS) is an essential instrument in disaster management, which contains four steps: mitigation, preparedness, response, and recovery. During the preparation phase, GIS could assist in planning the action in advance and increasing the effectiveness of the response, allowing to save ERT lives, reduce damage to properties, and enhance productivity in the stage of recovery. GIS can identify the spatial coincidence, forecast the route direction that depends on traffic, and support the wind direction for Hazmat transport. GIS integrated with CAMEO software to make a hazard model. Future innovations will confidently manage emergencies thanks to a combination of GIS, remote sensing, telecommunication technologies and Intelligent Transportation Systems (ITS).

2.4.8 Maria Pia Fanti (Fanti et al., 2015)

Decision Support Systems (DSS) can monitor hazmat trucks in real time and offline, taking into account the type of traffic, the hazmat goods being transported, and the people along the highway. DSS have two main modules: Risk Assessment Module (RAM) and simulation modules (SM) while different scenarios. SM uses a colored Petri net (CPN) framework to model the highway network. The RAM uses an information and communication technology (ICT) tool to evaluate the social risk, or more specifically, the actual risk of a hazardous accident. The DSS operation recommends the safest path for hazmat transporters after assessing the societal risk. DSS should assist hazmat vehicle decision-making, but in the future, it should focus on various modules to suggest the optimal route for hazmat trucks.

2.4.9 Uday Kumar Chakrabarti, Jigisha K. Parikh (Chakrabarti & Parikh, 2012)

The risk assessment for Hazmat transportation used the HAZOP and Hazard analysis (HAZAN) technique. HAZAN assists in the design of both the emergency response system and the low-risk route for hazardous traffic. This method evaluates both individual and community risks associated with hazardous transport. The amount of fatality risk fluctuates with the length of the roadway; as the length of the roadway increases, the fatality risk decreases. Class 3 Hazardous Goods offer a lower risk of death than Class 2 Hazardous Goods and the risk of thermal radiation from pool fires occurs prior to BLEVE (Boling Liquid Expansion Vapor Explosion) or UVCE. Compared to flammable LPG occurrences, the poisonous ammonia emission has a wider effect zone. According to HSE of UK guidelines, the three study hazmats—LPG (class 2 hazmat), which is flammable, Ammonia (class 2 hazmat), which is poisonous, and Petrol (class 3 hazmat), which is flammable—each have distinct risks that fall within the as low as reasonably practicable (ALARP) acceptable region. While the ALARP covers the societal risks associated with LPG and gasoline, it does not cover ammonia releasing. An effective emergency plan can regulate the reduction of hazardous damage.

2.4.10 Prapaipim Sutheewasinnon and Prasopchai Pasunon (Sutheewasinnon, 2016)

This research study relies on a targeted sampling qualitative research strategy. Snowball or chain sampling is one of 16 qualitative research sampling strategies presented by Miles and Huberman. The snowball is one of the well-known qualitative research sampling techniques. The researcher must initially make an effort to discover the first sample, select the expert in the field, and obtain the first sample. The first sample is then asked for the second and further samples by the researcher. This process works like a snowball, growing from small to large until there is no more room for study or learning due to data saturation or redundancy. Bias occurs if the sample recommends the same sample of characters, and it affects all kinds of data.

2.4.11 Duncan Wilson, Glenn I. Hawe, Graham Coates, Roger S. Crouch (Wilson et al., 2014)

The performance of an emergency response team depends on quick responses and effective routing. The decision support model supported in the management of the emergency response and the distribution of resources in this particular scenario. The purpose of this study was for researchers to determine route validity and travel time predictions generated by decision support programs. Despite being useful for emergency logistics, the Mass Casualty Incident (MCI) model is not viable for an actual transportation network. Examining the optimal route and travel time results allows for a simulation and analysis of the disruption. Therefore, only this study is appropriate for the realistic model simulation. Dijkstra's algorithm is used to determine the shortest path that is also within the parameters of the standard network. MCI decides on the routing and assesses it using a Monte Carlo experiment in order to achieve a short and consistent travel time. Researchers should utilize the Bayesian to update the probability whenever they obtain more information. In actuality, emergency response situations should have access to the routing and travel time data.

2.4.12 Ravi K. Sharma (Sharma et al., 2015)

This paper study about electronic-Incident Command System (e-ICS) which is an automated network system in emergency response strategy at Indian Oil Corporation Limited (IOCL). ICS serves as a tool to lessen human error, commotion, and confusion during emergency response for efficient emergency preparedness, however improper ICS training results in failure.The effectiveness of an e-ICS depends on information access and response speed, but in practice it is hampered by the behavioral tendencies of the teams' approach to teamwork, duty, and human error.

2.4.13 Jiang-Hua Zhang, Jin Li, Zhi-Ping Liu (Zhang et al., 2012)

Emergency resource allocation is a critical step in emergency response management. Multiple resource and secondary disasters in an actual situation ignore this message. Mathematical programming using integers can solve this problem (heuristic algorithm). Options are prioritized depending on each location, where a second disaster is likely to occur. These methods and algorithms also operate in a practical situation on a vast scale. Three steps make up the methodolog: (1) data fusion to predict the alleviation requirement in many areas, (2) fuzzy clustering to categorize influenced area into the groups, (3) multi- criteria decision designing to rank the command priority. This study investigates the most reliable strategy for distributing emergency supplies from depots to disaster areas. Effective emergency resource allocation can reduce costs and reduce disaster losses. The results of the existing algorithms are all optimal solution operations, and it is difficult to provide emergency response in real time. An effective and flexible strategy is difficult to adapt to large-scale scenarios or practical situations.

2.4.14 Thanyarat Tiya-apisit and Uttapol Smutkupt (Thanyarat Tiya-apisit & Uttapol Smutkupt, 2017)

Analytic Hierarchy Process (AHP) technique and Fuzzy set theory is used by multi-criteria decision making process to choose the vehicle's maintenance service provider model. FAHP (Fuzzy Analytic Hierarchy Process) method is integrated by AHP technique and Fuzzy set theory to improve the AHP's limitation that consists of 5 steps: fuzzy set, the linguistic variables, the fuzzy operators, reasoning in fuzzy logic and defuzzification. The quality criteria are collected by the literatures and classified in 5 criteria. The sub-criteria is chosen by brainstorm and set in AHP structure to get the influencing factors which are input to the questionnaire that has 1-9 scores. The left factor is important more than the right factor when the score less than 5, the left and the right factor are the same level in 5 score and the right factor is more important when the score more than 5. Six maintenance service providers assess this questionnaire. This method evaluates the relationship that effects each criteria. FAHP (Fuzzy Analytic Hierarchy Process) is used to appraise the weight each criteria.

2.4.15 Rujipan Phangchandha and Arroon Ketsakorn (Rujipun Phangchandha & Arron Ketsakorn, 2018)

The aim of this cross-sectional study in fuel oil transportation makes the new opportunity criteria and weight the relative of criteria by applying the Delphi technique and Analytic Hierarchy Process (AHP) in order to acquire accuracy and reliability criteria in the fuel oil unloading process.

# CHAPTER 3
# RESEARCH METHODOLOGY

## 3.1 Location

The Chalerm Maha Nakhon Expressway is selected as the incident location for this study. This expressway leads directly to Khlong Toei Port, an area characterized by high population density and traffic congestion (Wilson et al., 2014). These factors are particularly relevant to our analysis of emergency response. The Chalerm Maha Nakhon Expressway comprises three main routes, all converging at the Tha Ruea Interchange as shown in Figure 3.1

- Din Daeng-Tha Ruea Line: This route originates at the end of Vibhavadi Rangsit Road, passes through the Makkasan Interchange, and concludes at Khlong Toei Port.

- Bang Na-Tha Ruea Line: Starting from Bang Na, this line proceeds through At Narong and terminates at Khlong Toei Port.

- Dao Khanong-Tha Ruea Line: This route begins in Dao Khanong, travels through Suksawat, Rama III, and Sathu Pradit, finally ending at Khlong Toei Port.

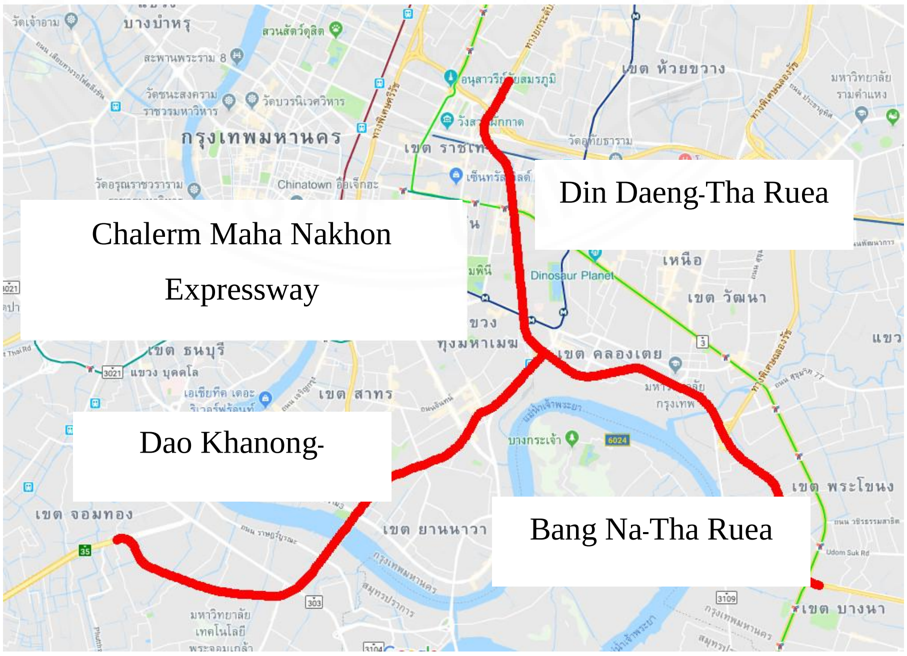



Figure 3.1 The Chalerm Maha Nakhon Expressway

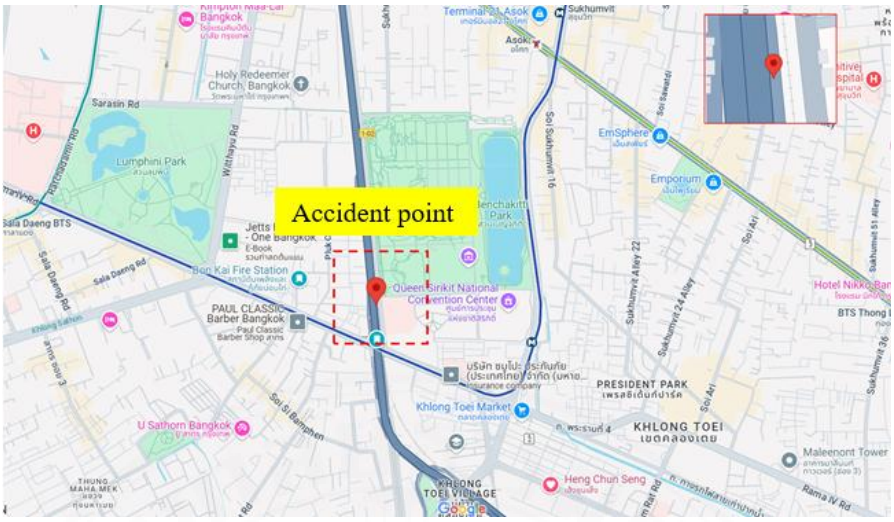



Figure 3.2 The accident point on Chalerm Mahanakorn route

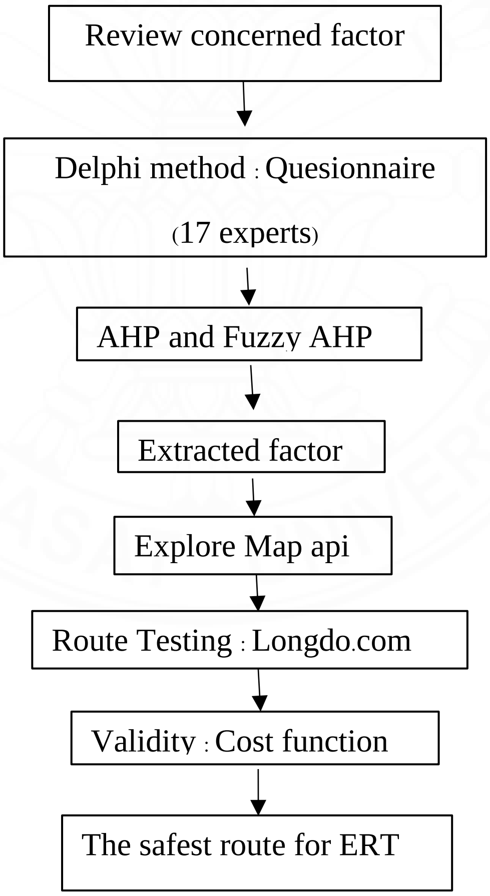



Figure 3.3 The chemical emergency response process

### 3.2 Questionnaire

The research commenced with the development of a questionnaire, meticulously crafted through a two-step process. This involved a comprehensive literature review to identify and subsequently categorize key factors influencing emergency response effectiveness, forming the questionnaire's foundational content. The instrument was structured into two primary sections: Part 1 gathered general demographic data from expert participants, while Part 2 aimed to elicit their opinions on critical factors for emergency route selection during chemical spills on the Chalerm Maha Nakhon Expressway.

Part 1 gathered general demographic data from expert participants

- Age was categorized into four groups: ≤ 30 years, 31-40 years, 41-50 years, and >50 years.

- Gender was categorized into two groups: male and female.

- Academic rank was categorized as follows: Lecturer, Assistant Professor, Associate Professor, Professor, Other (please specify)

- Administrative position within the organization was categorized as: Operational level, Management level (Department head and above)

- Level of education was categorized as: Below Bachelor's Degree, Bachelor's Degree, Master's Degree, Doctoral Degree

- Area of specialization was categorized as: Occupational Health, Logistics, Emergency Response, Computer Science, Transport, Environmental, Other (please specify)

- Years of experience in current organization were categorized as: ≤5 years, >5 years (please specify)

Part 2 aimed to elicit their opinions on critical factors for emergency route selection during chemical spills on the Chalerm Maha Nakhon Expressway.

Component 1: Travel Time

Travel time refers to the factors influencing the duration it takes to reach an incident site. These factors include:

- Traffic flow: The fluidity of traffic volume.

- Route selection regulations/standards: Established guidelines for choosing a route.

- The shortest path: The minimum distance required to reach the destination.

- Route complexity: Factors such as the number of intersections and turns.

- Comfortable road: The ease and quality of the road surface for transit.

Component 2: Chemical Data

Chemical data refers to the factors that influence the assessment of the severity and dispersion of a chemical spill. These factors include:

- Chemical concentration level: The amount of the chemical present

- Incident location: The precise position of the spill.

- Chemical dispersion diagram (footprint from ALOHA): Visual representation of how the chemical is spreading, often modeled using tools like ALOHA.

Component 3: Social Impact Data

Social impact data refers to factors that could affect society, communities, and the environment, which must be considered when selecting an emergency response route. These factors include:

- Population density (community areas)

- Business density (business districts)

- Environmental conditions (impact on the surrounding environment)

Component 4: Traffic Data Accessibility

Traffic data accessibility refers to the channels through which traffic volume information can be obtained. These include:

- Google Maps application on mobile phones/computers

- EXAT Traffic application on mobile phones

-Intelligent Transportation System (ITS) signs displaying traffic information at expressway toll plazas

Component 5: Emergency Response Team (ERT) Performance

Emergency Response Team (ERT) performance refers to the factors influencing the effectiveness of the ERT's incident response. These factors include:

- Readiness of equipment and resources for incident response.

- Location of the ERT.

For each research question, please evaluate its suitability, ethical alignment, and consistency with the study's variables. Use the following scale for your assessment:

1 = Consistent/Agree

0 = Unsure

-1 = Inconsistent/Disagree

The developed questionnaire was then submitted to a committee of five experts for instrument quality review, specifically focusing on content validity. This committee comprised:

- Two experts from the Faculty of Public Health, Thammasat University.

- One expert from the Faculty of Environment and Resource Studies, Mahidol University.

- One expert from the Department of Public Health, Faculty of Physical Education, Srinakharinwirot University.

- One expert from the Program in Safety Technology and Occupational Health, Faculty of Industrial Technology, Suan Sunandha Rajabhat University.

$$\text{IOC} = \frac{\Sigma R}{N}$$

Equation 3.1 IOC calculation

$\Sigma R$ = The sum of the scores given by experts for a particular item (e.g., +1 for relevant, 0 for unsure, -1 for irrelevant)

N = The total number of experts

To ensure the validity of this questionnaire, it underwent an Index of Consistency (IOC) analysis. This validation process involved a review by a five-member expert committee specializing in occupational health. The questionnaire was distributed to these committee members via email, with a two-week period allocated for their comprehensive evaluation. Notably, items with an IOC value below 0.5 (indicating insufficient consistency) were not immediately eliminated. Instead, the questionnaire underwent subsequent refinement and improvement, integrating the feedback and suggestions provided by the IOC committee. (Wongrukmitr, 2021)

## 3.3 Delphi method

### 3.3.1 Expert selecting

Following the initial Index of Consistency (IOC) quality check of the questionnaire, 17 experts were meticulously selected to participate in this study. This specific number was chosen to help ensure a low error rate, a decision consistent with findings from prior research on expert elicitation as shown in Table 3.1. (Savkovic et al., 2022) (Wang et al., 2022) (Agarwal et al., 2014) (J. et al., 2012)

Table 3.1 Reduction in error of expert size

| Expert size | Error reduction | Net change |
|---|---|---|
| 1 - 5 | 1.02 - 0.70 | 0.50 |
| 5 - 9 | 0.70 – 0.58 | 0.12 |
| 9 – 13 | 0.58 – 0.54 | 0.04 |
| 13 – 17 | 0.54 – 0.50 | 0.04 |
| 17 – 21 | 0.50 - 0.48 | 0.02 |
| 21 – 25 | 0.48 – 0.46 | 0.02 |
| 25 – 28 | 0.46 – 0.44 | 0.02 |

The selected experts possessed extensive knowledge across critical domains, specifically in hazardous materials transportation, occupational health, chemical spill response, and route planning utilizing mapping technologies. Furthermore, their participation underscored a demonstrable interest in the study's objectives as shown in Table 3.2. A snowball sampling technique was employed for their selection.

Table 3.2 Qualification of Expert

| Sector | No. | Position | Specific Field | Experience (Yrs) | Person |
|---|---|---|---|---|---|
| **Government** | 1 | Occupational Health Lecturer | Chemical Emergency Response | >5 | 2 |
| | 2 | MOT, PORT officer | Hazmat Transport | >5 | 2 |
| | 3 | DDPM, MIT (ปภ.) | Hazmat Emergency Response | >5 | 2 |
| | 4 | Fire Fighting officer | Hazmat Emergency Response | >5 | 3 |
| | 5 | ERT, EXAT | Hazmat Emergency Response | >5 | 2 |
| | 6 | PCD officer | Air Pollutiion | >5 | 1 |
| **Private** | 7 | Hazardous substance logistics | Hazmat Transport | >5 | 2 |
| | 8 | Model | Route selection specialist | >5 | 3 |
| | | Total | | | 17 |

### 3.3.2 Expert evaluation

The questionnaire, after successfully passing the Index of Consistency (IOC) validation, was distributed via email to all 17 selected experts. Each round of questionnaire distribution and response collection generally did not exceed a two-week period. The steps for each round were as follows:

(1) In the first round (initial) is opened end version, collecting expert opinions and returning within 2 weeks.

(2) The second round (rating scale) was developed on the basis of the first round and was again submitted to the panel for comments. In this round, the questionnaire should prioritize expert-judged rating scales to find patterns, quartiles, or interquartile ranges (IRs) in ratings.

(3) The third (important) round, developed from the second round, depends on the IR. If the IR-value is low, an expert opinion can be drawn, which means the opinion corresponds to the group, but the IR-value is high, include the R-value in the questionnaire and send it back to them again. This round is very important because within the same question, the answers are unbiased.

(4) There is a rating scale in the fourth round, and this round will replicate the third round if the IR is low value and same the last round, it means that the expert's opinion has harmony and can conclude the result.

An item was considered to have achieved expert consensus when both of the following conditions were satisfied: Interquartile Range ≤ 1.5: Indicating acceptable response variability among experts. Mode-Median Difference ≤ 1.0: Demonstrating minimal discrepancy between central tendency measures Non-Consensus Identification. Items failing to meet either criterion were classified as lacking sufficient expert consensus, indicating continued disagreement or uncertainty among the expert panel regarding the specific factor or statement.

The opinions of these 17 experts were then utilized for subsequent calculations. Factors identified with an Interquartile Range (IQR) value > 1.5, specifically "Work Instruction (WI)," "Environment," and "EXAT Traffic," were excluded from further analysis due to insufficient expert consensus. Conversely, the remaining factors, which demonstrated high expert agreement (IQR < 1.5), were subsequently used as inputs for calculations employing both the Fuzzy Analytic Hierarchy Process (FAHP) and the Analytic Hierarchy Process (AHP) methodologies.

Following this crucial adjustment, the research instrument successfully received ethical approval from the Human Research Ethics Committee of

Thammasat University (Science), (HREC-TUSc) under research project code 67PU015, ensuring all procedures adhered to human research ethics guidelines.

### 3.3.3 Statistical Analysis

#### 3.3.3.1 Median

$$\boldsymbol{M_m = l + \left(\frac{\frac{n}{2} - cf}{f}\right) h}$$

$l$ = lower limit of median class,

$n$ = number of observations,

$cf$ = cumulative frequency of class preceding the median class,

$f$ = frequency of median class,

$h$ = class size (assuming class size to be equal)

#### 3.3.3.2 Interquartile Range

The Interquartile Range (IQR) serves as a robust indicator of statistical dispersion, specifically quantifying the spread of the central 50% of a given dataset. This measure is arithmetically derived by calculating the difference between the third quartile (Q3) and the first quartile (Q1)

$$IQR = Q3 - Q1$$

#### 3.2.3.3 Mode

The formula for calculating the mode is employed to identify the value that appears with the highest frequency within a dataset. This statistical tool is particularly relevant and utilized when analyzing grouped data

$$Mode = l + \left(\frac{f_1 - f_0}{2f_1 - f_0 - f_2}\right) h$$

$l$ = lower limit of the modal class,

$h$ = size of the class interval ,

$f_1$= frequency of the modal class,

$f_0$ = frequency of the class preceding the modal class,

$f_2$ = frequency of the class succeeding the modal class,

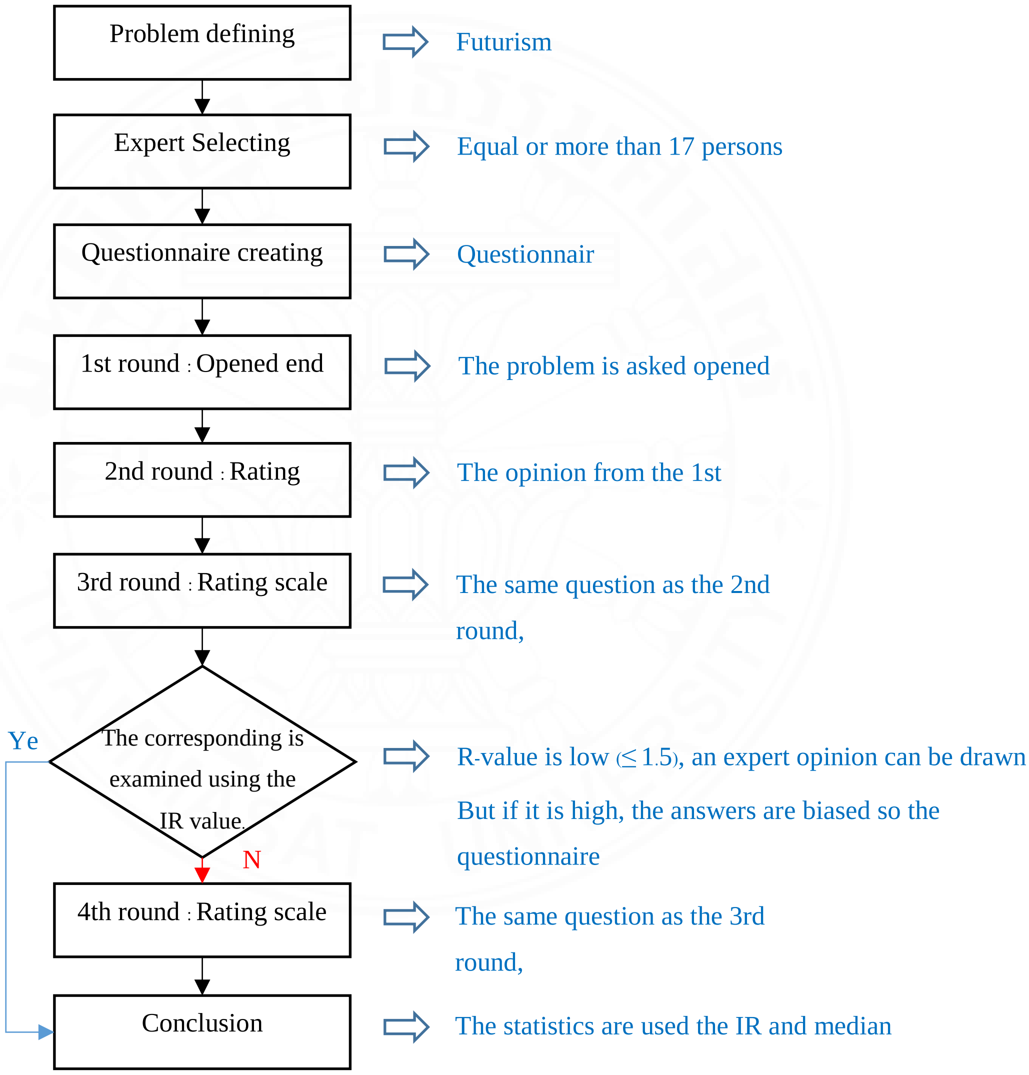



Figure 3.4 Diagram of Delphi method

### 3.4 Analytic Hierarchy Process (AHP)

One of the most effective multi-criteria evaluation techniques and multi-criteria decision-making (MCDM) techniques for determining the best option is the Analytic Hierarchy Process (AHP) created by Saaty. (Vudhivanich, 2003) (Murat et al., 2016) The Analytic Hierarchy Process (AHP) is a straightforward principle that categorizes problems into various classifications. The three components that AHP considers as essential are (Murat et al., 2016)

(1) Decomposition : The evaluation of the hierarchy is divided into three levels: goals, criteria, sub-criteria, and alternatives. The influencing factors that affect the effective and safest emergency response route are defined, including objectives, criteria and alternatives, as shown in

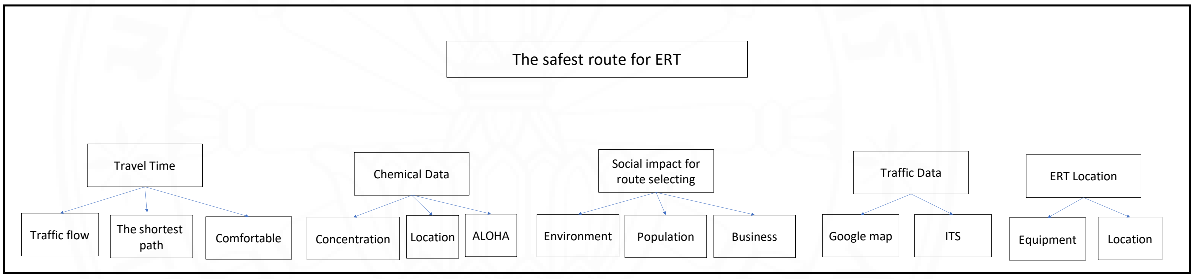



Figure 3.5 The affecting factor Hierarchy structure of AHP

This section presented five primary components identified through previous rounds as crucial determinants for optimal route selection during chemical spill emergencies on the Chalerm Mahanakorn Expressway. Each component was accompanied by group statistical measures (median, interquartile range) and individual expert's previous responses to facilitate informed reassessment:

Component 1: Travel Time Optimization (Response Time Factors)

Definition: Temporal efficiency in emergency response deployment from origin to incident location Primary Determinant: Traffic flow dynamics and current road conditions Measurement Criteria: Response time minimization considering real-time traffic conditions, route accessibility, and travel distance optimization

This component encompassed temporal considerations essential for rapid emergency response deployment:

- Traffic Flow Dynamics: Assessment of current traffic conditions and their impact on emergency vehicle travel speed

- Shortest Path Selection: Evaluation of optimal distance routing strategies from emergency response origins to incident destinations

- Route Complexity Assessment: Analysis of intersection density, turning requirements, and navigational challenges affecting travel convenience and road accessibility

Component 2: Chemical Hazard Characteristics

Definition: Technical evaluation of chemical spill characteristics and associated risks Primary Data Source: ALOHA (Areal Locations of Hazardous Atmospheres) software analysis Measurement Criteria: Chemical dispersion modeling, concentration levels, toxicity assessment, and atmospheric impact evaluation incorporating meteorological variables

This component addressed technical aspects of chemical spill incidents that directly influence route selection priorities:

- Atmospheric Concentration Levels: Assessment of chemical concentration in ambient atmosphere and evaluation of fire risk potential relative to Lower Explosive Limit (LEL) thresholds

- Incident Location Specificity: Precise geographic positioning on expressway infrastructure, with particular emphasis on proximity to entry and exit points

- Dispersion Pattern Analysis: Chemical footprint modeling utilizing ALOHA (Areal Locations of Hazardous Atmospheres) software, incorporating meteorological variables including wind direction and speed, alongside chemical properties such as spill volume, toxicity levels, and potential health impact severity

Component 3: Socioeconomic Impact Considerations

Definition: Assessment of potential effects on surrounding communities and societal infrastructure Primary Assessment Method: Affected community area evaluation Measurement Criteria: Population density analysis, residential area proximity, vulnerable population identification, and social infrastructure impact assessment

This component evaluated potential effects on surrounding communities and economic activities:

- Population Density Assessment: Systematic evaluation of residential community exposure risks, emphasizing preference for alternative routes when safer options exist despite potentially longer travel times

- Commercial Activity Density: Assessment of business district exposure and potential economic impact magnitude

Component 4: Traffic Information Accessibility

Definition: Availability and reliability of real-time traffic data for informed route selection Primary Data Source: Google Maps and associated traffic monitoring systems Measurement Criteria: Real-time traffic condition accuracy, alternative route availability, and information system reliability

This component addressed the availability and reliability of real-time traffic data systems:

- Mobile Technology Integration: Utilization of GPS-based navigation applications including Google Maps and similar platforms on mobile devices and computer systems

- Intelligent Transportation System (ITS) Infrastructure: Access to electronic signage and digital displays providing real-time traffic information at expressway toll booth locations and strategic monitoring points

Component 5: Emergency Response Team (ERT) Operational Readiness

Definition: Operational readiness and deployment capability of emergency response resources Primary Assessment Parameter: Resource readiness of fire stations and emergency response units Measurement Criteria: Personnel availability, equipment readiness, response time capability, and operational coordination effectiveness. Given the Department of Disaster Prevention and Mitigation's (DDPM) standard for emergency response of no more than 8 minutes (Lertsookheekasem, 2023), we've selected fire stations located within a 3.5 km radius of the incident site. This ensures that the potential response time aligns with the DDPM's established standard.

This component evaluated the preparedness and strategic positioning of emergency response resources:

- Resource Availability Assessment: Comprehensive evaluation utilizing the 4M framework:

1. Manpower: Assessment of trained personnel adequacy and deployment capacity

2. Materials/Equipment: Availability of specialized emergency response equipment including chemical absorbent materials, fire suppression vehicles, and containment systems

3. Methods: Evaluation of established response protocols, standard operating procedures, and intervention strategies

4. Management: Assessment of coordination mechanisms and command structure effectiveness

Location (Strategic Positioning) Geographic distribution analysis of Emergency Response Teams relative to potential incident locations and optimal deployment strategies for rapid response implementation

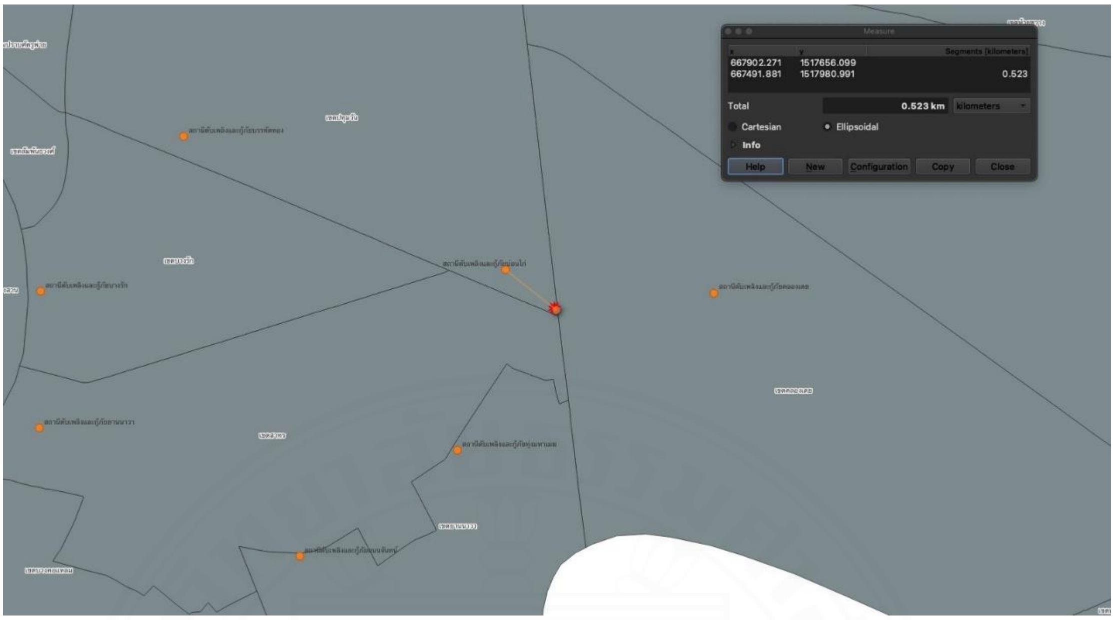



Figure 3.6 The distance to the Bon Kai Fire Station was measured by calculating the coordinates using the Expressway Authority of Thailand's (EXAT) GIS system.

(2) Calculation of relative priority (Prioritization) : When performing pairwise comparisons, the expert selected the best alternative. Each problem compared one by one and weighted them to obtain the more important alternative. The AHP measurement scale as showed in Table 2.1 Saaty's 1-9 scale of pairwise comparisons (Afshari et al., 2010)

(3) Synthesis : This step makes use of the matrix of pairwise Comparison as shown in Equation 3.2

$$\mathbf{A}^k = \begin{array}{c} \\ A_1 \\ \vdots \\ A_n \end{array} \begin{array}{c} \begin{array}{ccc} A_1 & \cdots & A_n \end{array} \\ \begin{bmatrix} a^k{}_{11} & \cdots & a^k{}_{1n} \\ \vdots & \ddots & \vdots \\ a^k{}_{n1} & \cdots & a^k{}_{nn} \end{bmatrix} \end{array}$$

Equation 3.2 Matrix for evaluation

Table 3.3 Pairwise Comparison Matrix for Affecting Factors

| Factor | Pairwise comparison for the relative weights of criteria | | | | | | | | | | | | | | | | | Factor |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | more than | | | | | | | | | less than | | | | | | | | |
| | Extremely more important | Far more important to extremely more important | Far more important | Much to far more important | Much more important | Slightly to much more important | Slightly more important | Equally or slightly more important | Equally important | Equally or slightly more important | Slightly more important | Slightly to much more important | Much more important | Much to far more important | Far more important | Far more important to extremely more important | Extremely more important | |
| A1 Traffic flow | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A2 The shortest path |
| A1 Traffic flow | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A3 Comfortable |
| A2 The shortest path | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A3 Comfortable |
| F1 Concentration | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | F2 Location |
| F1 Concentration | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | F3 ALOHA |
| F2 Location | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | F3 ALOHA |
| B1 Population | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | B2 Business |
| C1 Google map | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | C2 ITS |
| D1 Equipment | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D2 Location |

The expert team analyzes the draft versions of the questionnaires to ensure that they are clear and meet the study's objectives before deploying them. The ameliorated questionnaire is re-sent to the experts group to validate before using formal version. The official questionnaire was distributed to a panel of experts who assessed each factor and weighted pairwise comparisons. For each pair of factors, a pairwise comparison was conducted, and the geometric mean of the individual expert judgments was calculated based on the responses from all 17 experts. the geometric mean method was employed instead of arithmetic mean based on the theoretical foundation established by Aczél and Saaty (1983), who mathematically proved that geometric mean is the only aggregation procedure that satisfies all fundamental AHP properties: separability, unanimity, homogeneity, and the reciprocal property.

Following the Analytical Hierarchy Process (AHP) calculation, there are five subsequent steps. An illustrative example for factor 'A' is presented in the figure below

(1) Step 1 : The pairwise comparison of the expert weights is presented in the matrix (= The multiplicative scale for pairwise comparison was applied to the judgments of 17 experts ^ (1/17)

The values within this comparison pairwise matrix are derived from the geometric mean (GM) of the expert judgments. In this matrix, if the resulting fraction is an integer (i.e., greater than or equal to 1), the factor in the row is considered more important than the factor in the column. Conversely, if the fraction is less than one (a true fraction), the factor in the row is considered less important than the factor in the column.

$$GM = \sqrt[n]{(x_1 * x_2 * \ldots * x_n)}$$

Equation 3.3 Geometric Mean ($GM$)

= The multiplicative scale for pairwise comparison was applied to the judgments of 17 experts ^ (1/17)

(2) Step 2 : Summarize the factor value in each column Table 3.4 - Table 3.6 and calculation in each cell for step 3 with the formula = value in each cell/summarize value in each column Table 3.7 - Table 3.8

Table 3.4 The factor value of factor A (Factor A is defined as Travel Time)

| | A1 | A2 | A3 |
|---|---|---|---|
| A1 | 1.0000 | 2.6875 | 2.9209 |
| A2 | 0.3721 | 1.0000 | 2.7913 |
| A3 | 0.3424 | 0.3582 | 1.0000 |
| ∑ | 1.7144 | 4.0458 | 6.7123 |

GM (upper triangle); 1/GM (lower triangle)

Table 3.5 The factor value of factor F (Factor F is defined as Chemical Data)

| | F1 | F2 | F3 |
|---|---|---|---|
| F1 | 1.0000 | 1.5468 | 0.0000 |
| F2 | 0.6465 | 1.0000 | 0.0000 |
| F3 | 0.0000 | 0.0000 | 1.0000 |
| ∑ | 1.6465 | 2.5468 | 1.0000 |

Table 3.6 The factor value of factor B, C and D (Factor B is defined as Social Impact, Factor C is defined as Traffic Data and Factor D is defined as ERT Performance)

| | B1 | B2 |
|---|---|---|
| B1 | 1.0000 | 5.2014 |
| B2 | 0.1923 | 1.0000 |
| ∑ | 1.1923 | 6.2014 |

| | C1 | C3 |
|---|---|---|
| C1 | 1.0000 | 3.2487 |
| C3 | 0.3078 | 1.0000 |
| ∑ | 1.3078 | 4.2487 |

| | D1 | D2 |
|---|---|---|
| D1 | 1.0000 | 3.8334 |
| D2 | 0.2609 | 1.0000 |
| ∑ | 1.2609 | 4.8334 |

(3) Step 3 : A set of linear equations has an associated vector called the eigenvector. According to the table, the eigenvector formula is calculated as a fraction of the summed values for each row and summed all the values. The sum eigenvector is less than or equal to one.

Table 3.7 The calculation for the result value for step 3

| Factor | A1 | A2 | A3 |
|---|---|---|---|
| **A1** | 1/1.7144 | 2.6875/4.0458 | 2.9209/6.7123 |
| **A2** | 0.3721/1.7144 | 1/ 4.0458 | 2.7913/6.7123 |
| **A3** | 0.3424/1.7144 | 0.3582/4.0458 | 1/6.7123 |

| Factor | F1 | F2 | F3 |
|---|---|---|---|

| | | | |
|---|---|---|---|
| **F1** | 1/1.6465 | 1.5468/2.5468 | 0/1 |
| **F2** | 0.6465/1.6465 | 1/2.5468 | 0/1 |
| **F3** | 0 /1.6465 | 0/2.5468 | 1/1 |

| **Factor** | **B1** | **B2** |
|---|---|---|
| **B1** | 1/1.1923 | 5.2014/6.2014 |
| **B2** | 0.1923/1.1923 | 1/6.2014 |

| **Factor** | **C1** | **C2** |
|---|---|---|
| **C1** | 1/1.3078 | 3.2487/4.2487 |
| **C2** | 0.3078/1.3078 | 1/4.2487 |

| **Factor** | **D1** | **D2** |
|---|---|---|
| **D1** | 1/1.2609 | 3.8334/4.8334 |
| **D2** | 0.2609/1.2609 | 1/4.8334 |

Table 3.8 The eigenvector calculation

| | A1 | A2 | A3 | sum row | eigenvector |
|---|---|---|---|---|---|
| A1 | 0.5833 | 0.6643 | 0.4352 | 1.6827 | 0.5609 |
| A2 | 0.2170 | 0.2472 | 0.4159 | 0.8801 | 0.2934 |
| A3 | 0.1997 | 0.0885 | 0.1490 | 0.4372 | 0.1457 |
| | 1.0000 | 1.0000 | 1.0000 | 3.0000 | 1.0000 |

Eigenvector calculation row A1 = 1.6827/3 = 0.5609

Eigenvector calculation row A2 = 0.8801/3 = 0.2934

Eigenvector calculation row A3 = 0.4372/3 = 0.1457

| | F1 | F2 | F3 | sum row | eigenvector |
|---|---|---|---|---|---|
| F1 | 0.6074 | 0.6074 | 0.0000 | 1.2147 | 0.4049 |
| F2 | 0.3926 | 0.3926 | 0.0000 | 0.7853 | 0.2618 |
| F3 | 0.0000 | 0.0000 | 1.0000 | 1.0000 | 0.3333 |
| | 1.0000 | 1.0000 | 1.0000 | 3.0000 | 1.0000 |

Eigenvector calculation row F1 = 1.2147/3 = 0.4049

Eigenvector calculation row F2 = 0.7853/3 = 0.2618

Eigenvector calculation row F3 = 1/3 = 0.3333

| | B1 | B2 | sum row | eigenvector |
|---|---|---|---|---|
| B1 | 0.8387 | 0.8387 | 1.6775 | 0.8387 |
| B2 | 0.1613 | 0.1613 | 0.3225 | 0.1613 |
| | 1.0000 | 1.0000 | 2.0000 | 1.0000 |

Eigenvector calculation row B1 = 1.6775/2 = 0.8387

Eigenvector calculation row B2 = 0.3225/2 = 0.1613

| | C1 | C3 | sum row | eigenvector |
|---|---|---|---|---|
| C1 | 0.7646 | 0.7646 | 1.5293 | 0.7646 |
| C3 | 0.2354 | 0.2354 | 0.4707 | 0.2354 |
| | 1.0000 | 1.0000 | 2.0000 | 1.0000 |

Eigenvector calculation row C1 = 1.5293/2 = 0.7646

Eigenvector calculation row C2 = 0.4704/2 = 0.2354

| | D1 | D2 | sum row | eigenvector |
|---|---|---|---|---|
| D1 | 0.7931 | 0.7931 | 1.5862 | 0.7931 |
| D2 | 0.2069 | 0.2069 | 0.4138 | 0.2069 |
| | 1.0000 | 1.0000 | 2.0000 | 1.0000 |

Eigenvector calculation row D1 = 1.5862/2 = 0.7931

Eigenvector calculation row D2 = 0.4138/2 = 0.2069

(4) Step 4

Table 3.9 -

Table 3.13 illustrate the consistency vector values obtained from steps 2 and 3 for the calculation of the consistency ratio (CR).

Consistency vector of A1

= (1.0000*0.5609)+(2.6875*0.2934)+(2.9209*0.1457)/0.5609 = 3.1645

Consistency vector of A2

= (0.3721*0.5609)+(1.0000*0.2934)+(2.7913*0.1457)/0.2934 = 3.0982

Consistency vector of A3

= (0.3424*0.5609)+(0.3582*0.2934)+(1.000*0.1457)/0.1457 = 3.0387

Table 3.9 Consistency vector calculation (A factor)

| | | | | **Step 3** | **Consistency Vector** |
|---|---|---|---|---|---|
| **Step 2** | A1 | A2 | A3 | Eigenvector | |
| **A1** | 1.0000 | 2.6875 | 2.9209 | 0.5609 | 3.1645 |
| **A2** | 0.3724 | 1.0000 | 2.7913 | 0.2934 | 3.0982 |
| **A3** | 0.3424 | 0.3582 | 1.0000 | 0.1457 | 3.0387 |
| ∑ | 1.4813 | 5.2827 | 6.7123 | 1 | 9.3015 |

Consistency vector of F1

= (1.0000*0.4447)+(1.5768*0.3132)+(1.6902*0.2421)/ 0.4447= 3.0095

Consistency vector of F2

= (0.6465*0.4447)+(1.000*0.3132)+(1.4084*0.2421)/ 0.3132= 3.0068

Consistency vector of F3

= (0.5916*0.4447)+(0.7100*0.3132)+(1.000*0.2421)/ 0.2421= 3.0051

Table 3.10 Consistency vector calculation (F factor)

| | | | | Step 3 | Consistency Vector |
|---|---|---|---|---|---|
| **Step 2** | F1 | F2 | F3 | Eigenvector | |
| **F1** | 1.0000 | 1.5468 | 1.6902 | 0.4447 | 3.0095 |
| **F2** | 0.6465 | 1.0000 | 1.4084 | 0.3132 | 3.0058 |
| **F3** | 0.5916 | 0.7100 | 1.0000 | 0.2421 | 3.0051 |
| ∑ | 1.7443 | 3.8788 | 6.6786 | 1 | 9.0215 |

Consistency vector of B1

= (1.0000*0.6222)+(1.6471*0.3778)/ 0.6222 = 1.6222

Consistency vector of B2

= (0.6071*0.6222)+(1.000*0.3778)/ 0.3778 = 1.3778

Table 3.11 Consistency vector calculation (B factor)

| | | | Step 3 | Consistency Vector |
|---|---|---|---|---|
| **Step 2** | B1 | B2 | Eigenvector | |
| **B1** | 1.0000 | 1.6471 | 0.6222 | 1.6222 |
| **B2** | 0.6071 | 1.0000 | 0.3778 | 1.3778 |
| ∑ | 1.6071 | 2.6471 | 1 | 3.0000 |

Consistency vector of C1

= (1.0000*0.7671)+(3.2941*0.2329)/ 0.7671 = 1.7671

Consistency vector of C2

= (0.3036*0.7671)+(1.0000*0.2329)/ 0.2329 = 1.2329

Table 3.12 Consistency vector calculation (C factor)

| | | | Step 3 | Consistency Vector |
|---|---|---|---|---|
| **Step 2** | C1 | C2 | Eigenvector | |
| **C1** | 1.0000 | 3.2941 | 0.7671 | 1.7671 |
| **C2** | 0.3036 | 1.0000 | 0.2329 | 1.2329 |
| ∑ | 1.3036 | 4.2941 | 1 | 3.0000 |

Consistency vector of D1

= (1.0000*0.8097)+(4.2549*0.1903)/ 0.8097 = 1.8097

Consistency vector of D2

= (0.2350*0.8097)+(1.000*0.1903)/ 0.1903 = 1.1903

Table 3.13 Consistency vector calculation (D factor)

| | | | Step 3 | Consistency Vector |
|---|---|---|---|---|
| **Step 2** | D1 | D2 | Eigenvector | |
| **D1** | 1.0000 | 4.2549 | 0.8097 | 1.8097 |
| **D2** | 0.2350 | 1.0000 | 0.1903 | 1.1903 |
| ∑ | 1.2350 | 5.2549 | 1 | 3.0000 |

(5) Step 5 : Consistency Ratio (CR) calculation follow this formula

CR = CI (Consistency Index)/RI (Random Index)

CI = (L-n)/(n-1)

The value for each variable in this formula was displayed as follows:

1) RI standard as shown in Table 3.14

Table 3.14 Random Index standard

| n | Random Index (RI) | Cut-off CI (10%) |
|---|---|---|
| **1** | 0.00 | 0.00 |
| **2** | 0.00 | 0.00 |
| **3** | 0.58 | 0.058 |
| **4** | 0.90 | 0.090 |
| **5** | 1.21 | 0.121 |
| **6** | 1.24 | 0.124 |
| **7** | 1.32 | 0.132 |
| **8** | 1.41 | 0.141 |
| **9** | 1.45 | 0.145 |
| **10** | 1.49 | 0.149 |
| **11** | 1.51 | 0.151 |
| **12** | 1.48 | 0.148 |
| **13** | 1.56 | 0.156 |
| **14** | 1.57 | 0.157 |
| **15** | 1.59 | 0.159 |

2) L = sum (consistency vector) /n

Factor A, L = 9.3015/3 = 3.1005

Factor F, L = 9.0215/3 = 3.0072

Factor B, L = 3.0000/2 = 1.5000

Factor C, L = 3.0000/2 = 1.5000

Factor D, L = 3.0000/2 = 1.5000

CI calculation in each factor

Factor A, L = (3.1005-3)/(3-1) = 0.0502

Factor F, L = (3.0072-3)/(3-1) = 0.0036

Factor B, L = (1.5000-2)/(2-1) = 0.0000

Factor C, L = (1.5000-2)/(2-1) = 0.0000

Factor D, L = (1.5000-2)/(2-1) = 0.0000

CR calculation in each factor, A Consistency Ratio (CR) value of less than 0.1 indicates an acceptable level of consistency in the pairwise comparisons, allowing the eigenvector to be reliably used for deriving factor weights.

Factor A, L = 0.0502/0.58 = 0.0866

Factor F, L = 0.0036/0.58 = 0.0062

Factor B, L = 0.0000/0 = 0

Factor C, L = 0.0000/0 = 0

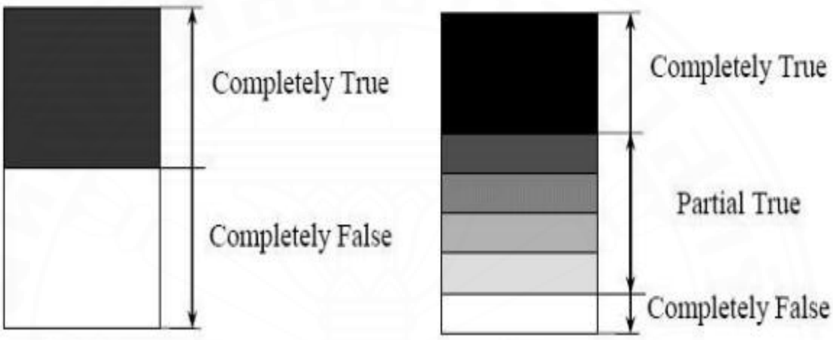
Factor D, L = 0.0000/0 = 0

The identified factors demonstrate varying degrees of interdependency and influence on overall emergency response effectiveness. The AHP methodology enabled the systematic evaluation of these relationships, establishing a hierarchical structure that reflects the relative importance of each factor in the decision-making process. The factor prioritization results from this analysis provide a quantitative foundation for subsequent Fuzzy AHP analysis and emergency response system optimization, ensuring that resource allocation and response strategies are aligned with the most critical determinants of emergency response effectiveness. The dual-methodology approach utilizing both manual calculations and Expert Choice software provided robust validation of the AHP results. Consistency ratios were calculated for all pairwise comparison matrices to ensure the reliability of expert judgments and the mathematical validity of the derived priority weights.

## 3.5 Fuzzy Analytic Hierarchy Process (FAHP)

### 3.5.1 Fuzzy Logic

Fuzzy logic is a many-valued logic pattern that allows any real number between 0 and 1 to represent a truth value variable. Fuzzy logic is suitable for the partial truth concept, where the true value has a range between completely true and completely false in any real number between 0 and 1. On the other hand, the truth value variables of Boolean logic have the integer values 0 or 1 as shown in Figure 3.7




Boonlean logic Fuzzy logic

Figure 3.7 Truth value between Boonlean logic and Fuzzy logic

Bivalence, which has only two membership functions, contrasts with fuzziness or multivalence, which has more than two membership functions. Fuzzy logic method (Dernoncourt, 2013) start with Analytic Hierarchy Process (AHP) scoring results that are more managed as shown below

(1) Membership function identification for this method focuses on fuzzy logic triangular membership function and fuzzy logic trapezoidal membership function

The triangular membership function consists of three parameters {a b c}as shown in Equation 3.4

$$f(x,a,b,c) = \begin{cases} 0, & x < a \\ (x-a)/(b-a), & a \le x < b \\ (c-x)/(c-b), & b \le x < c \\ 0, & x > c \end{cases}$$

Equation 3.4

Trapezoidal membership function consists of three parameters {a b c} as shown in Equation 3.5

$$f(x,a,b,c,d) = \begin{cases} 0, & x < a \\ (x-a)/(b-a), & a \le x < b \\ 1, & b \le x < c \\ (d-x)/(d-c), & c \le x < d \\ 0, & d \le x \end{cases}$$

Equation 3.5

(2) Selecting the membership function type

(3) Membership function calculation using the provided equation

The AHP method excludes the ambiguity of expert judgment, and fuzzy logic improves this problem. Through pairwise comparisons of criteria and alternatives, the Fuzzy Analytic Hierarchy Process (FAHP) (Ayhan, 2013) evaluates linguistic factors that resulted in Triangular Fuzzy Numbers (TFNs). The format of TFNs is (l, m, u) to replace a single integer (1–9); l and u are the upper and lower boundary values, respectively, and m is the mean of M(x). The substitution as represented in Equation 3.6

$$\mu(x/M) = \begin{cases} 0, & x < l \\ (x-l)/(m-l), & l \le x < m \\ (u-x)/(u-m), & m \le x < u \\ 0, & x > u \end{cases}$$

Equation 3.6

Triangular Fuzzy number calculations and summary of Triangular Fuzzy number are shown as Equation 3.7

Equation 3.7 $(l_1, m_1, u_1) + (l_2, m_2, u_2) = (l_1+l_2, m_1+m_2, u_1+u_2)$

Difference of Triangular Fuzzy number in Equation 3.8 - Equation 3.10

Equation 3.8 $(l_1, m_1, u_1) - (l_2, m_2, u_2) = (l_1 - l_2, m_1 - m_2, u_1 - u_2)$

Multiplication of Triangular Fuzzy number in Equation 3.9

Equation 3.9 $(l_1, m_1, u_1) \times (l_2, m_2, u_2) = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2)$

Division of Triangular Fuzzy number in Equation 3.10

Equation 3.10 $(l_1, m_1, u_1) - 1 = (1/u_1 , 1/m_1 , 1/l_1)$

The Chang's technique (Chang, 1996) was improved by Buckley's method (Buckley, 1985) to establish the relative importance weights for the criteria and alternatives. The steps as follow

Step 1 Depict the hierarchical chart

Step 2 Determine fuzzy number with linguistic variables follow in Table 3.15 and membership function of triangular fuzzy number shown in Figure 3.8

Table 3.15 Linguistic variables and the corresponding triangular fuzzy numbers

| **Saaty scale** | **Definition** | **Fuzzy Triangular Scale** |
|---|---|---|
| 1 | Equally important (Eq. Imp.) | (1, 1, 1) |
| 3 | Weakly important (W. Imp.) | (2, 3, 4) |
| 5 | Fairly important (F. Imp.) | (4, 5, 6) |
| 7 | Strongly important (S. Imp.) | (6, 7, 8) |
| 9 | Absolutely important (A. Imp.) | (9, 9, 9) |
| 2 | The intermittent values between two adjacent scales | (1, 2, 3) |
| 4 | | (3, 4, 5) |
| 6 | | (5, 6, 7) |
| 8 | | (7, 8, 9) |

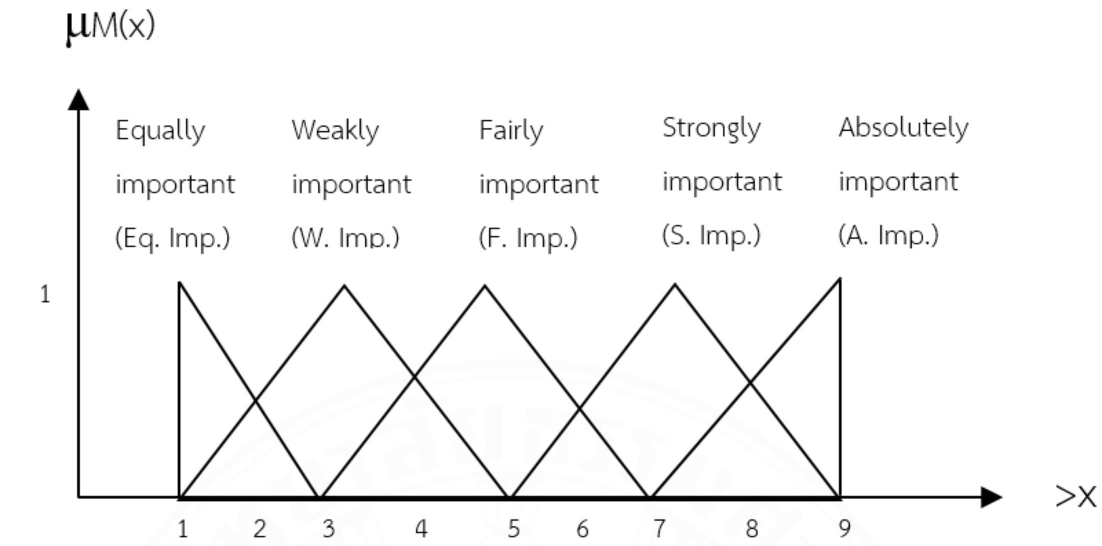



Figure 3.8 Membership function of triangular fuzzy number

The definition of X = {$x_1$, $x_2$, ..., $x_n$} is an Object set or alternatives, G = {$g_1$, $g_2$, ..., $g_n$}v is a Gold set. Hence fuzzy analytics for each object becomes as shown below

$M^1_{gi}$, $M^2_{gi}$ , ...,$M^m_{gi}$ , if i=1,2,...,n

then $M^j_{gi}$ (j=1,2,...,m) is the triangular fuzzy numbers

Step 3 Make the pairwise comparison matrix with fuzzy numbers is shown as Equation 3.11

$$(M^j_{gi})_{nxm} = \begin{bmatrix} M^1_{g1} & M^2_{g1} & \dots & M^m_{g1} \\ M^1_{g2} & M^2_{g2} & \dots & M^m_{g2} \\ . & . & . & . \\ . & . & . & . \\ M^1_{gn} & M^2_{gn} & \dots & M^m_{gn} \end{bmatrix} = \begin{bmatrix} (1,1,1) & (l_{12},m_{12},u_{12}) & \dots & (l_{1m},m_{1m},u_{1m}) \\ (l_{21},m_{21},u_{21}) & (1,1,1) & \dots & (l_{2m},m_{2m},u_{2m}) \\ . & . & . & . \\ . & . & . & . \\ (l_{n1},m_{n1},u_{n1}) & (l_{n2},m_{n2},u_{n2}) & \dots & (1,1,1) \end{bmatrix}$$

Equation 3.11

$(l_{ij}, m_{ij}, u_{ij}) = (1/u_{ij} , 1/m_{ij} , 1/l_{ij})$ when i=1,2,...n , j=1,2,...m and $i \neq j$

$(l_{ij}, m_{ij}, u_{ij}) = (1,1,1)$ when i = j

Step 4 Synthetic extent value (Si) calculations can compute for each row of pairwise comparison matrix

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1}$$

Equation 3.12

When,

- i means the row number and j means the column number
- $S_i$ is a Synthetic extent value
- $\sum_{j=1}^{m} M_{gi}^{j}$ is a summary of Triangular Fuzzy Number of pairwise comparison matrices.
- $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$ can be computed by following equations, respectively :

Step 5 Magnitude of Si calculation

$S_i \geq S_j$ $S_i = (l_i, m_i, u_i)$ and $S_j = (l_j, m_j, u_j)$ when i=1,2,… n and j=1,2,…m and i ≠ j

$$V(S_i \geq S_j) = \begin{cases} 1 & \text{if } m_i \geq m_j \\ 0 & \text{if } l_j \geq u_i \\ \dfrac{l_j - u_i}{(m_i - u_i) - (m_j - l_j)} & \text{other} \end{cases}$$

Equation 3.13

$S_i \geq S_j$ $S_i = (li,mi,ui)$ and $S_j = (lj,mj,uj)$ for other conditions as

$$V(S_i \geq S_j) \Big| j=1,2,....m \text{ ; } i \neq j) = \min V(S_i \geq S_j) \Big| j=1,2,....m \text{ ; } i \neq j)$$

Equation 3.14

Step 6 The weight of the criteria and alternatives calculation in the pairwise comparison matrix , the unnormalized weight vector

$$w'_i = \min V(S_i \geq S_j) \mid j=1,2,....m\ ;\ i \neq j)$$

Step 7 Final weight vector calculation, the weight vector computed to normalized

$$Wi = \frac{w'_i}{\sum_{i=1}^{n} w'_i}$$

Equation 3.15

$$W = (w_1, w_2, \ldots, w_n)^T$$

Equation 3.16

Following the identification of primary factors through conventional AHP analysis, the study proceeded to conduct detailed sub-factor analysis using the Fuzzy Analytic Hierarchy Process (FAHP) methodology. This advanced approach was specifically selected to address the inherent uncertainties and ambiguities characteristic of expert opinions in complex emergency response scenarios, where traditional crisp values may inadequately represent the nuanced nature of expert judgments.

The FAHP methodology enabled the incorporation of linguistic variables and fuzzy numbers to better capture the imprecision and subjectivity inherent in expert evaluations, thereby providing more realistic weight distributions for sub-factor prioritization.

Sub-Factor Weight Distribution Analysis

The FAHP analysis yielded comprehensive weight distributions for sub-factors within each primary factor category. The results demonstrate clear hierarchical preferences and significant weight variations among sub-categories:

Traffic Flow Condition Assessment (Google, 2024)

The traffic flow analysis revealed a strong preference for optimal conditions with substantial weight concentration in free-flow scenarios:

- Blue (Free Flow Conditions): W_blue = 0.55708

- Yellow (Moderate Flow Conditions): W_yellow = 0.26674
- Red (Congested Flow Conditions): W_red = 0.12013
- Deep Red (Critical Congestion): W_deepred = 0.05606

Table 3.16 FAHP calculation of Traffic flow

**Step 1 : Triangular Fuzzy Number (TFN)**

| | Green (G) | | | Yellow (Y) | | | Red (R) | | | Deep Red (DR) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Green (G) | 1 | 1 | 1 | 2 | 3 | 4 | 4 | 5 | 6 | 6 | 7 | 8 |
| Yellow (Y) | 1/4 | 1/3 | 1/2 | 1 | 1 | 1 | 2 | 3 | 4 | 4 | 5 | 6 |
| Red (R) | 1/6 | 1/5 | 1/4 | 1/4 | 1/3 | 1/2 | 1 | 1 | 1 | 2 | 3 | 4 |
| Deep Red (DR) | 1/8 | 1/7 | 1/6 | 1/6 | 1/5 | 1/4 | 1/4 | 1/3 | 1/2 | 1 | 1 | 1 |

**Step 2 : Fuzzy Geometric Mean (L : Low, M : Medium, U : Up)**

| | | | |
|---|---|---|---|
| Column G | **(1*2*4*6)^(1/4)** | **(1*3*5*7)^(1/4)** | **(1*4*6*8)^(1/4)** |
| Column Y | (1/4*1*2*4)^(1/4) | (1/3*1*3*5)^(1/4) | (1/2*1*4*6)^(1/4) |
| Column R | (1/6*1/4*1*2)^(1/4) | (1/5*1/3*1*3)^(1/4) | (1/4*1/2*1*4)^(1/4) |
| Column DR | (1/8*1/6*1/4*1)^(1/4) | (1/7*1/5*1/3*1)^(1/4) | (1/6*1/4*1/2*1)^(1/4) |
| | L | M | U |

**Step 3 Summary of Geometric Mean**

| | | | |
|---|---|---|---|
| Column G | **2.63215** | **3.7224** | **3.7224** |
| Column Y | 1.18921 | 1.4953 | 1.8612 |
| Column R | 0.53728 | 0.6687 | 0.8409 |
| Column DR | 0.26864 | 0.3124 | 0.3799 |
| Sum | 4.6273 | 5.6776 | 6.8044 |
| | L | M | U |

**Step 4 Fuzzy Weight**

| | | | |
|---|---|---|---|
| Column G | **2.63215/6.8044** | **3.7224/5.6776** | **3.7224/4.6273** |
| Column Y | 1.18921/6.8044 | 1.4953/5.6776 | 1.8612/4.6273 |

| | | | |
|---|---|---|---|
| Column R | 0.53728/6.8044 | 0.6687/5.6776 | 0.8409/4.6273 |
| Column DR | 0.26864/6.8044 | 0.3124/5.6776 | 0.3799/4.6273 |

| **Step 5 Defuzzification** | | | | |
|---|---|---|---|---|
| Fuzzy Weight | | | | **Sum** |
| Column G | **0.3868** | **0.5638** | **0.8145** | **1.7551** |
| Column Y | 0.1748 | 0.2634 | 0.4022 | 0.8404 |
| Column R | 0.0790 | 0.1178 | 0.1817 | 0.3785 |
| Column DR | 0.0395 | 0.0550 | 0.0821 | 0.1766 |
| Sum of Fuzzy Weight | | Defuzzification | | |
| Column G | **1.7551** | **1.7551/3** = | | **0.58503** |
| Column Y | 0.8404 | 0.8404/3 = | | 0.28012 |
| Column R | 0.3785 | 0.3785/3 = | | 0.12616 |
| Column DR | 0.1766 | 0.1766/3 = | | 0.05887 |
| Sum | | | | 1.05018 |

| **Step 6 Normalization** | | |
|---|---|---|
| | Normalization | |
| Column G | **0.58503**/1.05018 | **0.55708** |
| Column Y | 0.28012/1.05018 | 0.26674 |
| Column R | 0.12616/1.05018 | 0.12013 |
| Column DR | 0.05887/1.05018 | 0.05606 |
| **sum** | 1.05018 | 1 |

The weight distribution indicates overwhelming expert preference for free-flow conditions, reflecting the critical importance of unimpeded emergency vehicle movement during chemical spill responses.

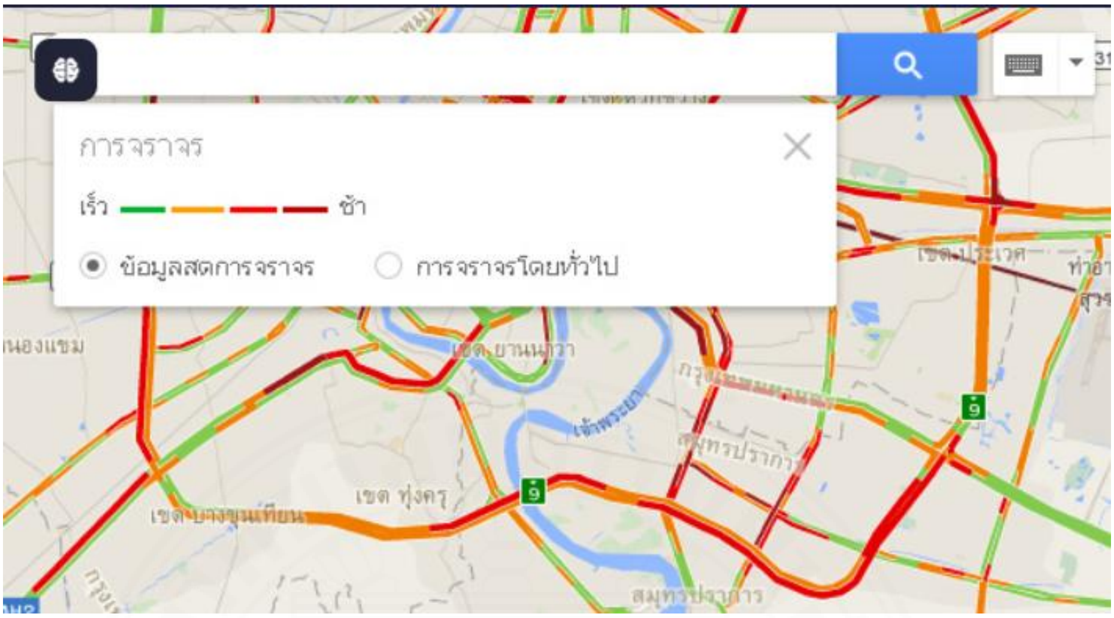



Figure 3.9 Color codes are frequently utilized to visually represent traffic conditions.

ALOHA Chemical Hazard Severity Assessment

The chemical hazard evaluation demonstrated strong preference for safe operational conditions:

- Green (Safe Conditions): W_green = 0.93318
- Yellow (Minor Impact Level): W_yellow = 0.05972
- Orange (Severe Impact Level): W_orange = 0.00711

Table 3.17 FAHP calculation of ALOHA Chemical Hazard

| **Step 1 : Triangular Fuzzy Number (TFN)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Yellow (Y) | | | Orange (O) | | | Red (R) | | |
| **Yellow (Y)** | 1 | 1 | 1 | 4 | 5 | 6 | 6 | 7 | 8 |
| **Orange (O)** | 1/6 | 1/5 | 1/4 | 1 | 1 | 1 | 2 | 3 | 4 |
| **Red (R)** | 1/8 | 1/7 | 1/6 | 1/4 | 1/3 | 1/2 | 1 | 1 | 1 |

| **Step 2 : Fuzzy Geometric Mean (L : Low, M : Medium, U : Up)** | | | |
|---|---|---|---|
| Column Y | **(1*4*6)^(1/3)** | **(1*5*7)^ (1/3)** | **(1*6*8)^(1/3)** |
| Column O | (1/6*1*2)^ **(1/3)** | (1/5*1*3)^(1/3) | (1/4*1*4)^(1/3) |
| Column R | (1/8*1/4*1)^(1/3) | (1/7*1/3*1)^(1/3) | (1/6*1/2*1)^(1/3) |
| | L | M | U |

| **Step 3 Summary of Geometric Mean** | | | |
|---|---|---|---|
| Column Y | **2.8845** | **6.2711** | **3.6342** |
| Column O | 0.69336 | 0.8434 | 1 |
| Column R | 0.31498 | 0.3625 | 0.4368 |
| Sum | 3.89284 | 4.477 | 5.071 |
| | L | M | U |

| **Step 4 Fuzzy Weight** | | | |
|---|---|---|---|
| Column Y | **2.8845**/5.071 | **6.2711/4.477** | **3.6342/4.6273** |
| Column O | 0.69336/5.071 | 0.8434/**4.477** | 1/4.6273 |
| Column R | 0.31498/5.071 | 0.3625/**4.477** | 0.4368/4.6273 |

| **Step 5 Defuzzification** | | | | |
|---|---|---|---|---|
| Fuzzy Weight | | | | **Sum** |
| Column Y | **0.5688** | **0.7306** | **0.9336** | **2.2330** |
| Column O | 0.1367 | 0.1884 | 0.2569 | 0.5820 |
| Column R | 0.0621 | 0.081 | 0.1122 | 0.2553 |
| Sum of Fuzzy Weight | | Defuzzification | | |
| Column Y | | **2.2330** | **2.2330/3** = | **0.74434** |
| Column O | | 0.5820 | 0.5820/3 = | 0.1940 |
| Column R | | 0.2553 | 0.2553/3 = | 0.08509 |
| Sum | | | | 1.02344 |

| **Step 6 Normalization** | | |
|---|---|---|
| | Normalization | |
| Column Y | **0.74434**/1.02344 | **0.7273** |
| Column O | 0.1940/1.02344 | 0.18956 |
| Column R | 0.08509/1.02344 | 0.08314 |
| **sum** | 1.02344 | 1 |

This distribution reflects expert consensus prioritizing scenarios with minimal chemical hazard exposure, emphasizing safety considerations in emergency response route selection.

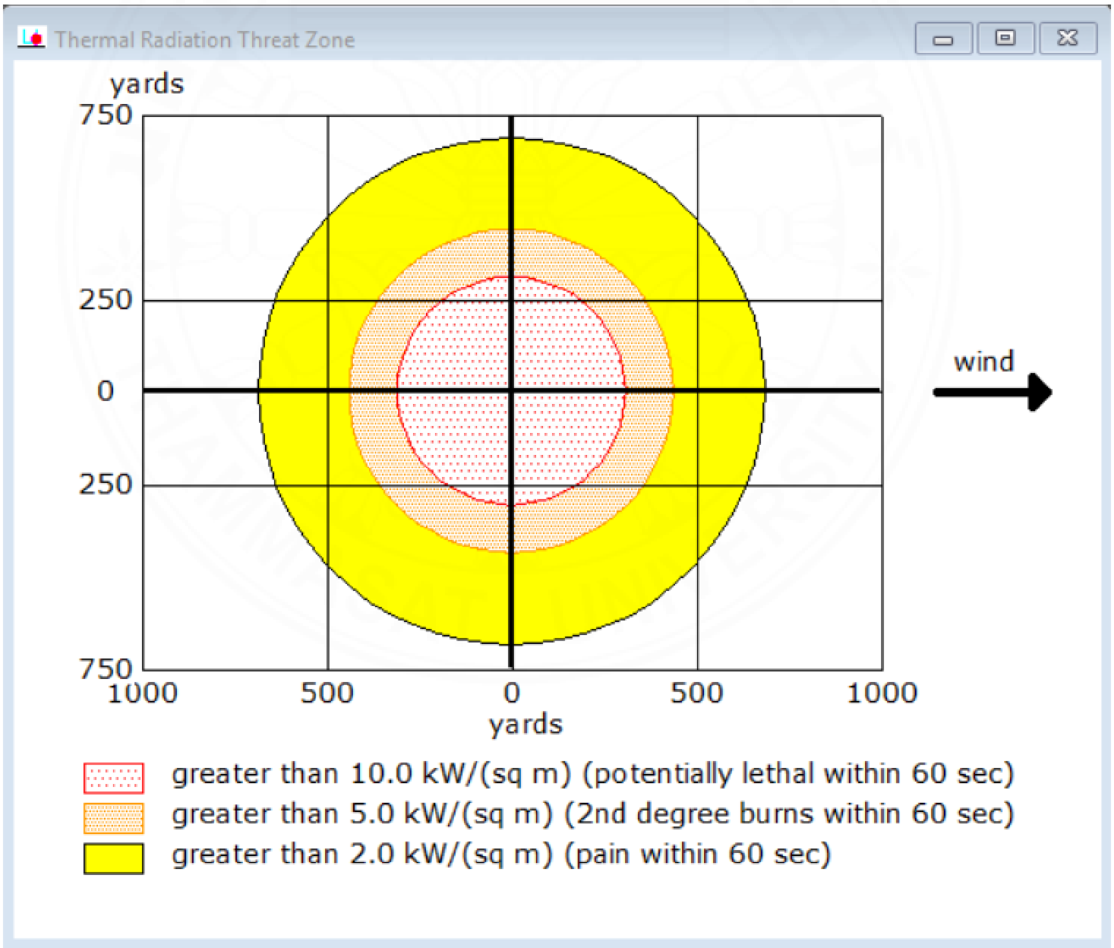



Figure 3.10 To illustrate the dispersion of Fusel Oil (UN No. 1201) using ALOHA software with a wind speed of approximately 1 m/s.

In the ALOHA Chemical Dispersion Plot simulations, researchers modeled incident scenarios based on typical wind speeds across eight cardinal wind directions (Marine Meteorological Center, 2024): North (N), Northeast (NE), East (E), Southeast (SE), South (S), Southwest (SW), West (W), and Northwest (NW). However, a key finding emerged from these simulations: at a low wind speed of 1 m/s, the resulting chemical dispersion patterns exhibited no discernible variation across all simulated wind directions.

The wind speed data was obtained from the Environmental Quality Monitoring System operated by the Expressway Authority of Thailand (EXAT)

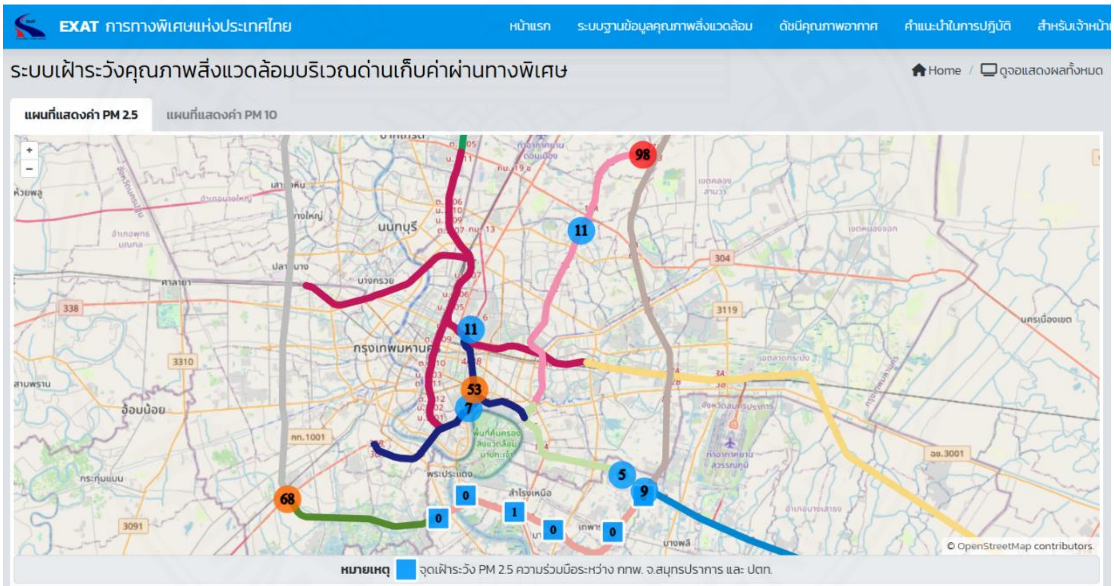



Figure 3.11 The Environmental Quality Monitoring System operated by the Expressway Authority of Thailand (EXAT)

Socioeconomic Impact on Community and Society (Bureau of Policy and Planning, 2024)

The community impact assessment revealed counterintuitive weighting patterns prioritizing high-impact awareness:

- Red (Very Severe Impact): W_red = 0.93318
- Orange (Moderate Impact): W_orange = 0.05972
- Pink (Minor Impact): W_pink = 0.00711

Table 3.18 FAHP calculation of Socioeconomic Impact on Community and Society

| **Step 1 : Triangular Fuzzy Number (TFN)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Yellow (Y) | | | Orange (O) | | | Red (R) | | |
| **Yellow (Y)** | 1 | 1 | 1 | 2 | 3 | 4 | 4 | 5 | 6 |
| **Orange (O)** | 1/4 | 1/3 | 1/2 | 1 | 1 | 1 | 2 | 3 | 4 |
| **Red (R)** | 1/6 | 1/5 | 1/4 | 1/4 | 1/3 | 1/2 | 1 | 1 | 1 |

| **Step 2 : Fuzzy Geometric Mean (L : Low, M : Medium, U : Up)** | | | |
|---|---|---|---|
| Column Y | **(1*2*4)^(1/3)** | **(1*3*5)^ (1/3)** | **(1*4*6)^(1/3)** |
| Column O | (1/4*1*2)^ **(1/3)** | (1/3*1*2)^(1/3) | (1/2*1*3)^(1/3) |
| Column R | (1/6*1/4*1)^(1/3) | (1/5*1/3*1)^(1/3) | (1/4*1/2*1)^(1/3) |
| | L | M | U |

| **Step 3 Summary of Geometric Mean** | | | |
|---|---|---|---|
| Column Y | **2** | **2.4662** | **2.8845** |
| Column O | 0.7934 | 1 | 1.2599 |
| Column R | 0.34668 | 0.4055 | 0.5 |
| Sum | 3.14038 | 3.8717 | 4.6444 |
| | L | M | U |

| **Step 4 Fuzzy Weight** | | | |
|---|---|---|---|
| Column Y | **2/4.6444** | **2.4662/0.3817** | **2.8845/3.14038** |
| Column O | 0.7934/**4.6444** | **1/0.3817** | 1.2599/**3.14038** |
| Column R | 0.34668/**4.6444** | 0.4055/**0.3817** | /**3.14038** |

| **Step 5 Defuzzification** | | | | |
|---|---|---|---|---|
| Fuzzy Weight | | | | **Sum** |
| Column Y | **0.4306** | **0.637** | **0.9185** | **1.9861** |

| **Step 5 Defuzzification** | | | | |
|---|---|---|---|---|
| Column O | 0.1709 | 0.2583 | 0.4012 | 0.8304 |
| Column R | 0.0746 | 0.1047 | 0.1592 | 0.3386 |

| Sum of Fuzzy Weight | | Defuzzification | |
|---|---|---|---|
| Column G | **1.9861** | **1.9861/3** = | **0.66204** |
| Column Y | 0.8304 | 0.8304/3 = | 0.27679 |
| Column R | 0.3386 | 0.3386/3 = | 0.11286 |
| Sum | | | 1.0517 |

| **Step 6 Normalization** | | |
|---|---|---|
| | Normalization | |
| Column G | **0.66204**/1.0517 | **0.6295** |
| Column Y | 0.27679/1.0517 | 0.26319 |
| Column R | 0.11286/1.0517 | 0.10732 |
| **sum** | 1.0517 | 1 |

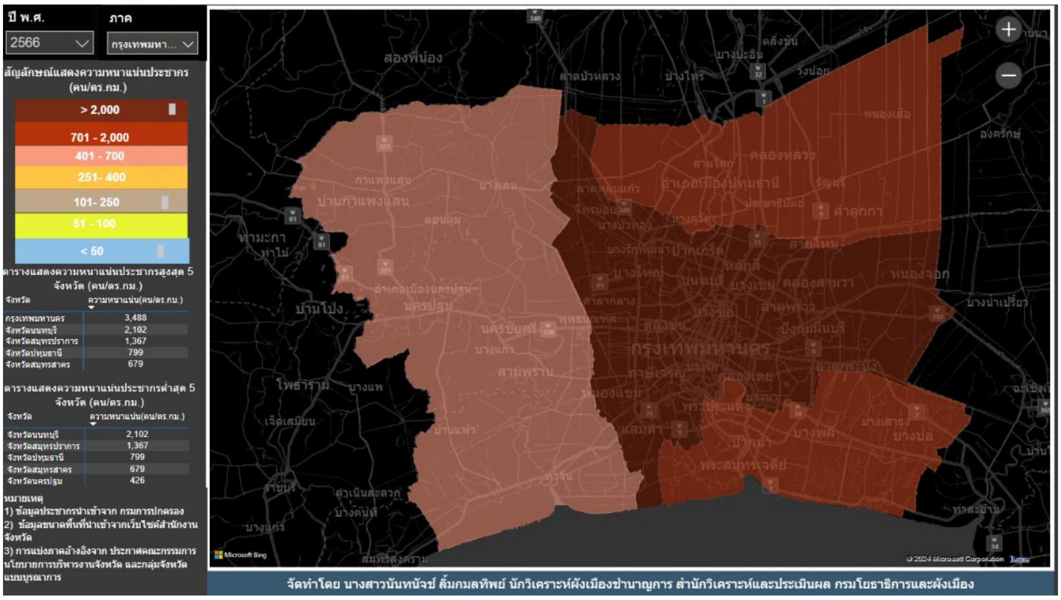



Figure 3.12 A map illustrating the population density within Bangkok Metropolitan Area for the year 2024

Traffic data (Brent & Beland, 2020) (Manual, 2000)

Traffic Data (Google Maps): The factors influencing route color indications on Google Maps, which were derived from user reviews, were normalized as:

- Congestion: 0.54000
- Time Variability: 0.16300
- Capacity: 0.29700

Table 3.19 FAHP calculation of Traffic data

| **Step 1 : Triangular Fuzzy Number (TFN)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Congestion | | | Time Variability | | | Capacity | | |
| **Congestion** | 1 | 1 | 1 | 2.5 | 3 | 3.5 | 1.5 | 2 | 2.5 |
| **Time Variability** | 1/3.5 | 1/3 | 1/2.5 | 1 | 1 | 1 | 1/2.5 | 1/2 | 1/1.5 |
| **Capacity** | 1/2.5 | 1/2 | 1/2.5 | 1.5 | 2 | 2.5 | 1 | 1 | 1 |

| **Step 2 : Fuzzy Geometric Mean (L : Low, M : Medium, U : Up)** | | | |
|---|---|---|---|
| **Congestion** | **(1*2.5*1.5)^(1/3)** | **(1*3*2.5)^ (1/3)** | **(1*3.5*2.5)^(1/3)** |
| **Time Variability** | (1/3.5*1*1/2.5)^ **(1/3)** | (1/3*1*1/2)^(1/3) | (1/2.5*1*1/1.5)^(1/3) |
| **Capacity** | (1/2.5*1.5*1)^(1/3) | (1/2*2*1)^(1/3) | (1/2.5*2.5*1)^(1/3) |
| | L | M | U |

| **Step 3 Summary of Geometric Mean** | | | |
|---|---|---|---|
| **Congestion** | **1.55362** | **1.8171** | **2.0606** |
| **Time Variability** | 0.48529 | 0.5503 | 0.6437 |
| **Capacity** | 0.84343 | 1 | 1.1856 |
| Sum | 2.88233 | 3.3674 | 3.8899 |
| | L | M | U |

| **Step 4 Fuzzy Weight** | | | |
|---|---|---|---|
| **Congestion** | **1.55362/3.8899** | **1.8171/3.3674** | **2.0606/2.88233** |
| **Time Variability** | **0.48529/3.8899** | **0.5503/3.3674** | **0.6437/2.88233** |
| **Capacity** | **0.84343/3.8899** | **1/3.3674** | **1.1856/2.88233** |

| **Step 5 Defuzzification** | | | | |
|---|---|---|---|---|
| Fuzzy Weight | | | | **Sum** |
| **Congestion** | **0.3994** | **0.5396** | **0.7149** | **1.6539** |
| **Time Variability** | 0.1248 | 0.1634 | 0.2233 | 0.5115 |
| **Capacity** | 0.2168 | 0.297 | 0.4113 | 0.9251 |
| Sum of Fuzzy Weight | | Defuzzification | | |
| **Congestion** | | **1.6539** | **1.6539/3** = | **0.55131** |
| **Time Variability** | | 0.5115 | 0.5115/3 = | 0.1705 |
| **Capacity** | | 0.9251 | 0.9251/3 = | 0.30838 |
| Sum | | | | 1.03018 |

| **Step 6 Normalization** | | |
|---|---|---|
| | Normalization | |
| **Congestion** | **0.55131**/1.03018 | **0.53516** |
| **Time Variability** | 0.1705/1.03018 | 0.1655 |
| **Capacity** | 0.30838/1.03018 | 0.29934 |
| **sum** | 1.03018 | 1 |

The high weighting for severe impact scenarios suggests expert emphasis on routes that acknowledge and account for significant community exposure risks.

Emergency Response Team Effectiveness: Fire Station Resource Readiness

The analysis of fire station resource readiness revealed significant geographical preferences based on operational capacity and strategic positioning:

- Bonkai Fire Station: W_bonkai = 0.8048
- Klongtoei Fire Station: W_klongtoei = 0.12899
- Mahamek Fire Station: W_mahamek = 0.04672
- Chan Road Fire Station: W_chanrd = 0.01475
- Buntudthong Fire Station: W_buntudthong = 0.00473

**Step 1 : Triangular Fuzzy Number (TFN)**

| | Bonkai | | | Klongtoey | | | Thung Mahamek | | | Chan Rd. | | | Banthat Thong | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Bonkai** | 1 | 1 | 1 | 1 | 2 | 3 | 2 | 3 | 4 | 3 | 4 | 5 | 4 | 5 | 6 |
| **Klongtoey** | 1/3 | 1/2 | 1/1 | 1 | 1 | 1 | 1 | 2 | 3 | 2 | 3 | 4 | 3 | 4 | 5 |
| **Thung Mahamek** | 1/4 | 1/3 | 1/2 | 1/3 | 1/2 | 1/1 | 1 | 1 | 1 | 1 | 2 | 3 | 2 | 3 | 4 |
| **Chan Rd.** | 1/5 | 1/4 | 1/3 | 1/4 | 1/3 | 1/2 | 1/3 | 1/2 | 1/1 | 1 | 1 | 1 | 1 | 2 | 3 |
| **Banthat Thong** | 1/6 | 1/5 | 1/4 | 1/5 | 1/4 | 1/3 | 1/4 | 1/3 | 1/2 | 1/3 | 1/2 | 1/1 | 1 | 1 | 1 |

**Step 2 : Fuzzy Geometric Mean (L : Low, M : Medium, U : Up)**

| | | | |
|---|---|---|---|
| **Bonkai** | (1*1*2*3*5)^(1/5) | (1*2*3*4*5)^( 1/5) | (1*3*4*5*6)^( 1/5) |
| **Klongtoey** | (1/3*1*1*2*3)^( 1/5) | (1/2*1*2*3*4)^( 1/5) | (1*1*3*4*5)^( 1/5) |
| **Thung Mahamek** | (1/4*1/3*1*1*2)^( 1/5) | (1/3*1/2*1*2*3)^( 1/5) | (1/2*1*1*3*4)^( 1/5) |
| **Chan Rd.** | (1/5*1/4*1/3*1*1)^( 1/5) | (1/4*1/3*1/2*1*2)^( 1/5) | (1/3*1/2*1*1*3)^( 1/5) |
| **Banthat Thong** | (1/6*1/5*1/4*1/3*1)^(1/5) | (1/5*1/4*1/3*1/2*1)^(1/5) | (1/4*1/3*1/2*1*1)^(1/5) |
| | L | M | U |

**Step 3 Summary of Geometric Mean**

| | | | |
|---|---|---|---|
| **Bonkai** | **1.8882** | **2.605** | **3.245** |
| **Klongtoey** | 1.1487 | 1.644 | 2.268 |

| | | | |
|---|---|---|---|
| **Thung Mahamek** | 0.6988 | 1 | 1.431 |
| **Chan Rd.** | 0.4409 | 0.608 | 0.871 |
| **Banthat Thong** | 0.3081 | 0.384 | 0.530 |
| Sum | 4.4848 | 6.2410 | 8.3440 |
| | L | M | U |

| **Step 4 Fuzzy Weight** | | | |
|---|---|---|---|
| **Bonkai** | **1.8882/8.3440** | **2.605/6.2410** | **3.245/4.4848** |
| **Klongtoey** | **1.1487/8.3440** | **1.644/6.2410** | **2.268/4.4848** |
| **Thung Mahamek** | **0.6988/8.3440** | **1/6.2410** | **1.431/4.4848** |
| **Chan Rd.** | **0.4409/8.3440** | **0.608/6.2410** | **0.871/4.4848** |
| **Banthat Thong** | **0.3081/8.3440** | **0.384/6.2410** | **0.530/4.4848** |

| **Step 5 Defuzzification** | | | | |
|---|---|---|---|---|
| Fuzzy Weight | | | | **Sum** |
| **Bonkai** | **0.2263** | **0.417** | **0.724** | **1.3673** |
| **Klongtoey** | 0.1377 | 0.263 | 0.506 | 0.9067 |
| **Thung Mahamek** | 0.0837 | 0.16 | 0.319 | 0.5630 |
| **Chan Rd.** | 0.0528 | 0.0975 | 0.1941 | 0.3444 |
| **Banthat Thong** | 0.0369 | 0.0615 | 0.1181 | 0.2165 |

| Sum of Fuzzy Weight | | Defuzzification | |
|---|---|---|---|
| **Bonkai** | **1.3673** | **1.3673/3 =** | **0.4558** |
| **Klongtoey** | 0.9067 | 0.9067/3 = | 0.3022 |
| **Thung Mahamek** | 0.5630 | 0.5630/3 = | 0.1877 |
| **Chan Rd.** | 0.3444 | 0.3444/3 = | 0.1148 |
| **Banthat Thong** | 0.2165 | 0.2165/3 = | 0.0722 |
| Sum | | | 1.1327 |

| **Step 6 Normalization** | | |
|---|---|---|
| | Normalization | |
| **Bonkai** | **0.4558/1.1327** | **0.4024** |
| **Klongtoey** | **0.3022/1.1327** | 0.2668 |
| **Thung Mahamek** | **0.1877/1.1327** | 0.1657 |
| **Chan Rd.** | **0.1148/1.1327** | 0.1014 |
| **Banthat Thong** | **0.0722/1.1327** | 0.0637 |
| **sum** | | 1 |

The substantial weighting concentration at Bonkai Fire Station indicates superior resource readiness, strategic location, or operational capacity relative to other facilities within the emergency response network.

Weight Distribution Implications

The FAHP results reveal several critical insights regarding emergency response prioritization:

1. Risk Minimization Priority: High weights for safe conditions (traffic and chemical) indicate expert preference for risk-minimizing route selection strategies.

2. Resource Optimization: The concentrated weighting at specific facilities suggests the importance of leveraging high-capacity emergency response resources.

3. Community Impact Awareness: The weighting pattern for socioeconomic factors emphasizes the necessity of considering severe impact scenarios in emergency planning.

These weight distributions provide quantitative foundations for emergency response decision-making algorithms and route optimization systems, enabling evidence-based resource allocation and response strategy development.

**3.6 Computer program**

Under pressure, the Emergency Response Team (ERT) must respond swiftly. Failure will result from human factors or mistakes that are related to human decision-making and external circumstances that have an impact on precision (Yu & Guan, 2016) (Woodcock & Au, 2013) This problem can be resolved and minimized by the computer software. (Vaez & Nourai, 2013) This problem can be resolved and minimized by the computer software. (Vaez & Nourai, 2013) It can properly manage the emergency response command.

**3.6.1 Route Selection**

The decision to choose a remedial route has implications for emergency response planning. Commanders need to assess relevant data, such as weather and traffic flow, in real time. Accidents before and after toll booths are affected by traffic congestion. Emergency response procedures are different than normal. (Fanti et al., 2014) When an incident or accident develops into a disaster, evacuation is the most effective emergency response strategy. The victim has to be transferred to a safe place. The optimal evacuation route must be chosen by the commander. (COVA, 1999) Routing must be effective and prompt for an emergency response to be successful. Commanders can autonomously choose the most efficient route by using routing policies. Reducing facilities and decreasing travel times are advantages for choosing an efficient route decision that reduces discomfort (Wilson et al., 2014)

**3.6.2 GPS technology**

During emergencies, the Global Positioning System (GPS) technology is used to immediately make decisions and select the most efficient route. For optimal route evaluation and the required real-time response, the GPS needs to be aware of the transport network information (Wilson et al., 2014) (Sharma et al., 2015)

**3.2.3 Hazardous material response**

The CAMEO software suite is a program for planning and responding to chemical emergencies. The emergency response team on the front lines can work safely with the aid of this program. To follow an emergency response plan, they can use the app to assess the situation and consider important data. The program comprises a mapping feature, an air dispersion model, and a chemical database. All units are able to work together and immediately communicate important information to the ERT or other units. CAMEO Data Manager, CAMEO Chemical, MARPLOT, and ALOHA are all integral parts of the CAMEO system. CAMEO chemical has huge chemical datasheets which are important for first aid, firefighting, and spill response. MARPLOT is an application for mapping. Users can build or create the appropriate object on the map. The displayed chemical effusion scenario or the possibly hazardous location to aid the reaction team's decision-making process. Based on toxicological, climatic, chemical datasheets, and the actual scene of the chemical release, ALOHA evaluates the chemical risk that spreads in the air. Marplot is capable of computing and illustrate the threat zone. It supports users' evaluation of geographic data. ((EPA), 2016)

**3.7 Evaluation**

The suitability of routes is assessed using a cost function for calculation. In this context, a cost function (also known as an objective function or loss function) is a mathematical formula designed to quantify the "cost" or "undesirability" of a particular route, with the primary goal being to find the route that minimizes this calculated cost. Essentially, to determine the "best" path, a cost function assigns a numerical value to each possible route based on various influencing factors; a lower numerical value indicates a "better" or "more suitable" path according to the defined criteria. This function incorporates various relevant parameters, which, for assessing route suitability in an emergency response scenario, would likely include travel time (a critical factor for faster response), distance, traffic congestion (using real-time or historical data), population density (potentially weighted to reflect risk or response needs), road conditions. (Cheng & Ansari, 2003)

# CHAPTER 4
# RESULTS AND DISCUSSION

## 4.1 Questionnaire

To ensure the validity of this questionnaire, it underwent an Index of Consistency (IOC) analysis. Notably, items with an IOC value below 0.5 (indicating insufficient consistency) were not immediately eliminated. Instead, the questionnaire underwent subsequent refinement and improvement, integrating the feedback and suggestions provided by the IOC committee. The results of these calculations are presented in the following Table 4.1

Table 4.1 IOC Result

| **Part2** | **Component** | **Expert** | | | | | |
|---|---|---|---|---|---|---|---|
| | **Travel Time** | No.1 | No.2 | No.3 | No.4 | No.5 | IOC |
| **1** | Traffic flow | 0 | 1 | 1 | 0 | 1 | 0.6 |
| **2** | Route selection regulations | 0 | 1 | 1 | 0 | 1 | 0.6 |
| **3** | The shortest path | 1 | 0 | 1 | 0 | 1 | 0.6 |
| **4** | Route complexity | 0 | -1 | 1 | 0 | 1 | 0.2 |
| **5** | Comfortable road | 0 | 1 | 1 | 0 | 1 | 0.6 |
| | **Chemical Data** | | | | | | |
| **1** | Concentration level | 1 | 1 | 1 | 0 | 1 | 0.8 |
| **2** | Location | 1 | 1 | 1 | 0 | 1 | 0.8 |
| **3** | Dispersion diagram | 0 | 1 | 1 | 0 | 1 | 0.6 |
| | Social Impact | | | | | | |
| **1** | Population density | 1 | 1 | 1 | 0 | 1 | 0.8 |
| **2** | Business density | 1 | 1 | 1 | 0 | 1 | 0.8 |
| **3** | Environmental conditions | 1 | 1 | 1 | 0 | 1 | 0.8 |
| | Traffic Data Accessibility | | | | | | |
| **1** | Google Maps | 1 | 0 | 1 | 0 | 1 | 0.6 |

| Part2 | Component | Expert | | | | | |
|---|---|---|---|---|---|---|---|
| **2** | EXAT Traffic application | 0 | 1 | 1 | 0 | 1 | 0.6 |
| **3** | Intelligent Transportation System (ITS) signs | 1 | 1 | 0 | 0 | 1 | 0.6 |
| | Emergency Response Team (ERT) Performance | | | | | | |
| **1** | Readiness of equipment | 0 | 1 | 1 | 0 | 1 | 0.6 |
| **2** | Location of the ERT | 1 | 0 | 1 | 0 | 1 | 0.6 |

**4.2 Delphi Technique**

The questionnaire, after successfully passing the Index of Consistency (IOC) validation, was distributed via email to all 17 selected experts. An item was considered to have achieved expert consensus when both of the following conditions were satisfied: Interquartile Range ≤ 1.5: Indicating acceptable response variability among experts. Mode-Median Difference ≤ 1.0: Demonstrating minimal discrepancy between central tendency measures Non-Consensus Identification. Items failing to meet either criterion were classified as lacking sufficient expert consensus, indicating continued disagreement or uncertainty among the expert panel regarding the specific factor or statement.

The opinions of these 17 experts were then utilized for subsequent calculations. Factors identified with an Interquartile Range (IQR) value > 1. 5, specifically "Work Instruction (WI)," "Environment," and "EXAT Traffic," were excluded from further analysis due to insufficient expert consensus. Conversely, the remaining factors, which demonstrated high expert agreement (IQR ≤ 1.5), were subsequently used as inputs for calculations employing both the Fuzzy Analytic Hierarchy Process (FAHP) and the Analytic Hierarchy Process (AHP) methodologies.

Table 4.2 Summary of Expert Consensus from Delphi 3rd rounds

| Travel Time | **Sum of the 17 experts' evaluations** | **Med** | **IR<1.5** | **Mode** | **Mod-Med** | **Result** |
|---|---|---|---|---|---|---|
| 1.Traffic flow | 80 | 5 | 0 | 5 | 0 | / |
| 2.Route selection regulations | 62 | 4 | 2 | 5 | 1 | X |
| 3.The shortest path | 74 | 5 | 1 | 5 | 0 | / |
| 4.Comfortable road | 69 | 4 | 1 | 5 | 1 | / |
| Chemical Data | | | | | | |
| 1.Concentration level | 76 | 5 | 1 | 5 | 0 | / |
| 2.Location | 79 | 5 | 0 | 5 | 0 | / |
| 3.Dispersion diagram | 76 | 5 | 1 | 5 | 0 | / |
| Social Impact | | | | | | |
| 1.Population density | 81 | 5 | 0 | 5 | 0 | / |
| 2.Business density | 69 | 4 | 1 | 4 | 0 | / |
| 3.Environmental conditions | 67 | 4 | 2 | 5 | 1 | X |
| Traffic Data Accessibility | | | | | | |
| 1.Google Maps | 81 | 5 | 0 | 5 | 0 | / |

| Travel Time | **Sum of the 17 experts' evaluations** | **Med** | **IR<1.5** | **Mode** | **Mod-Med** | **Result** |
|---|---|---|---|---|---|---|
| 2.EXAT Traffic application | 62 | 3 | 2 | 3 | 0 | X |
| 3.Intelligent Transportation System (ITS) signs | 67 | 3 | 1 | 3 | 0 | / |
| Emergency Response Team (ERT) | | | | | | |
| 1.Performance (4M) | 82 | 5 | 0 | 5 | 0 | / |
| 2.Location of the ERT | 71 | 4 | 1 | 5 | 1 | / |

**4.3 AHP Method**

The identified factors exhibit varying degrees of interdependency and influence on overall emergency response effectiveness. The Analytic Hierarchy Process (AHP) methodology facilitated the systematic evaluation of these relationships, thereby establishing a hierarchical structure that reflects the relative importance of each factor in the decision-making process. The results of the calculations for the contributing factors using the AHP method are presented in the following Table 4.3

Table 4.3 AHP Result

| Factor | AHP (Eigenvector) | Normalized AHP |
|---|---|---|
| 1. Travel Time | | |
| - Traffic flow | 0.568 | 0.568/3.399=0.167 |
| - The shortest path | 0.29 | |
| - Comfortable | 0.142 | |
| 2 Chemical data | | |
| - ALOHA Chemical Dispersion Plot | 0.434 | 0.434/3.399=0.128 |
| - Concentration | 0.316 | 0.316 |
| - Location | 0.251 | 0.251 |
| 3. Community impact | | |
| - Population | 0.839 | 0.839/3.399=0.247 |
| - Business | 0.161 | 0.161 |
| 4. Traffic data | | |
| - Google map | 0.765 | 0.765/3.399=0.225 |
| - ITS | 0.235 | 0.235 |
| 5. Emergency Response Team Effectiveness | | |
| - Equipment | 0.793 | 0.793/3.399=0.233 |
| - Location | 0.207 | 0.207 |
| $\sum = 0.568+0.434+0.839+0.765+0.793$ | 3.399 | |

**4.4 Fuzzy AHP Method**

The FAHP results reveal several critical insights regarding emergency response prioritization:

1. Risk Minimization Priority: High weights for safe conditions (traffic and chemical) indicate expert preference for risk-minimizing route selection strategies.

2. Resource Optimization: The concentrated weighting at specific facilities suggests the importance of leveraging high-capacity emergency response resources.

3. Community Impact Awareness: The weighting pattern for socioeconomic factors emphasizes the necessity of considering severe impact scenarios in emergency planning.

The Fuzzy Analytic Hierarchy Process (FAHP) results are presented as Table 4.4 weight distributions for the cost function. These weight distributions provide a quantitative foundation for developing emergency response decision-making algorithms and route optimization systems.

Table 4.4 Fuzzy AHP Result

| Sub-factor (Main factor from AHP) | Fuzzy AHP (W) |
|---|---|
| 1. Traffic flow | |
| - Green (Free Flow Conditions) | 0.55708 |
| - Yellow (Moderate Flow Conditions) | 0.26674 |
| - Red (Congested Flow Conditions) | 0.12013 |
| - Deep Red (Critical Congestion) | 0.05606 |
| 2 ALOHA Chemical Dispersion Plot | |
| - Yellow (Minor Impact Level) | 0.7273 |
| - Orange (Middle Impact Level) | 0.18956 |
| - Red (Severe Impact Level) | 0.08314 |
| 3. Population impact (Population density) | |
| - Red (Very Severe Impact) | 0.6295 |
| - Orange (Moderate Impact) | 0.26319 |
| - Pink (Minor Impact) | 0.10732 |
| 4. Google map | |
| - Traffic Congestion Level | 0.54 |
| - Travel Time Variability | 0.163 |
| - Road Capacity Utilization | 0.297 |
| 5. ERT Equipment : Fire station | |
| - Bon Kai | 0.4024 |
| - Klong Toey | 0.2668 |
| - Thung Maha Mek | 0.1657 |
| - Chan Road | 0.1014 |
| - Banthat Thong | 0.0637 |

### 4.5 Emergency Response Route Simulation

The study's primary objective was to simulate emergency response routes for chemical spills, identifying optimal paths by assessing factors such as travel time, chemical impact, and the response team's preparedness. These simulations integrated sub-factor weights derived from Fuzzy AHP and utilized the Longdo.com Map API, which incorporated real-time traffic data from Google Maps.

The simulation setup involved an incident origin at latitude 13.724894, longitude 100.552500 on the Chalerm Mahanakorn Expressway. Destination fire stations were selected for their proximity, specifically those within a 3.5 km radius of the incident. This selection adhered to the Local Fire Department Standard, which stipulates that travel to an incident area should not exceed 8 minutes. Five potential fire stations were identified within this radius: Bon Kai (0.523 km), Klong Toey (1.301 km), Thung Maha Mek (1.404 km), Chan Road (2.902 km), and Banthat Thong (3.353 km).

Route generation on the Longdo.com Map API was optimized to reflect realistic conditions, specifically by configuring it to avoid traffic congestion. This optimization was directly supported by the integration of real-time traffic data from Google Maps, ensuring consistency with the study's focus on vehicle and expressway dynamics. Simulations were executed for both daytime (approximately 2:30-2:45 p.m.) and nighttime (approximately 11:30 p.m. - 00.00 a.m.) scenarios. A key regulatory factor considered was the Expressway Authority's prohibition on chemical transport vehicles operating between 06:00-10:00 a.m. and 03:00-10:00 p.m. The paramount result derived from these simulations was the travel time, detailed in Table 4.5

Table 4.5 presents the simulated travel times from the incident origin to each of the five identified fire stations.

| Fire station | Travel Time at day (mins) | Travel Time at night (mins) |
|---|---|---|
| Bon Kai | 11 | 7 |
| Klong Toey | 18 | 12 |
| Thung Maha Mek | 18 | 11 |
| Chan Road | 16 | 11 |
| Banthat Thong | 14 | 9 |

### 4.5.1 Optimal Route Determination through Cost Function Analysis

1. AHP Method for Factor Weighting

The Analytic Hierarchy Process (AHP) was employed to extract the primary factors influencing emergency response, and the results are presented as follows, indicating the local weight (L) for each sub-factor:

Travel time: Traffic flow (=0.568)

Chemical data: ALOHA (=0.434)

Impact on community/society: Population (=0.839)

Traffic data: Google Maps (=0.765)

Effective fire station: Equipment (=0.793)

2. Fuzzy AHP Normalization of Sub-Factors

Following the identification of primary factors through the Analytic Hierarchy Process (AHP), the sub-factors were further analyzed using the Fuzzy AHP method to derive their normalized weights. This normalization process quantifies the relative importance of each sub-factor within its respective main factor, considering the inherent uncertainties and imprecisions in decision-making. The results for each main factor and its sub-factors are presented below:

Travel Time: The sub-factors related to traffic flow were normalized as follows:

- Green: 0.55708
- Yellow: 0.26674
- Red: 0.12013
- Deep Red: 0.05606

Chemical Data: The ALOHA-derived impact levels were normalized as:

- Yellow: 0.72730
- Orange: 0.18956
- Red: 0.08314

Impact on Community/Society: The population density levels were normalized as:

- Red: 0.62950
- Orange: 0.26319
- Pink: 0.10732

Traffic Data (Google Maps): The factors influencing route color indications on Google Maps, which were derived from user reviews, were normalized as:

- Congestion: 0.54000
- Time Variability: 0.16300
- Capacity: 0.29700

Effectiveness of Fire Station (Equipment): The effectiveness of individual fire stations, specifically concerning their equipment, was normalized, indicating their relative contribution as:

- Bon Kai : 0.40240
- Klong Toey: 0.26680
- Thung Maha Mek: 0.16570
- Chan Road: 0.10140

- Banthat Thong: 0.06370

3. Cost Function

Fuzzy Analytic Hierarchy Process (Fuzzy AHP) is an effective tool for determining factor weights, particularly when evaluations are conducted under conditions of uncertainty or incomplete data. The weights derived from Fuzzy AHP reflect the relative importance of each factor within a specific decision-making context. In route selection or emergency response scenarios, the Cost Function is typically formulated as a weighted sum of various factors, expressed as:

$$\text{Cost} = \sum_{i=1}^{n} w_i P_i$$

Equation 4.1

Where:

- Cost: Represents the total cost or total damage to be minimized.
- $w_i$ : Denotes the weight of factor i, obtained from Fuzzy AHP.
- $P_i$ : Represents the value of factor i (which may be raw, standardized, or normalized).

Based on the identified factors—Travel time, Chemical data, Effect, and Effectiveness of Emergency Response Team—the specific Cost Function for this study is defined as Equation 4.2 :

Equation 4.2 : Cost = w1(Travel time)+w2(Chemical data)+w3(Impact on Community and Society)+w4(Effectiveness of Emergency Response Team

Since each of these variables was considered to have equal initial importance and was not directly compared against each other, a Hierarchical Analysis with Independent Groups structure was employed. This approach involved separate Fuzzy AHP evaluations for each criterion group. Consequently, the sum of the resulting weights exceeded one, necessitating a subsequent Normalized Weight adjustment to ensure appropriate scaling for the Cost Function.

Equation 4.3 : Normalized Wi = Local Weight / Σ(All Local Weights)

The normalized global weights assigned to each critical factor are as follows:

| Factor | AHP (weight) | Normalization Weight |
|---|---|---|
| 1.Travel time : Traffic flow | 0.568 | 0.568/3.399 = 0.167 |
| 2.Chemical data : ALOHA | 0.434 | 0.434/3.399 = 0.128 |
| 3.Impact on community/society: Population | 0.839 | 0.839/3.399 = 0.247 |
| 4.Traffic data: Google Maps (congestion) | 0.765 | 0.765/3.399 = 0.225 |
| 5.Effective fire station: Equipment (Bonkai) | 0.793 | 0.793/3.399 = 0.233 |
| sum | 3.399 | 1 |

Cost Calculation Formula

The Total Cost for each route was computed using the following weighted sum formula

Total Cost = $(W_1 \times C_1) + (W_2 \times C_2) + (W_3 \times C_3) + (W_4 \times C_4) + (W_5 \times C_5)$

Where:

$W_1$ represents the global normalized weight of factor i

$C_1$ represents the normalized value of factor I for a given route and time scenario

Route-Specific Cost Calculations

The detailed calculations for each of the five fire station routes under both daytime and nighttime conditions are presented below. The Ci values for each factor are derived from [mention your normalization method here, e.g., the previously discussed normalization steps, or refer to a table where these values are explained]. For Travel Time (C1), values are normalized against a maximum observed time of 18 minutes (e.g., actual time / 18).

To ensure comparability and consistent evaluation across diverse criteria, each main factor was standardized and assigned a quantitative value based on its specific characteristics within the simulation. The standardization approach for each factor is detailed below:

C1 (Travel Time)

Travel time for each simulated route was quantified as a normalized value. This was calculated by dividing the observed travel time for a specific route by the maximum travel time recorded across all routes under investigation. This normalization allows for a comparative assessment of route efficiency, where a lower normalized value indicates a more optimal travel time.

$$C_1 = \frac{\text{Simulated Travel Time}}{\text{Maximum Observed Travel Time}}$$

Equation 4.4

Table 4.6 C1 (Travel Time) Value

| Fire station | Travel Time at day (mins) | Travel Time at night (mins) | C1 day | C1 night |
|---|---|---|---|---|
| Bon Kai | 11 | 7 | 11/18=0.611 | 7/12=0.583 |
| Klong Toey | 18 | 12 | 18/18=1 | 12/12=1 |
| Thung Maha Mek | 18 | 11 | 18/18=1 | 11/12=0.917 |
| Chan Road | 16 | 11 | 16/18=0.889 | 11/12=0.917 |
| Banthat Thong | 14 | 9 | 14/18=0.778 | 9/12=0.75 |

C2 (Chemical Risk)

Chemical risk was determined based on the potential dispersion pattern of hazardous substances. Utilizing the CAMEO ALOHA software, the simulated chemical dispersion indicated a circular spread, implying a uniform level of danger in all directions from the incident origin. Consequently, the chemical risk for the study area was uniformly assigned to the Yellow zone, representing a significant but manageable hazard level.

Table 4.7 C2 (Chemical Risk) Value

| Sub-factor (Main factor from AHP) | Fuzzy AHP (W) | 1 - Fuzzy AHP |
|---|---|---|
| 2 ALOHA Chemical Dispersion Plot | | |
| - Yellow (Minor Impact Level) | 0.7273 | 0.2727 |
| - Orange (Middle Impact Level) | 0.18956 | 0.81044 |
| - Red (Severe Impact Level) | 0.08314 | 0.91686 |

C3 (Population Impact)

Population impact assessed the vulnerability of communities to a chemical spill based on demographic density within the study area. Analysis revealed that the population density in the vicinity of the incident was exceptionally high, surpassing all other density classifications. Therefore, the population impact for this region was categorized as the Red zone, signifying the highest potential for widespread societal consequences. Population impact is a critical factor where a high impact correlates with a high cost, indicating it is an undesirable factor for route selection. Consequently, the value for 'C' (presumably a coefficient or weight related to population impact within your cost function) is not adjusted, as the results from the Fuzzy AHP analysis are consistent with its contribution to the cost function.

C4 (Traffic Congestion)

Traffic congestion was evaluated based on the real-time traffic conditions visualized by color-coded routes on Google Maps. The contributing factors to traffic conditions, as identified through a comprehensive literature review, include congestion level, time variability, and road capacity. From this review, congestion was determined to be the most influential factor dictating the overall traffic state and, subsequently, the efficiency of emergency vehicle movement. Consequently, the value for 'C' (presumably a coefficient or weight related to traffic congestion within your cost function) is not adjusted, as the results from the Fuzzy AHP analysis are consistent with its contribution to the cost function.

C5 (Station Effectiveness)

Station effectiveness was defined by the readiness and capacity of individual fire stations' emergency response equipment. This criterion was operationalized by considering the number of vehicles and available equipment at each fire station, derived from the Open Data Bangkok repository. The specific inventory for each station is detailed in Table 4.8

Table 4.8 C5 (Station Effectiveness)

| id | Id division | division | Report_year | Report_month | Use_vehicla_equipment |
|---|---|---|---|---|---|
| 11 | Operations Division | Fire station : Thung Maha Mek | 2567 | February | 12 |
| 12 | Operations Division | Fire station : Chan Road | 2567 | February | 6 |
| 13 | Operations Division | Fire station : Klong Toey | 2567 | February | 14 |
| 14 | Operations Division | Fire station : Banthat Thong | 2567 | February | 14 |
| 15 | Operations Division | Fire station : Bon Kai | 2567 | February | 42 |

The C5 value for each fire station was re-calculated using the Resource Capacity Index (RCI) formula, referencing a framework for resource allocation in fire departments

The calculated C5 values for each station are presented below:

$$C5 = 1 - (Vi / Vmax)$$

Where

Vi denote the number of vehicles at station i,

Vmax represent the maximum vehicle capacity within the entire system.

Bon Kai : $C5 = 1 - (42/42) = 0.000$

Klong Toey: $C5 = 1 - (14/42) = 0.667$

Thung Maha Mek: $C5 = 1 - (12/42) = 0.714$

Chan Road: $C5 = 1 - (6/42) = 0.857$

Banthat Thong: $C5 = 1 - (14/42) = 0.667$

Route-Specific Total Cost Analysis

The recalculated Total Costs for each of the five identified routes, considering both daytime and nighttime scenarios, are detailed below. The common C-values for Chemical Risk ($C_2 = 0.18956$, Yellow Zone), Population Impact ($C_3 = 0.6295$, Red Zone), and Traffic Congestion ($C_4 = 0.54$, Congestion) remained constant across all routes and times, reflecting the specific incident scenario.

Route 1: Bonkai

The Bonkai route consistently demonstrates the lowest total cost in both scenarios, largely attributable to its ideal C5 (Fire Station RCI) value of 0.000, indicating full resource availability.

Daytime Calculation:

C1 (Travel Time): $11/18 = 0.611$

C2 (Chemical data): Yellow = 0.810

C3 (Population Impact): Red = 0.630

C4 (Traffic data): Congestion = 0.540

C5 (Fire Station Effectiveness) : $1-(42/42) = 0.000$

Total Cost (Daytime)

$= 0.167\times0.611 + 0.128\times0.810 + 0.247\times0.630 + 0.225\times0.540 + 0.233\times0.000$

$= 0.102 + 0.104 + 0.156 + 0.122 + 0.000 = 0.484$

Nighttime Calculation:

C1 (Travel Time): 7/12=0.583

C2 (Chemical data): Yellow = 0.810

C3 (Population Impact): Red = 0.630

C4 (Traffic data): Congestion = 0.540

C5 (Fire Station Effectiveness) : 1-(42/42) = 0.000

Total Cost (Nighttime)

$= 0.167 \times 0.583 + 0.128 \times 0.810 + 0.247 \times 0.630 + 0.225 \times 0.54 + 0.233 \times 0.000$

$= 0.097 + 0.104 + 0.156 + 0.1215 + 0.000 = 0.4785$

Route 2: Klongtoey

The Klongtoey route exhibits moderate costs, influenced by a C5 value of 0.667, reflecting partial resource capacity.

Daytime Calculation:

C1 (Travel Time): 18/18=1.0

C2 (Chemical data): Yellow = 0.810

C3 (Population Impact): Red = 0.630

C4 (Traffic data): Congestion = 0.540

C5 (Fire Station Effectiveness) : 1-(14/42) = 0.667

Total Cost (Daytime)

$= (0.167 \times 1.0) + (0.128 \times 0.810) + (0.247 \times 0.630) + (0.225 \times 0.54) + (0.233 \times 0.667)$

$= 0.167 + 0.1037 + 0.1556 + 0.1215 + 0.1554 = 0.7032$

Nighttime Calculation:

C1 (Travel Time): 12/12 = 1

C2 (Chemical data): Yellow = 0.810

C3 (Population Impact): Red = 0.630

C4 (Traffic data): Congestion = 0.540

C5 (Fire Station Effectiveness) : 1-(14/42) = 0.667

Total Cost (Nighttime)

$=0.167\times1.0)+(0.128\times0.810)+(0.247\times0.630)+(0.225\times0.54)+$

$(0.233\times0.667)$

$= 0.167+0.1037+0.1556+0.1215+0.1554 = 0.7032$

<u>Route 3</u>: Thung Maha Mek

The Thung Maha Mek route consistently shows the highest total costs, primarily due to its $C_5$ (Fire Station RCI) value of 1.000, indicating a complete lack of available vehicles.

<u>Daytime Calculation</u>:

C1 (Travel Time): 18/18=1.0

C2 (Chemical data): Yellow = 0.810

C3 (Population Impact): Red = 0.630

C4 (Traffic data): Congestion = 0.540

C5 (Fire Station Effectiveness) : 1-(12/42) = 0.714

Total Cost (Daytime)

$= (0.167\times1.0)+(0.128\times0.810)+(0.247\times0.630)+(0.225\times0.54)+$

$(0.233\times0.714)$

$= 0.167+0.1037+0.1556+0.1215+0.1664 = 0.7142$

<u>Nighttime Calculation</u>:

C1 (Travel Time): 11/12=0.917

C2 (Chemical data): Yellow = 0.810

C3 (Population Impact): Red = 0.630

C4 (Traffic data): Congestion = 0.540

C5 (Fire Station Effectiveness) : 1-(12/42) = 0.714

Total Cost (Nighttime)

= (0.167×0.917)+ (0.128×0.810)+(0.247×0.630)+(0.225×0.54) +(0.233×0.714)

= 0.1531+0.1037+0.1556+0.122+0.1664 = 0.7008

Route 4: Chan Road

The Chan Road route presents higher costs, influenced by its C5 value of 0.857, suggesting limited resource availability.

Daytime Calculation:

C1 (Travel Time): 16/18=0.889

C2 (Chemical data): Yellow = 0.810

C3 (Population Impact): Red = 0.630

C4 (Traffic data): Congestion = 0.540

C5 (Fire Station Effectiveness) : 1-(6/42) = 0.857

Total Cost (Daytime)

= (0.167×0.889)+ (0.128×0.810)+(0.247×0.630)+(0.225×0.54) +(0.233×0.857)

= 0.148+ 0.1037+0.1556+0.122+0.1997 = 0.729

Nighttime Calculation:

C1 (Travel Time): 11/12 =0.917

C2 (Chemical data): Yellow = 0.810

C3 (Population Impact): Red = 0.630

C4 (Traffic data): Congestion = 0.540

C5 (Fire Station Effectiveness) : 1-(6/42) = 0.857

Total Cost (Nighttime)

= (0.167×0.917) +(0.128×0.810)+(0.247×0.630)+(0.225×0.54) +(0.233×0.857)

= 0.1531+ 0.1037+0.1556+0.122+0.1997 = 0.7341

Route 5: Banthat Thong

The Banthat Thong route demonstrates a relatively favorable cost profile compared to Mahamek and Chan Rd, with a C5 value of 0.714.

Daytime Calculation:

C1 (Travel Time): 14/18=0.778

C2 (Chemical data): Yellow = 0.810

C3 (Population Impact): Red = 0.630

C4 (Traffic data): Congestion = 0.540

C5 (Fire Station Effectiveness) : 1-(14/42) = 0.667

Total Cost (Daytime)

$= (0.167\times0.778) + (0.128\times0.810)+(0.247\times0.630)+(0.225\times0.54)+ (0.233\times0.667)$

$= 0.130 + 0.1037+0.1556+0.122+ 0.155 = 0.663$

Nighttime Calculation:

C1 (Travel Time): 9/12=0.75

C2 (Chemical data): Yellow = 0.810

C3 (Population Impact): Red = 0.630

C4 (Traffic data): Congestion = 0.540

C5 (Fire Station Effectiveness) : 1-(14/42) = 0.667

Total Cost (Nighttime)

$= (0.167\times0.750) + (0.128\times0.810)+(0.247\times0.630)+(0.225\times0.54)+ (0.233\times0.667) = 0.125 + 0.1037+0.1556+0.122+ 0.155 = 0.6613$

The final comparison of Total Costs, integrating the RCI, is summarized in Table 4.9, clearly indicating the most optimal route for emergency response under both daytime and nighttime conditions.

Table 4.9 The final comparison of Total Costs

| Route | Daytime Total Cost | Nighttime Total Cost |
| --- | --- | --- |
| Bonkai | **0.484** | **0.4785** |
| Banthat Thong | 0.663 | 0.6613 |
| Klongtoey | 0.7032 | 0.7032 |
| Chan Rd | 0.729 | 0.7341 |
| Thung Maha Mek | 0.7142 | 0.7008 |

The ranking of routes, based on their calculated values (where a lower value indicates higher suitability), is as follows:

Day Time

**Bon Kai = 0.484 (The lowest value, indicating the most suitable route)**

Banthat Thong: 0.663

Klongtoey = 0.7032

Thung Maha Mek = 0.7142

Chan Road = 0.729

Night Time

**Bon Kai = 0.4785 (The lowest value, indicating the most suitable route)**

Banthat Thong: 0.6613

Thung Maha Mek = 0.7008

Klongtoey = 0.7032

Chan Road = 0.7341

## 4.6 Discussion

This section delves into the findings and contributions of this research, specifically addressing the application of the Analytical Hierarchy Process (AHP), the necessity of Fuzzy AHP, the innovative development of the cost function, and the implications of the route selection results.

### 4.6.1 Achievement of Research Objectives

1) General Objective: Human Error Mitigation through Computational Framework

The primary objective of developing a computer-based framework to address human error in emergency route selection has been comprehensively achieved through the systematic integration of multiple analytical techniques. Human error in emergency situations typically manifests through several critical pathways: cognitive overload during time-critical decisions, inconsistent application of selection criteria, subjective bias in route evaluation, and failure to consider all relevant factors simultaneously. The computational framework developed in this study addresses each of these error sources through specific design elements.

The framework transforms the traditionally subjective and error-prone manual route selection process into a systematic, reproducible computational procedure. By encoding expert knowledge through the Delphi process and implementing consistent decision logic through Fuzzy AHP, the system eliminates variations in human judgment that often lead to suboptimal emergency response decisions. The integration of real-time data through map API ensures that decisions are based on current rather than outdated information, a common source of error in manual systems.

The computational approach also provides audit trails and transparency in decision-making, allowing for post-incident analysis and continuous improvement. This capability addresses the accountability gap often present in human-centered emergency response systems, where decision rationales may be unclear or unreproducible. The framework's ability to handle multiple scenarios simultaneously and provide ranked alternatives reduces the cognitive burden on emergency responders while maintaining decision quality.

2) Specific Objective :

- Factor Determination through Delphi and Fuzzy AHP

The first specific objective has been successfully accomplished through a rigorous two-stage methodology that systematically identified and prioritized factors critical to emergency response systems. The Delphi technique provided an effective mechanism for capturing tacit expert knowledge and achieving consensus on factor importance across diverse professional perspectives. This structured approach ensured comprehensive coverage of relevant variables while avoiding the limitations of individual expert opinions or ad-hoc factor selection.

The implementation of Fuzzy AHP for factor weighting addressed a critical gap in traditional emergency response systems, where factor importance is often assumed rather than systematically determined. The fuzzy extension proved particularly valuable in handling the inherent uncertainty and linguistic imprecision associated with expert judgments in emergency contexts. The methodology successfully converted qualitative expert assessments into quantitative weights suitable for computational processing, bridging the gap between human expertise and algorithmic implementation.

The identified factors encompass multiple dimensions of emergency response effectiveness, including temporal considerations (day/night variations), spatial factors (traffic density, proximity to resources), operational constraints (resource availability, response time requirements), and safety considerations (population exposure, environmental impact). This comprehensive factor identification provides a robust foundation for emergency response optimization that extends beyond simple distance or time minimization approaches commonly found in existing literature.

The consistency validation process ensured that expert judgments met acceptable standards of logical coherence, with consistency ratios maintained within established thresholds. This validation step is crucial for maintaining the credibility of the factor weighting scheme and ensuring that computational decisions are based on reliable expert input. The iterative nature of the Delphi process allowed for refinement of factor definitions and importance assessments, resulting in a more robust and consensual framework.

- Chemical Spill Simulation using Map API

The second specific objective has been effectively realized through the development and implementation of a comprehensive simulation platform that accurately models chemical spill scenarios on the Chalerm Mahanakorn expressway. The map API integration provides several critical capabilities that enhance the realism and applicability of emergency response modeling.

The simulation framework successfully incorporates real-time traffic data, road network topology, and geographical constraints that significantly impact emergency response effectiveness. This technological integration represents a substantial advancement over theoretical models that rely on simplified assumptions about urban environments. The ability to visualize spill scenarios and response routes provides emergency managers with intuitive tools for understanding complex spatial relationships and potential response challenges.

The dynamic nature of the map API integration enables the simulation of various spill scenarios under different conditions, including varying traffic patterns, weather conditions, and resource availability. This capability supports scenario-based planning and training activities that are essential for effective emergency preparedness. The platform's ability to process real-time data ensures that simulations reflect current rather than historical conditions, improving the relevance and accuracy of emergency response planning.

The simulation results demonstrate the significant impact of temporal and spatial factors on optimal response strategies, validating the importance of dynamic rather than static emergency response protocols. The visual representation capabilities of the map API platform facilitate communication between technical analysts and operational personnel, reducing the likelihood of misunderstandings or misinterpretations that could compromise response effectiveness.

- Emergency Response Route Development

The third specific objective has been comprehensively achieved through the integration of factor analysis, simulation capabilities, and optimization algorithms to develop appropriate emergency response routes for the Chalerm Mahanakorn expressway. The route development process successfully balances multiple competing objectives while maintaining computational efficiency suitable for real-time applications.

The developed routes demonstrate clear improvements over conventional approaches that rely primarily on distance or time minimization. By incorporating the comprehensive factor framework identified through the Delphi-Fuzzy AHP process, the optimized routes account for complex interactions between response time, safety considerations, resource availability, and operational constraints. This multi-objective optimization approach produces solutions that are more robust and practical for real-world emergency response operations.

The time-dependent nature of the route optimization algorithm addresses a critical limitation in existing emergency response systems, where static protocols may not be optimal under varying operational conditions. The demonstrated differences between day and night optimal routes validate the importance of adaptive response strategies and provide emergency managers with actionable insights for improving response effectiveness.

The integration of fire station prioritization within the route optimization framework ensures that resource allocation decisions are coordinated with routing strategies. This integrated approach prevents suboptimal solutions that might result from independent optimization of routing and resource allocation components. The framework's ability to provide ranked alternatives gives emergency responders flexibility while ensuring that all options are based on systematic analysis rather than intuition.

The validation of route recommendations through simulation using real geographical data and traffic patterns demonstrates the practical applicability of the developed solutions. The routes can be directly implemented using existing navigation technologies and emergency response protocols, facilitating adoption by emergency management organizations.

### 4.6.2 Integrated Route Selection for Expressway Traffic Management

This study proposes integrating the route selection results with the Expressway Authority of Thailand (EXAT)'s traffic data. By using the route selection outcomes as a foundational dataset, we can transmit this information directly to the Expressway Traffic Management Center (ETMC). This integration would provide EXAT communication officers with a clearer visualization of optimal response routes, significantly enhancing the efficiency of traffic incident notifications disseminated to expressway users. Notifications could be delivered through various EXAT channels, including Intelligent Transport System (ITS) signage and the EXAT Portal application's smart notification feature. This proactive dissemination of information would empower users to be aware of and avoid incident-affected routes, thereby mitigating traffic congestion. Consequently, this would ensure that Emergency Response Team (ERT) vehicles can access incident sites with less traffic impedance, resulting in reduced travel times and faster on-scene arrival for critical traffic incident responses.

### 4.6.3 Computational Framework and Human Error Mitigation

Beyond the specific objective achievements, the overall computational framework represents a paradigm shift from intuitive to systematic emergency response decision-making. The framework addresses multiple types of human error commonly observed in emergency situations: procedural errors from inconsistent application of protocols, cognitive errors from information overload, and judgment errors from subjective bias or incomplete information processing.

The systematic integration of expert knowledge through the Delphi process creates a knowledge base that is more comprehensive and reliable than individual decision-maker expertise. This collective intelligence approach reduces the risk of critical oversights that can occur when response decisions depend on individual knowledge and experience. The computational implementation ensures consistent application of this knowledge across different emergency scenarios and response teams.

The real-time data integration capability addresses temporal errors that occur when decisions are based on outdated information. By incorporating current traffic, weather, and resource availability data, the framework ensures that response strategies reflect actual rather than assumed conditions. This capability is particularly important for chemical spill incidents where rapid changes in environmental conditions can significantly impact optimal response strategies.

### 4.6.4 Practical Implications for Emergency Management

The research findings have several important implications for emergency management practice and policy development. The demonstration of significant differences between day and night optimal routes suggests that emergency response protocols should incorporate temporal variations as a standard component of planning processes. Emergency services could benefit from implementing time-dependent response strategies that automatically adjust resource allocation and route selection based on current conditions.

The fire station prioritization results provide valuable insights for resource deployment strategies and could inform decisions about station location, equipment distribution, and personnel scheduling. The ability to predict optimal resource allocation patterns for different scenarios enables more efficient use of emergency response resources and potentially improved response times.

The computer-based decision support framework offers a practical tool for reducing human error in emergency situations while maintaining the flexibility to accommodate unique circumstances. The system's ability to provide ranked alternatives rather than single solutions gives emergency responders options while ensuring that decisions are based on systematic analysis rather than intuition alone.

# CHAPTER 5
# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusion

This research successfully demonstrates the efficacy of an integrated Delphi- Fuzzy AHP framework for emergency route selection in chemical spill scenarios. The findings confirm that optimal emergency response strategies must account for the variability across the studied factors. A computer-aided decision support system can significantly reduce human error while maintaining operational flexibility. The methodological innovation presented in this study provides a foundation for future developments in enhancing emergency management optimization and offers a valuable tool for improving emergency response performance in urban environments.

### 5.1.1 Achievement of Research Objectives

This study successfully achieved its primary objective: the development of a robust route selection system for hazardous chemical spill responses on expressways. This system was meticulously crafted through the systematic integration of the Analytic Hierarchy Process (AHP), Fuzzy AHP, and a comprehensive Cost Function. The resulting framework effectively supports decision-making processes for emergency responders in critical situations, enhancing their operational efficiency.

### 5.1.2 Key Contributions of the Study

- Integration

This paper effectively integrates the Analytic Hierarchy Process (AHP) and Fuzzy AHP to enhance decision-making in expressway route selection. This integration enables a comprehensive evaluation of various factors, including costs, social benefits, and environmental impacts, leading to more balanced and informed choices.

- Methodological Framework

This paper establishes a clear methodological framework for route selection, detailing the steps involved in applying both the Analytic Hierarchy Process (AHP) and Fuzzy AHP. This framework can serve as a guiding tool for future projects in similar contexts, ensuring that decision-makers can effectively replicate the process.

- Case Study Application

This paper includes a practical case study demonstrating the application of the proposed methodology. By analyzing different route plans based on various fire stations, it illustrates how to evaluate and compare alternatives using both qualitative and quantitative criteria, making the research findings applicable to real-world scenarios.

- Quantitative Scoring System

The authors developed a quantitative scoring system to measure the performance of each route plan. This system, based on expert opinions and weighted scores, provides a clear and objective method for evaluating the value of different alternatives, thereby facilitating more rational decision-making.

- Emphasizing Value Maximization

This paper underscores the importance of maximizing value on expressways, focusing on both economic and social benefits. It highlights the necessity of holistic infrastructure planning, which can lead to improved outcomes for communities and stakeholders.

- Emergency Response Route Planning

The findings of this research contribute to the broader field of emergency response route planning by offering insights into effective route selection methodologies. This can empower emergency teams from both the Expressway Authority of Thailand (EXAT) and the Bangkok Metropolitan Administration (BMA) to make more informed decisions, aligning with sustainable development goals and enhancing overall emergency response efficiency.

- Creation of a Comprehensive Cost Function:

A novel Total Cost formula (Total cost = W1C1 + W2C2 + W3C3 + W4C4 + W5C5) was established.

The Resource Capacity Index (RCI) was innovatively integrated into the calculation of C5, providing a precise and realistic measure of resource readiness at each station.

## 5.2 Recommendations for Further Study

To further enhance the generalizability and robustness of our findings, future research should expand the study areas to include other incident locations on expressways. This expansion is crucial for comparing the cost function values derived from route selection in different operational environments, specifically contrasting them with those obtained from urban areas. The rationale for this comparative analysis stems from the inherent differences in several key variables within the cost function formula:

- C3 (Population Impact): The impact of an incident on population density and distribution varies significantly between highly populated urban centers and less densely populated expressway stretches. Evaluating this variable in different contexts will provide a more nuanced understanding of its influence on optimal route selection.

- C4 (Traffic Data): Traffic characteristics, such as volume, speed, and congestion patterns, differ substantially between urban roads and expressways. Analyzing these differences across various locations will help validate the applicability and sensitivity of our traffic data parameter.

- C5 (Fire Station Effectiveness): The proximity, accessibility, and response capabilities of emergency services (e.g., fire stations) can vary greatly depending on the geographical location, whether it's within city limits or along an expressway. This comparison will allow us to assess how "Fire Station Effectiveness" influences the overall cost function in diverse settings.

By conducting this comparative study, we can validate the adaptability of our route selection model and refine the weighting or formulation of these variables, ultimately leading to a more comprehensive and universally applicable solution for expressway traffic management and incident response.

# REFERENCES

(EPA), U. S. E. P. A. (2016). ALOHA software version 5.4.7. United States Environmental Protection Agency (EPA). Retrieved 3 June 2020 from https://www.epa.gov/cameo/aloha-software

(NOAA), N. O. a. A. A. (2022). Chemical spills. https://response.restoration.noaa.gov/oil-and-chemical-spills/chemical-spills

Abayomi, P. (2021). The application of geographic information system as an intelligent system towards emergency responses in road traffic accident in Ibadan. . Journal of Transport and Supply Chain Management. https://doi.org/10.4102/JTSCM.V15I0.546 (04 March 2021)

Afshari, A., Mojahed, M., & Yusuff, R. M. (2010). Simple additive weighting approach to personnel selection problem. International journal of innovation, management and technology, 1(5), 511.

Agarwal, P., Sahai, M., Mishra, V., Bag, M., & Singh, V. (2014). Supplier selection in dynamic environment using analytic hierarchy process. International Journal of Information Engineering and Electronic Business, 6(4), 20.

Ayhan, M. B. (2013). A fuzzy AHP approach for supplier selection problem: A case study in a Gear motor company. arXiv preprint arXiv:1311.2886.

Brent, D., & Beland, L.-P. (2020). Traffic congestion, transportation policies, and the performance of first responders. Journal of Environmental Economics and Management, 103, 102339.

Buckley, J. J. (1985). Fuzzy hierarchical analysis. Fuzzy sets and systems, 17(3), 233-247.

Bureau of Policy and Planning, D. o. P. W. a. T. C. P. (2024). Population Data Statistics (PowerBI): Regional Population Density by Province, 1997-2024. https://app.powerbi.com/view?r=eyJrIjoiNjhjYzBkMmItYjBiMy00YjAxLTg3MWQtZjFkZTNjYjZiNWViIiwidCI6IjRiNTY3YTJlLTg0MmUtNDZjNy1hNzgwLWUxZTA1

ZjFmODRhYyIsImMiOjEwfQ%3D%3D&pageName=ReportSection607c32c0dc4e473d89d8

Chakrabarti, U. K., & Parikh, J. K. (2012). Applying HAZAN methodology to hazmat transportation risk assessment. Process Safety and Environmental Protection, 90(5), 368-375. https://doi.org/10.1016/j.psep.2012.05.011

Chang, D.-Y. (1996). Applications of the extent analysis method on fuzzy AHP. European journal of operational research, 95(3), 649-655.

Cheng, G., & Ansari, N. (2003). A theoretical framework for selecting the cost function for source routing. IEEE International Conference on Communications, 2003. ICC'03.,

COVA, T. J. (1999). Geographical Information Systems: Principles, Techniques, Applications, and Management : GIS in emergency management (M. F. G. P.A. Longley, D.J. Maguire, D.W. Rhind, Ed.). John Wiley & Sons, New York. https://www.researchgate.net/publication/305347817_GIS_in_Emergency_Management

Crawford, I. W., Mackway-Jones, K., Russell, D. R., & Carley, S. D. (2004). Delphi based consensus study into planning for chemical incidents. Emerg Med J, 21(1), 24-28. https://doi.org/10.1136/emj.2003.003087

Dalalah, D., Al-Oqla, F., & Hayajneh, M. (2010). Application of the Analytic Hierarchy Process (AHP) in multi-criteria analysis of the selection of cranes. Jordan Journal of Mechanical & Industrial Engineering, 4(5).

Dalkey, N. (1969). An experimental study of group opinion: The Delphi method. Futures, 1(5), 408-426. https://doi.org/https://doi.org/10.1016/S0016-3287(69)80025-X

Dernoncourt, F. (2013). Introduction to fuzzy logic. Massachusetts Institute of Technology, 21, 50-56.

Dobbins, T. R., & Camp, W. G. (2003). Clinical Experiences For Agricultural Teacher Education Programs In North Carolina, South Carolina, & Virginia. Journal of Agricultural Education, 44(4), 11-21.

Fanti, M. P., Iacobellis, G., & Ukovich, W. (2014). A risk assessment framework for Hazmat transportation in highways by colored Petri nets. IEEE Transactions on Systems, Man, and Cybernetics: Systems, 45(3), 485-495.

Fanti, M. P., Iacobellis, G., & Ukovich, W. (2015). A Risk Assessment Framework for Hazmat Transportation in Highways by Colored Petri Nets. IEEE Transactions on Systems, Man, and Cybernetics: Systems, 45(3), 485-495. https://doi.org/10.1109/tsmc.2014.2351373

GIZ, t. G. g. t. D. G. f. I. Z. G. (2004). Present 04 factory. In t. G. g. t. D. G. f. I. Z. G. GIZ (Ed.).

GIZ, t. G. g. t. D. G. f. I. Z. G. (2019). Thai-German Dangerous Goods Project (TG-DGP). Retrieved 1 June 2020 from https://www.thai-german-cooperation.info/th/history_enviro_4/

Google. (2022). Direction API. https://developers.google.com/maps/documentation/directions/

Google. (2024). Routes API. https://developers.google.com/maps/documentation/routes#get-started

Grigorev, A., Mihaita, A.-S., Lee, S., & Chen, F. (2022). Incident duration prediction using a bi-level machine learning framework with outlier removal and intra–extra joint optimisation. Transportation Research Part C: Emerging Technologies, 141, 103721. https://doi.org/https://doi.org/10.1016/j.trc.2022.103721

Tomtom Traffic index. (2024). *Traffic index ranking*. https://www.tomtom.com/traffic-index/ranking/

J., M., R.H., G., R., F., & L., M. (2012). Fleet Safety Management Practices in Hazmat Transportation. Australian College of Road Safety (ACRS).

K. Puntumapon, T. Punyararj, & Pattara-atikom, W. (2009). Bangkok Road Traffic Characteristic. Conference: the Sixth International Joint Conference on Computer Science and Software Engineering (JCSSE2009), 1. https://www.researchgate.net/publication/279951324_Bangkok_Road_Traffic_Characteristic

Krit Jedwanna, Agachai Sumalee, Nutthapol Junkaew, Saroch Boonsiripant, & prapreut trianekpinit. (2014, 14-16 May 2014). Design and Development of HAZMAT Trucks system for EXAT 19th National Convention on Civil Engineering, Khon Kaen University, Khon Kaen, Thailand.

http://trsl.thairoads.org/FileUpLoad/1510/141004001510.pdf

Laboratory, H. a. S. (2009). Review of human reliability assessment methods.

https://www.hse.gov.uk/research/rrpdf/rr679.pdf

Ladkrabang, K. M. s. I. o. T. (2014). The Studying and Developing tracking systems and defining hazmat transport standard for the Expressway Authority of Thailand (EXAT).

Lertsookheekasem, B. (2023). Local Fire Department Standard. In.

Longdo, M. (2024). Routing restriction API. https://map-blog.longdo.com/routing-restriction-api/

Loukaitou-Sideris, A. (2000). Transit-Oriented Development in the Inner City: A Delphi Survey. Journal of Public Transportation, 3(2), 75-98.

https://doi.org/https://doi.org/10.5038/2375-0901.3.2.5

Manual, H. C. (2000). Highway capacity manual. Washington, DC, 2(1), 1.

Marine Meteorological Center. (2024). Wind Measurement.

http://www.marine.tmd.go.th/paper/windhtml/windhtml.html

Muñoz-Villamizar, A., Faulin, J., Reyes-Rubiano, L., Henriquez-Machado, R., & Solano-Charris, E. (2024). Integration of Google Maps API with mathematical modeling for solving the Real-Time VRP. Transportation Research Procedia, 78, 32-39. https://doi.org/https://doi.org/10.1016/j.trpro.2024.02.005

Murat, Y. S., Arslan, T., Cakici, Z., & Akçam, C. (2016). Analytical hierarchy process (AHP) based decision support system for urban intersections in transportation planning. In Using decision support systems for transportation planning efficiency (pp. 203-222). IGI Global Scientific Publishing.

Namphung, M. (2016). การ วิจัย ด้วย เทคนิค เด ล ฟาย: การ หลีก เลี่ยง มโน ทัศน์ ที่ ไม่ ถูก ต้อง. Veridian E-Journal, Silpakorn University (Humanities, Social Sciences and arts), 9(1), 1256-1267.

NOAA. (2025). Pasquill Stability Classes. https://www.ready.noaa.gov/READYpgclass.php

OpenStreet-Map. (2024). About OpenStreet Map. https://www.openstreetmap.org/about

P. Kanchit, Kaosa-ard**, M. S., & Pienchob***, P. (1994). Bangkok Traffic Congestion: Is There a Solution? TDRI Quarterly Review, 9, 20-23.

Puttinaovarat, S., Jutapruet, S., Saeliw, A., Pruitikanee, S., Kongcharoen, J., Jiamsawat, W., Limpasamanon, S., & Srirat, M. (2019). Facility maintenance management system based on GIS and indoor map. International Journal of Electrical and Computer Engineering, 9, 3323-3332. https://doi.org/10.11591/ijece.v9i4.pp3323-3332

Rujipun Phangchandha, & Arron Ketsakorn. (2018). A New Risk Assessment Criteria in the Process of Fuel Oil Unloading. Science and Technology RMUTT Journal, 8 (1), 89-105. http://www.sci.rmutt.ac.th/stj/index.php/stj/article/view/332/213

Savkovic, S., Jovancic, P., Djenadic, S., Tanasijevic, M., & Miletic, F. (2022). Development of the hybrid MCDM model for evaluating and selecting bucket wheel excavators for the modernization process. Expert Systems with Applications, 201, 117199.

Scerri, D., Hickmott, S., Bosomworth, K., & Padgham, L. (2012). Using modular simulation and agent based modelling to explore emergency management scenarios. Australian Journal of Emergency Management, 27, 44-48.

Seo, S.-K., Yoon, Y.-G., Lee, J.-s., Na, J., & Lee, C.-J. (2022). Deep Neural Network-based Optimization Framework for Safety Evacuation Route during Toxic Gas Leak Incidents. Reliability Engineering & System Safety, 218, 108102. https://doi.org/https://doi.org/10.1016/j.ress.2021.108102

Sharma, R. K., Gurjar, B. R., Singhal, A. V., Wate, S. R., Ghuge, S. P., & Agrawal, R. (2015). RETRACTED: Automation of emergency response for petroleum oil storage terminals. In: Elsevier.

Sutheewasinnon, P., and Prasopchai Pasunon. . (2016). Sampling Strategies for Qualitative Research. Parichart Journal, 29(2), 31-48.

Thanyarat Tiya-apisit, & Uttapol Smutkupt. (2017). Selection Model of Vehicle's Maintenance Service Providers by Using Fuzzy AHP Technique. Engineering Jounal Chiang Mai University, 24(3), 127-141. http://researchs.eng.cmu.ac.th/UserFiles/File/Journal/24_3/13.pdf

Transportation statistics sub-division, P. d., Department of Land Transport. (2019). Hazardous chemical truck statistics on 31 December 2019. Department of Land Transport (DLT). Retrieved 1 June 2020 from https://web.dlt.go.th/statistics/

Vaez, N., & Nourai, F. (2013). RANDAP: An integrated framework for reliability analysis of detailed action plans of combined automatic-operator emergency response taking into account control room operator errors. Journal of Loss Prevention in the Process Industries, 26(6), 1366-1379. https://doi.org/10.1016/j.jlp.2013.08.011

Vargas, L. G. (1990). An overview of the analytic hierarchy process and its applications. European journal of operational research, 48(1), 2-8.

Vudhivanich, V. (2003). Decision making by analytic hierachy process. Chollakorn. The Irrigation Alumni Association Under HM The King's Patronage. January. p.

Wang, P., Wang, S., Chi, L., Ren, X., Wu, W., & Cheng, W. (2022). Research and application of the network security monitoring capability evaluation model of power control system based on ahp and fuzzy comprehensive evaluation. Journal of Physics: Conference Series,

Warakorn Decha. (2005). The comparison of safety management score between hazardous material transportation sizes and accident occurrences Mahidol University]. http://www.thaithesis.org/detail.php?id=1202548000243

Wilson, D. T., Hawe, G. I., Coates, G., & Crouch, R. S. (2014). Evaluation of centralised and autonomous routing strategies in major incident response. Safety science, 70, 80-88.

Wongrukmitr, N. (2021). Development of DAISY Audio Books on Reading Comprehension for Visually Impaired Students. Rajabhat Chiang Mai Research Journal, 22(1), 149-162.

Woodcock, B., & Au, Z. (2013). Human factors issues in the management of emergency response at high hazard installations. Journal of Loss Prevention in the Process Industries, 26(3), 547-557. https://doi.org/10.1016/j.jlp.2012.07.002

Yu, Z.-f., & Guan, J.-l. (2016). Fire and Rescue Combat Technical Training System Construction for Dangerous Chemicals. Procedia Engineering, 135, 655-660. https://doi.org/10.1016/j.proeng.2016.01.133

Zhang, J.-H., Li, J., & Liu, Z.-P. (2012). Multiple-resource and multiple-depot emergency response problem considering secondary disasters. Expert Systems with Applications, 39(12), 11066-11071.

# APPENDICES

# APPENDIX A

## Questionnaire of IOC : Index of item objective congruence

### Research Instrument Content Validity Index (IOC) Assessment Form

### for Expert Review and Additional Recommendations

Questionnaire on Factors Influencing Emergency Route Selection for Chemical Spills on the Chalerm Maha Nakhon Expressway

Instructions: This Content Validity Index (IOC) assessment form for the research instrument on "Factors Influencing Emergency Route Selection for Chemical Spills on the Chalerm Maha Nakhon Expressway" aims to evaluate your opinion on the suitability of each item. This includes assessing its alignment with the studied variables, research content, and ethical considerations. The criteria for assessing validity are as follows:

+1 = Congruent

0 = Questionable

-1 = Incongruent

Please mark " ✓ " in the column indicating the extent to which the statement is consistent or accurate with your opinion.

| No | Questionnaire Items | Expert Opinion | | | Suggestion |
|---|---|---|---|---|---|
| | | Congruent | Questionable | Incongruent | |
| Section 1 General Information of Respondent | | | | | |
| 1 | Age<br>☐ 30 years or below<br>☐ 31-40 years<br>☐ 41-50 years<br>☐ Over 50 years | | | | |
| 2 | Gender<br>☐ Male<br>☐ Female<br>☐ Prefer not to say | | | | |
| 3 | Academic Position (For university lecturers)<br>☐ Lecturer | | | | |

| No | Questionnaire Items | Expert Opinion | | | Suggestion |
|---|---|---|---|---|---|
| | | Congruent | Questionable | Incongruent | |
| | □ Assistant Professor<br>□ Associate Professor<br><br>□ Professor<br>□ Others (please specify)................. | | | | |
| 4 | Administrative Position in Organization (Government/State Enterprise/Private)<br>□ Operational Level<br>□ Management Level (from department head upward) | | | | |
| 5 | The highest Education Level<br>□ Below Bachelor's Degree<br>□ Bachelor's Degree<br>□ Master's Degree<br>□ Doctoral Degree | | | | |
| 6 | Area of Expertise<br>□ Occupational health<br>□ Emergency Response<br>□ Transportation Engineering<br>□ Computer science : Data science) / Geographic Information System (GIS)<br>□ Logistics<br>□ Environmental<br>□ Others (please specify)....................... | | | | |
| 7 | Experience in field of expertise (from item 6)<br>□ 5 years<br>□ More than 5 years (please specify)............... | | | | |
| | Section 2 Opinions on Critical Factors Influencing Emergency | | | | |

| No | Questionnaire Items | Expert Opinion | | | Suggestion |
|---|---|---|---|---|---|
| | | Congruent | Questionable | Incongruent | |
| | Route Selection for Chemical Spills on the Chalerm Maha Nakhon Expressway | | | | |
| Component 1: Travel Time Travel time refers to the factors influencing the duration it takes to reach an incident site. These factors include: | | | | | |
| 1 | Traffic flow | | | | |
| 2 | Route selection regulations/standards | | | | |
| 3 | The shortest path | | | | |
| 4 | Route complexity, which includes factors such as intersections and turns. | | | | |
| 5 | Comfortable road) | | | | |
| Component 2: Chemical Data Chemical data refers to the factors that influence the assessment of the severity and dispersion of a chemical spill. | | | | | |
| 1 | Chemical concentration level | | | | |
| 2 | Incident location | | | | |
| 3 | Foot print from ALOHA | | | | |
| Component 3: Social Impact Data. Social impact data refers to impact factors that may affect society, communities, and the environment, which must be considered when selecting an emergency response route. | | | | | |
| 1 | Population density (community areas | | | | |
| 2 | Business Density (Business Districts) | | | | |
| 3 | Environmental Impact (referring to the | | | | |

| No | Questionnaire Items | Expert Opinion | | | Suggestion |
|---|---|---|---|---|---|
| | | Congruent | Questionable | Incongruent | |
| | surrounding environment) | | | | |
| Component 4: Traffic Data Accessibility. Traffic data accessibility refers to the channels through which traffic volume information can be accessed. These include: | | | | | |
| 1 | Google Maps application (mobile/desktop versions) | | | | |
| 2 | The EXAT Traffic mobile application (EXAT Portal) | | | | |
| 3 | Intelligent Transportation System (ITS) Variable Message Signs (VMS) displaying real-time traffic information at expressway toll plazas. | | | | |
| Component 5: Emergency Response Team (ERT) Performance. This component focuses on the effectiveness of the Emergency Response Team (ERT) in responding to incidents. | | | | | |
| 1 | Equipment and Resource Readiness for Incident Response | | | | |
| 2 | ERT (Emergency Response Team) Location | | | | |

Assessor's Signature.........................................................

Date........ Month..................Year...........

# APPENDIX B

## Human Ethics

ScF 03_01 (Eng)

The Human Research Ethics Committee of Thammasat University (Science), (HREC-TUSc) Room No 110, Piyachart Building, 1st Floor, Thammasat University Rangsit Campus, Prathumthani 12121, Thailand, Tel: 0-2564-4440 ext.7358 E-mail: ecsctu3@tu.ac.th

**COA No. 049/2567**

**Certificate of Approval**

**Project No.** : 67PU015
**Title of Project** : The Development of Chemical Emergency Response Simulation Model on Chalerm Mahanakorn Route for Thailand Expressway
**Principle Investigator** : Miss Wipaporn Kitthiphovanonth
**Place of Proposed Study/Institution**: Faculty of Public Health, Thammasat University

The Human Research Ethics Committee of Thammasat University (Science), Thailand, has approved the above study project in accordance with the compliance to the Declaration of Helsinki, the Belmont report, CIOMS guidelines and the International practice (ICH-GCP).

Signature: ..........................................
(Assoc. Prof. Jinda Wangboonskul, Ph.D.)
Chairman of the Human Research Ethics Committee of Thammasat University (Science).

Signature: ..........................................
(Assoc. Prof.Laksana Laokiat, Ph.D.)
Secretary of the Human Research Ethics Committee of Thammasat University (Science).

**Date of Approval:** May 20, 2024 **Approval Expire date:** May 19, 2025
**Progressing Report Due:** April 20, 2025

**Date of extension 1:** May 20, 2025 **Approval Expire date:** May 19, 2026
**Progressing Report Due:** April 20, 2026

**The approval documents including**
1) Research proposal Version 2/ 09-04-2024
2) Principal Investigator's Curriculum Vitae Version 2/ 09-04-2024
3) Patient/Participant Information Sheet Version 2/ 09-04-2024
4) Informed Consent Form Version 2/ 09-04-2024
5) Questionnaire Version 2/ 09-04-2024

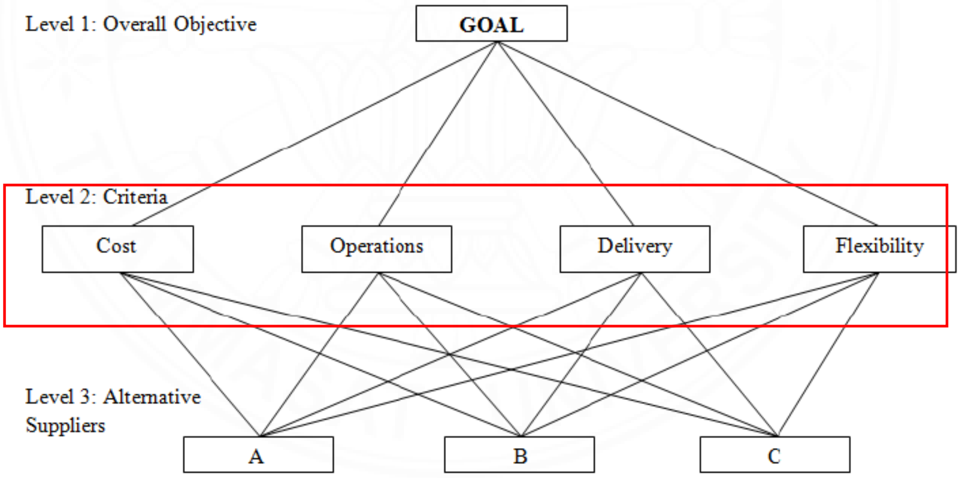
# APPENDIX C
# Questionnaire for Delphi Method

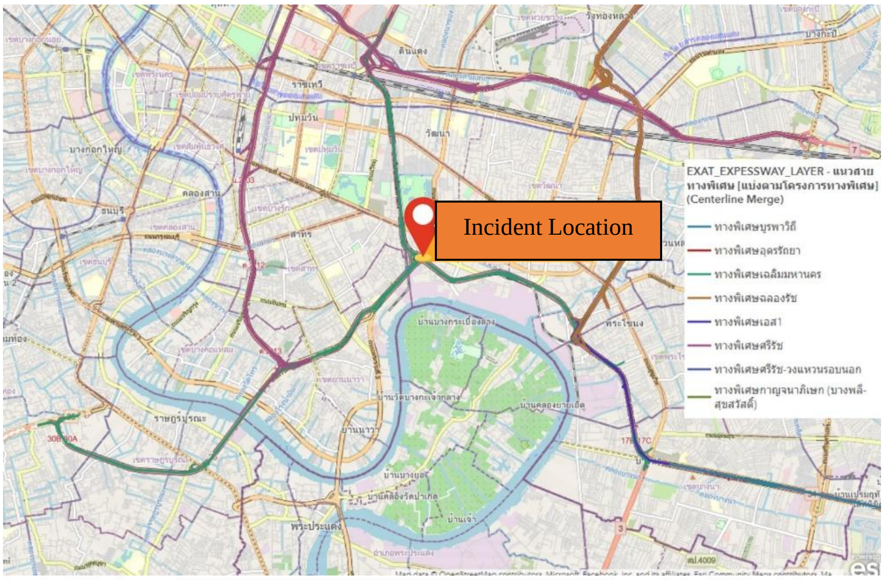
Questionnaire No..........

## Questionnaire on Factors Affecting Route Selection Chemical Spill Emergency Response on Chalerm Mahanakorn Expressway

Introduction

This questionnaire aims to explore the factors influencing the selection of the safest route for Emergency Response Teams (ERT) in the event of a chemical spill on Chalerm Mahanakorn Expressway. Factors were identified from literature reviews, relevant expressway authority information, and expert consensus using the Delphi Technique to define sub-objectives (Level 2).






Chalerm Mahanakorn Expressway

Section 1 General Information of Respondent

Instructions: Please mark / in the box ☐

1. Age

☐ 30 years or below ☐ 31-40 years ☐ 41-50 years ☐ Over 50 years

2. Gender

☐ Male ☐ Female ☐ Prefer not to say

3. Academic Position (For university lecturers)

☐ Lecturer ☐ Assistant Professor

☐ Associate Professor ☐ Professor

☐ Others (please specify)........................................................................

4. Administrative Position in Organization (Government/State Enterprise/Private)

☐ Operational Level ☐ Management Level (from department head upward)

5. The highest Education Level

☐ Below Bachelor's Degree ☐ Bachelor's Degree

☐ Master's Degree ☐ Doctoral Degree

6. Area of Expertise

☐ Occupational health ☐ Logistics

☐ Emergency Response ☐ Environmental

☐ Transportation Engineering ☐ Others (please specify)......................

☐ Computer science : Data science) / Geographic Information System (GIS)

7. Experience in field of expertise (from item 6)

☐ 5 years ☐ More than 5 years (please specify)......

Part 2: Opinions on Key Factors Influencing Emergency Route Selection for Chemical Spills on the Chalerm Maha Nakhon Expressway

Instructions: Please mark "✓" in the column that best reflects your opinion on the weighting. The scores are defined as follows:

| | |
|---|---|
| score of 5 | Most critical factors influencing route selection |
| score of 4 | Highly influential factors in route selection |
| score of 3 | Moderately influential factors in route selection |
| score of 2 | Less influential factors in route selection |
| score of 1 | Least influential factors in route selection |

**<u>Component 1: Travel Time</u>**

This refers to the factors that influence the travel time to reach an incident site.

| No | Questionnaire Items | Agree with the statement | | | | | Reason(s) |
|---|---|---|---|---|---|---|---|
| | | 5 | 4 | 3 | 2 | 1 | |
| 1 | Traffic flow | | | | | | |
| 2 | Route Selection Regulations/Standards (Work Instructions/Standard Operating Procedures) for Emergency Incidents | | | | | | |
| 3 | Selecting the shortest path (from origin to destination) | | | | | | |
| 4 | Route complexity, which includes factors such as intersections and turns. (comfortable road) | | | | | | |

Additional Comments:................................................................................................................................................

.......................................................................................................................................................................

**<u>Component 2:</u> Chemical Data**

This refers to factors influencing the assessment of the severity and dispersion of a chemical spill.

| No | Questionnaire Items | Agree with the statement | | | | | Reason(s) |
|---|---|---|---|---|---|---|---|
| | | 5 | 4 | 3 | 2 | 1 | |
| 1 | Chemical concentration level | | | | | | |
| 2 | Incident location | | | | | | |
| 3 | Foot print from ALOHA) | | | | | | |

Additional Comments:................................................................................................................................................

.......................................................................................................................................................................

**Component 3: Social Impact Data**

This refers to impact factors that might affect society, communities, and the environment, which must be considered when selecting an emergency response route.

| No | Questionnaire Items | Agree with the statement | | | | | Reason(s) |
|---|---|---|---|---|---|---|---|
| | | 5 | 4 | 3 | 2 | 1 | |
| 1 | Population density (community areas | | | | | | |
| 2 | Business Density (Business Districts) | | | | | | |
| 3 | Environmental Impact (referring to the surrounding environment) | | | | | | |

Additional Comments:......................................................................................................................................................

..............................................................................................................................................................................

**Component 4: Traffic Data Accessibility**

This refers to the channels through which traffic volume information can be accessed. These include:

| No | Questionnaire Items | Agree with the statement | | | | | Reason(s) |
|---|---|---|---|---|---|---|---|
| | | 5 | 4 | 3 | 2 | 1 | |
| 1 | Google Maps application (mobile/desktop versions) | | | | | | |
| 2 | The EXAT Traffic mobile application (EXAT Portal) | | | | | | |
| 3 | Intelligent Transportation System (ITS) Variable Message Signs (VMS) displaying real-time traffic information at expressway toll plazas. | | | | | | |

Additional Comments:........................................................................................................................................

..........................................................................................................................................................

**Component 5: Emergency Response Team (ERT) Performance**

This refers to the factors influencing the effectiveness of the Emergency Response Team (ERT) in responding to emergencies. These include:

| No | Questionnaire Items | Agree with the statement | | | | | Reason(s) |
|---|---|---|---|---|---|---|---|
| | | 5 | 4 | 3 | 2 | 1 | |
| 1 | Resource readiness (encompassing equipment, personnel, and supplies | | | | | | |
| 2 | ERT location | | | | | | |

Additional Comments:........................................................................................................................................

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..........................................................................................

( )

Research Participants

# APPENDIX D

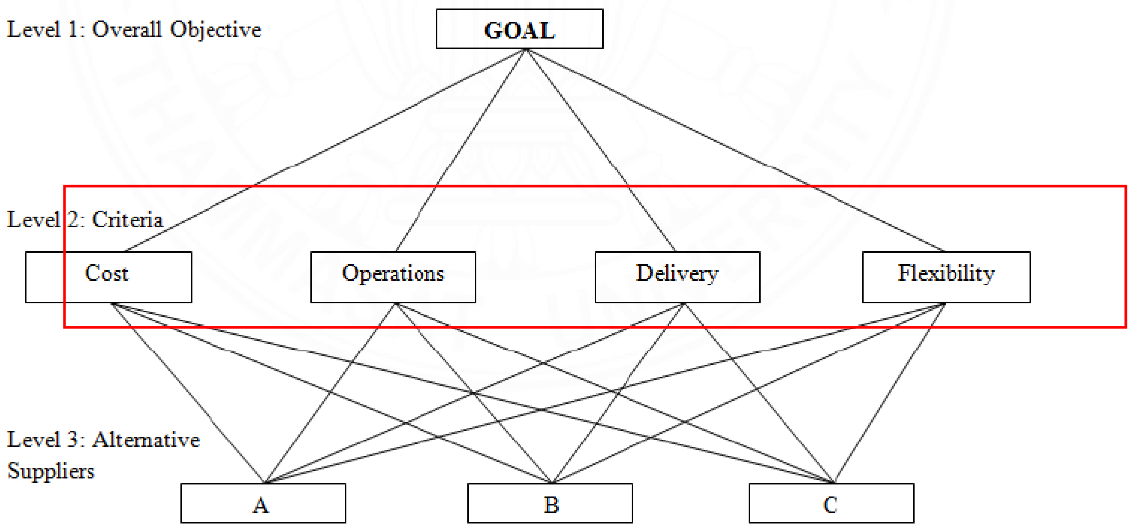
## Questionnaire of Response to Chemical Spills on Chaloem Mahanakhon Expressway for AHP Method

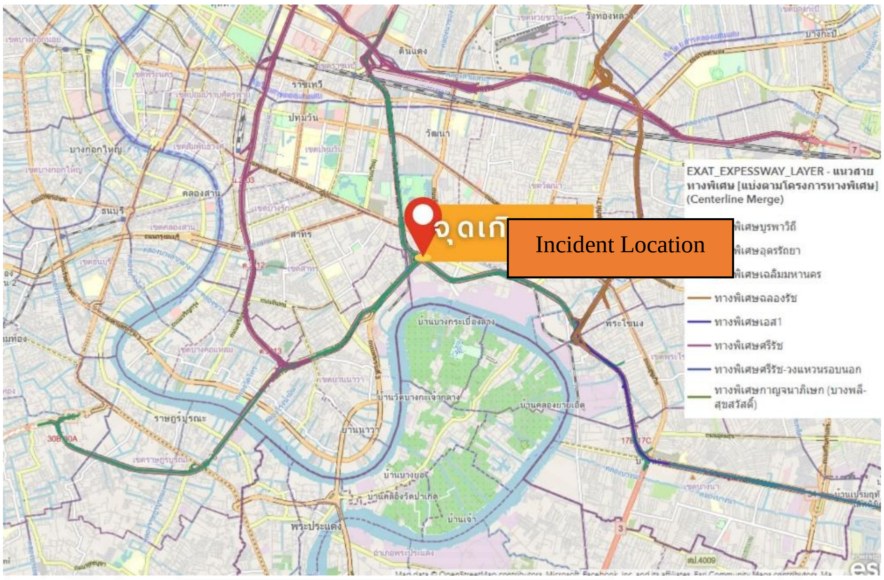
Questionnaire ID.......

### Questionnaire on Factors Affecting Route Selection Chemical Spill Emergency Response on Chalerm Mahanakorn Expressway

Introduction

This questionnaire aims to explore the factors influencing the selection of the safest route for Emergency Response Teams (ERT) in the event of a chemical spill on Chalerm Mahanakorn Expressway. Factors were identified from literature reviews, relevant expressway authority information, and expert consensus using the Delphi Technique to define sub-objectives (Level 2).






Chalerm Mahanakorn Expressway

<u>Section 1</u> General Information of Respondent

<u>Instructions:</u> Please mark / in the box ☐

1. Age

☐ 30 years or below ☐ 31-40 years ☐ 41-50 years ☐ Over 50 years

2. Gender

☐ Male ☐ Female ☐ Prefer not to say

3. Academic Position (For university lecturers)

☐ Lecturer ☐ Assistant Professor

☐ Associate Professor ☐ Professor

☐ Others (please specify)........................................................................

4. Administrative Position in Organization (Government/State Enterprise/Private)

☐ Operational Level ☐ Management Level (from department head upward)

5. The highest Education Level

☐ Below Bachelor's Degree ☐ Bachelor's Degree

☐ Master's Degree ☐ Doctoral Degree

6. Area of Expertise

☐ Occupational health ☐ Logistics

☐ Emergency Response ☐ Environmental

☐ Transportation Engineering ☐ Others (please specify)..............

☐ Computer science : Data science) / Geographic Information System (GIS)

7. Experience in field of expertise (from item 6)

☐ 5 years ☐ More than 5 years (please specify)................

Section 2 Opinions on Critical Factors Influencing Emergency Route Selection for Chemical Spills on the Chalerm Maha Nakhon Expressway

Instructions: Please mark "/" in the weight level that corresponds to your opinion. The scores are defined as follows:

| Intensity of Importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective |
| 3 | Moderate importance of one over another | Experience and judgment strongly favor one activity over another |
| 5 | Essential of strong importance | Experience and judgment strongly favor one activity over another |
| 7 | Very strong importance | An activity is strongly favored and its dominance demonstrated in practice |
| 9 | Extreme importance | The evidence favoring one activity over another is of the highest possible order of affirmation |
| 2,4,6,8 | Intermediate values between the two adjacent judgment | When compromise is needed |

## Component 1: Travel Time

**Travel time refers to the factors influencing the duration it takes to reach an incident site. These factors include:**

Question: Regarding the importance of factors, how much more significant is "**Traffic flow**" compared to "**Route selection regulations/standards**" in your assessment of importance?

| No. | Factor 1 | Prioritization of Factors 1 and 2 | | | | | | | | | | | | | | | | | Factor 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Traffic flow [A1]** | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | **Route selection regulations/standards [A2]** |
| | | ← | | | | | | | | ● | → | | | | | | | | |
| | | This dimension is more important | | | | | | | | | This dimension is more important | | | | | | | | |

Question: Regarding the importance of factors, how much more significant is "**Traffic flow**" compared to "**The shortest path**" in your assessment of importance?

| No. | Factor 1 | Prioritization of Factors 1 and 3 | | | | | | | | | | | | | | | | | Factor 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Traffic flow [A1]** | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | **The shortest path [A3]** |
| | | ← | | | | | | | | ● | → | | | | | | | | |
| | | This dimension is more important | | | | | | | | | This dimension is more important | | | | | | | | |

Question: Regarding the importance of factors, How much more significant is "**Traffic flow**" compared to "**Route complexity**" in your assessment of importance?

| No. | Factor 1 | Prioritization of Factors 1 and 4 | | | | | | | | | | | | | | | | | Factor 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Traffic flow [A1]** | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | **Route complexity [A4]** |
| | | ← | | | | | | | | ● | → | | | | | | | | |
| | | This dimension is more important | | | | | | | | | This dimension is more important | | | | | | | | |

Question: Regarding the importance of factors, How much more significant is "**Route selection regulations/standards**" compared to "**The shortest path**" in your assessment of importance?

| No. | Factor 2 | Prioritization of Factors 2 and 3 | | | | | | | | | | | | | | | | | Factor 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Route selection regulations/standards [A2]** | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | **The shortest path [A3]** |
| | | ← | | | | | | | | ● | → | | | | | | | | |
| | | This dimension is more important | | | | | | | | | This dimension is more important | | | | | | | | |

Question: Regarding the importance of factors, How much more significant is "**Route selection regulations/standards**" compared to "**Route complexity**" in your assessment of importance?

| No. | Factor 2 | Prioritization of Factors 2 and 4 | | | | | | | | | | | | | | | | | Factor 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Route selection regulations/standards [A2]** | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | **Route complexity [A4]** |
| | | ← | | | | | | | | • | | | | | | | | → | |
| | | This dimension is more important | | | | | | | | | This dimension is more important | | | | | | | | |

Question: Regarding the importance of factors, How much more significant is "**The shortest path**" compared to "**Route complexity**" in your assessment of importance?

| No. | Factor 3 | Prioritization of Factors 3 and 4 | | | | | | | | | | | | | | | | | Factor 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **The shortest path [A3]** | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | **Route complexity [A4]** |
| | | ← | | | | | | | | • | | | | | | | | → | |
| | | This dimension is more important | | | | | | | | | This dimension is more important | | | | | | | | |

**<u>Component 2: Chemical Data</u>**

**Chemical data refers to the factors that influence the assessment of the severity and dispersion of a chemical spill**.

Question: Regarding the importance of factors, How much more significant is "**Chemical concentration level**" compared to "**Incident location**" in your assessment of importance?

| No. | Factor 1 | Prioritization of Factors 1 and 2 | | | | | | | | | | | | | | | | | Factor 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Chemical concentration level [F1]** | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | **Incident location [F2]** |
| | | ← | | | | | | | | • | | | | | | | | → | |
| | | This dimension is more important | | | | | | | | | This dimension is more important | | | | | | | | |

Question: Regarding the importance of factors, How much more significant is "**Chemical concentration level**" compared to "**Foot print from ALOHA**" in your assessment of importance?

| No. | Factor 1 | Prioritization of Factors 1 and 3 | | | | | | | | | | | | | | | | | Factor 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Chemical concentration level [F1]** | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | **Foot print from ALOHA [F3]** |
| | | ← | | | | | | | | • | | | | | | | | → | |
| | | This dimension is more important | | | | | | | | | This dimension is more important | | | | | | | | |

Question: Regarding the importance of factors, How much more significant is "**Incident location**" compared to "**Foot print from ALOHA**" in your assessment of importance?

| No. | Factor 2 | Prioritization of Factors 2 and 3 | | | | | | | | | | | | | | | | | Factor 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Incident location** [**F2**] | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | **Foot print from ALOHA** [**F3**] |
| | | ← | | | | | | | | • | → | | | | | | | | |
| | | This dimension is more important | | | | | | | | | This dimension is more important | | | | | | | | |

## Component 3: Social Impact Data

**Social impact data refers to impact factors that may affect society, communities, and the environment, which must be considered when selecting an emergency response route.**

Question: Regarding the importance of factors, How much more significant is "**Population density (community areas)**" compared to " **Business density (business districts)**" in your assessment of importance?

| No. | Factor 1 | Prioritization of Factors 1 and 2 | | | | | | | | | | | | | | | | | Factor 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Population density (community areas)** [**B1**] | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | **Business density (business districts)** [**B2**] |
| | | ← | | | | | | | | • | → | | | | | | | | |
| | | This dimension is more important | | | | | | | | | This dimension is more important | | | | | | | | |

## Component 4: Traffic Data Accessibility

**Traffic data accessibility refers to the channels through which traffic volume information can be accessed. These include:**

Question: Regarding the importance of factors, How much more significant is "**Google map**" compared to "**ITS sign**" in your assessment of importance?

| No. | Factor 1 | Prioritization of Factors 1 and 2 | | | | | | | | | | | | | | | | | Factor 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Google map** [**C1**] | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | **ITS sign** [**B2**] |
| | | ← | | | | | | | | • | → | | | | | | | | |
| | | This dimension is more important | | | | | | | | | This dimension is more important | | | | | | | | |

**<u>Component 5: Emergency Response Team (ERT) Performance</u>**

**This component focuses on the effectiveness of the Emergency Response Team (ERT) in responding to incidents.**

Question: Regarding the importance of factors, How much more significant is "**Resource readiness**" compared to "**ERT (Emergency Response Team) Location**" in your assessment of importance?

<table>
<tr><td>No.</td><td>Factor 1</td><td colspan="17">Prioritization of Factors 1 and 2</td><td>Factor 2</td></tr>
<tr><td rowspan="3"></td><td rowspan="3">Resource readiness (D1)</td><td>9</td><td>8</td><td>7</td><td>6</td><td>5</td><td>4</td><td>3</td><td>2</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td rowspan="3">ERT Location (D2)</td></tr>
<tr><td colspan="8">◄</td><td>•</td><td colspan="8">►</td></tr>
<tr><td colspan="8">This dimension is more important</td><td></td><td colspan="8">This dimension is more important</td></tr>
</table>

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Research Participants

# BIOGRAPHY

| | |
|---|---|
| Name | Wipaporn Kitthiphovanonth |
| Educational Attainment | 2007: B.Sc. (Health Science)<br>Thammasat University<br>2012: M.Sc. (Industrial Hygiene and Safety) |
| Publications | |
| Work Experience | 1. Training Staff (Safety officer), Rajthanee Hospital Ayutthaya. Since May 2009 – July 2010<br>2. Safety officer, Thai Fuji Seiki Co,.Ltd Hitech , Ayutthaya. Since August 2010 – Jan 2012<br>3. Safety officer, AAPICO Hitech Public Co.,Ltd., Ayutthaya. Since May 2012 – Feb 2013<br>4. Safety officer (Section Head), Ayutthaya Glass Industry Co., Ltd. , Ayutthaya. Since Feb 2013 – July 2014<br>5. Safety officer (Assistant Manager), Western Digital (Thailand) Co., Ltd. , Navanakorn, Pathumthani. Since August 2014 – August 2015<br>6. Safety officer, Expressway Authority of Thailand, Bangkok. Since August 2015 - Present |