A Joint Model of Optimization and Simulation Methods for Humanitarian Logistics to Face Sumatra Megathrust

Rahmad Inca Liperda

A Thesis Submitted in Fulfillment of the Requirements for the Degree of Master of Engineering in Industrial and Systems Engineering

Prince of Songkla University

2019

A Joint Model of Optimization and Simulation Methods for Humanitarian Logistics to Face Sumatra Megathrust

Rahmad Inca Liperda

A Thesis Submitted in Fulfillment of the Requirements for the Degree of Master of Engineering in Industrial and Systems Engineering

Prince of Songkla University

2019

Thesis Title A Joint Model of Optimization and Simulation Methods for Humanitarian Logistics to Face Sumatra Megathrust

Author Mr. Rahmad Inca Liperda

Major Program Industrial and Systems Engineering

Academic Year 2018

ABSTRACT

A rapid-appropriate relief aid is crucial to be provided in the aftermath of a disaster event. The humanitarian logistics has been considered to assist the major contribution in the disaster relief operations. This research aims to obtain an integrated strategic-operational framework for the location-allocation and routing decisions to face the future tremendous hazard Sumatra Megathrust. The arrival pattern of the two terms evacuation assignment over the 72 hours of the planning period becomes the source of the deliberation to determine the amount of consumable goods to be delivered per day. In order to ensure the safe and adequate access, this research takes into consideration the analysis of the expected impassable path caused by tsunami inundation. During the preparedness stage, Geographic Information Systems (GIS) tool with maximal coverage is applied to generate a set of Local Distribution Centers (LDCs)' alternatives to be built. The selection of the appropriate LDCs per day is assessed based on the minimum opening cost and transportation cost. Two LDCs are selected to be opened in the first two days while three LDCs will be established in the third day. The total preparedness cost for fulfilling the needs of 410,670 persons during the three days of emergency period is expected to be 7,205.86 USD. In the response stage, GIS analysis combined with simulation approach are utilized to formulate the relief routing and assignment tasks. During this stage, the demand requirements, vehicle velocities, and the road restoration time are subject of uncertainties. The use of multi-vehicle with time windows is allowed to depict the actual relief delivery efforts during three days of emergency period. The effectiveness of two relief distribution strategies, the equalized strategy and the synchronized strategy are examined by calculating the minimum total handling cost for the distribution activities, the penalty cost of the unsatisfied fulfillment, and the holding cost for the excessive delivery. The simulation result signifies that the synchronized strategy yields in better outcome with average total cost 7,716.94 USD. Meanwhile, the average total cost resulted from the equalized strategy spends 47,256.30 USD.

Keywords : *Humanitarian Logistics, Sumatra Megathrust, GIS, Simulation*

ACKNOWLEDGEMENT

Firstly, I would like to express my foremost gratitude and sincere appreciation to my advisor Assoc. Prof. Dr. Nikorn Sirivongpaisal for his conscientious guidance and persistent support and encouragement behind the successful completion of this work.

I would also like to acknowledge Asst. Prof. Dr. Sakchai Prechaverakul, Dr. Somporn Chuai-aree, and Assoc. Prof. Dr. Somrote Komolavanij for their heartiness and collective insightful advice and suggestions as my thesis committees.

I am ineffably indebted to my lecturer, Mrs. Reinny Patrisina for her helpful suggestions, and all of my friends who directly or indirectly helped me during my study in Thailand.

I am, of course, very grateful to the financial support provided by Thailand's Education Hub for ASEAN Countries (THE-AC) scholarship and the Graduate School for assisting the research support funding for my thesis.

In addition, thank you to the Department of Industrial Engineering, Faculty of Engineering, Prince of Songkla University, Thailand, including all the staffs for their supports and assistance.

Finally, my deep sense of reverence goes to my family, especially my dearest parents, Lifarjon and Rismawida, and also my beloved sister, Anggun Dwifa Citra who have always supported and encouraged me in order to finish this study.

Rahmad Inca Liperda

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1. Research Background

The efforts of minimizing suffering and death caused by disaster has been recognized as serious concern in order to provide a prompt-appropriate relief aid. The severities and complexities accompanying the disaster occurrences lead to another challenge to be faced by the disaster managers. CRED, the Centre of Research on the Epidemiology of Disasters, claimed that at least 380 disaster incidents occur annually and affect to approximately 199 million people [1]. The CRED annual report also stated that this happening costs US$ 160 billion per year with earthquakes and tsunamis as the major contributors causing the highest number of deaths.

A thorough deliberation in enhancing the capability of the disaster countermeasure is essential to come up with the consequences resulted from disaster. The chaotic circumstances that may arise in the aftermath of disaster should be minimized by performing an adequate relief response in order to meet the beneficiaries' satisfaction. Disaster management is widely known as a fundamental strategy to obtain decent assistance aiming to prevent or reduce the injuries, fatalities, damages and finally to facilitate the victims to get ready to recover from disaster [2]. As an attempt to reduce the disaster impacts, disaster management consists of a series of activities including mitigation, preparedness, response, and recovery. These activities are incorporated into a form of life-cycle which is mainly classified based on two main phases; pre-event phase and post-event phase [3].

The preparedness level during the pre-event phase significantly affects to the effectiveness of the relief response. The lack of preparedness will cause many delays and losses in the response stage [4]. This tendency implies to the needs of the integrated manner for synthesizing both activities. During the preparedness phase, the development of the network design, IT construction, and establishing the collaboration between the relief actors are conducted. The actualization of the designed scheme is implemented after the disaster takes place. The objective of providing the basic services and dispatching the relief goods in an immediate period of time prevails in the emergency response operations [5]. In this phase, the scarce of resources and information are barriers to be faced by the relief stakeholders.

As a systematic approach for reducing the consequences of disaster, there is increasing recognition of the need for encompassing the logistical operations towards the disaster management particularly in the preparedness and response phase. The term of humanitarian logistics is interpreted as "planning, implementing, and controlling the efficient, cost-effective flow of and storage of goods and materials as well as related information, from point of origin to point of consumption for the purpose of alleviating the suffering of vulnerable people" [6]. Logistical operations contribute approximately 80% of disaster relief cost which assist to the most expensive part [4]. It involve the interrelated relation among actors [7] and should be managed properly to receive donor trust and long term commitment [5]. Due to the high influence of the logistical activities to the overall relief performance, the right investment will lead to efficiency and effectiveness of resources utilization in humanitarian operations [5].

In the actual operations, the implementation of the humanitarian logistics becomes more complicated and difficult application. The typical character of the humanitarian logistics is elaborated as below [8]:

- Demand uncertainty, in terms of the demand type and its quantity, the timing, and demand location
- Short lead time and sudden requirement of demand with large amount of needs
- Inadequate resources in terms of supply, human resource, technology, capacity, and financial support
- The lack of infrastructures and safety assurance

Different types of disaster should be precisely managed in different ways [7]. The agile humanitarian logistics should be performed according to the nature of the event. A proper recognition is intended to construct the logistical planning which yields the rapid-efficient relief response.

Indonesia is one of the top five vulnerable countries encountering the catastrophic incidents [1]. Indonesia's current risk index reaches 10.24% with 19.36% of exposure (very high grade), 52.87% of vulnerability, 30.09% of susceptibility, 79.49% for lack of coping capacities, and 49,04% for lack of adaptive capacities [9].

The effect of the geographic and geological circumstances increases the probability of the disaster occurrences in Indonesia. The constant movements of the three tectonic plates, Indo-Australian, Eurasia, and Pacific plates generate seismic volcanoes activities. Moreover, the hydro-meteorological hazard in Indonesia may also cause loss of life, injury, or social and environmental disruptions.

The 2004 Indian Ocean Tsunami has signified the necessity of performing a better preparedness in term of humanitarian logistics efforts. Another great earthquake triggering tsunami, the Sumatra Megathrust, is predicted to surge the Sumatra coastal area within the next few decades [10]. The magnitude of this future potential hazard is expected to be 8 M. The rupture at the subduction zones between the earth's tectonic plates which is known as *Megathrust* faults, will generate a giant earthquake. This displacement will lead to another hazard, tsunami due to its location which is lying under the ocean floor. The future tsunami is expected to inundate the western coast of Sumatra with height 10 meters or more and velocity reaches tens to thousands kilometer/hour. These rare calamities may cause the tremendous effect to human life, infrastructures and material damages as well as the long-lasting impact to the environment. **Table 1.1** defines the worst tsunami hazard prediction including the magnitude, depth of source, distance from the shoreline, the wave magnitude, the degree of inundation, tsunami duration, and the impact to people and infrastructures [11]. The scenario was developed with assumption that the residents were at home when the tsunami comes. The total expected losses are predicted to be similar with the previous Asian tsunami in 2004.

Table 1.1 The Sumatra Megathrust Hazard Prediction [10]

No	Item	Prediction
1	Magnitude	8.8 M
2	Depth	30 Km
3	Distance	150 Km southwest of Padang
4	First wave	10 - 15 m height, arrives in 5 - 10 min (to Mentawai Island)
5	Next wave	8 - 10 m height, arrives in 20 Min (West Sumatra shoreline)
6	Inundation	2 - 3 Km (lowland)
7	Duration	3 - 4 hours
8	Effect	Damaged infrastructures and victims

Regarding to the tremendous effects of Sumatra Megathrust, the Indonesian government through their constitution number 24 year 2007 guarantees the protection and sheltering of Indonesian citizen to provide welfare among victims. Moreover, the local authority of West Sumatra for the disaster countermeasure [11] has developed a comprehensive framework for mitigating the impacts of this upcoming catastrophe, namely the tsunami contingency plan. It encompasses the schematic collaboration among the related parties with the purpose of assisting the immediate relief aids for the beneficiaries. The magnitude and the risk consequences are comprehensively analyzed in order to anticipate the likelihood of the affected victims, infrastructures, and environments. The countermeasure strategies and policies are formulated as follows:

- Optimizing the resources performance in order to fulfill the basic needs of the victims and to give protection to the vulnerable people
- Organizing and coordinating the disaster management operations with the involved stakeholders
- The decentralization of the decision-making process to each province/district in term of the basic needs fulfillment by following the commands from the main organizational structures

The contingency plan contains the establishment of the structural clusters based on the number of the expected victims and the scope of the affected areas as well as the vulnerable aspects in each area. The objective and the main tasks of each sectors are also contained explicitly. Ultimately, there are six assigned sectors based on its activities in the response phase:

- Management and coordination sector
- Search and rescue sector
- Medical sector
- Transportation, information, and communication sector
- Infrastructure restoration sector
- Logistics, receiving and distributing sector

With regard to the importance of the logistical activities in playing a significant role for the successful relief efforts, these substantial elements are strongly required to be considered in the contingency plan. However, the recent contingency plan still misses the deliberation on the detailed scheme in organizing the well-planned humanitarian logistics activities. Hence, a primary concern is referred to the development of the rigorous logistical planning in order to better prepare for encountering the vast consequences of the upcoming event.

During the preparedness stage, the location-allocation problem becomes the strategic aspect in order to find the number of appropriate facilities which have capability to send the adequate relief aids within a short time period [12]. In the post-disaster occurrence, the relief aids (foods, medical kits, clothes, etc) should be immediately dispatched to the affected area. Questions have been raised about the proper transit points for stockpiling these commodities through the last mile stage of deliveries. The ad-hoc methods may result in an inefficient and ineffective response [12]. Consequently, the need of Local Distribution Centers (LDCs) is crucial to manage the large inflow and outflow of commodities. An LDC such as tent, prefabricated unit, school, etc is usually constructed in the aftermath of disaster. Several aspects including the dynamic increment of demand requirements, the relative distance between depot to its demand points, and the fixed opening cost should be under consideration for the establishment an LDC. Moreover, the expected impassable road based on the worst inundation scenario may complicate the location-allocation decision. Some demand points may be remotely inaccessible due to the road disruptions. The anticipation manner should be prepared in this stage either by restoring the road or utilizing another transportation mode. Subsequently, the activation of the preparedness plan on the selected depot and the quantity allocation of relief items to be sent to each recipients will be actualized during the response phase.

The logistical activities in the relief response comprises the operational tasks which corresponds to the location-allocation outcome in the strategic phase. In this phase, the relief distribution strategy is prominently necessary to obtain the optimal relief routing and assignment solution. Since disaster is an unreliable phenomenon, the post-occurrence of disaster may generate stochastic conditions. The actual demand requirements may vary from the expected approximation. In the same vein, the road restoration time as well as the vehicle velocity may be uncertain. In term of the time restriction, the restricted operational time due to safety and security factors may affect the relief vehicle requirement and utilization. Hence, a robust distribution strategy is essential for encompassing these constraints.

The Sumatra Megathrust issue generates the complex-unique aspects to be considered in determining the proper logistical operations. Performing the rapid-appropriate relief assistance means to save lives. Therefore, the development of an agile humanitarian logistics planning by incorporating the strategic and operational decision is encouraged.

2. Previous Works

This section discusses the previous related studies in the location-allocation problem, relief vehicle routing and assignment, as well as the integrated research in combining both steps.

2.1. Location-Allocation Problem

Numerous studies on the location-allocation problem have been carried out to determine the suitable facility locations aiming to improve the effectiveness of the relief response. The heuristic method proposed by Jia et al., [13] attempted to obtain number of appropriate facility with the maximal coverage analysis with consideration to the service quality. Their research examined three heuristic models in order to yield the best-suited solution. The determination on the facility location problem with the prepositioning decision is proposed by Balcik and Beamon [12]. The maximal coverage analysis is utilized with constraints to the multiple commodities, limited funding, and capacity restriction. Another research, the strategic planning on the selection of the buffer post as well as the allocation problem for encountering catastrophic hazard is suggested by Ariyana [14]. Their model encompasses the three-tier supply chain with objective to minimize the fixed opening cost, transportation cost, and inventory cost.

The employment of applied technologies in the location-allocation planning is widely used to generate a scrupulous solution with a relatively short computational processing time. Recently, the researchers have shown an increased interest for utilizing the Geographic Information System (GIS) due to its advantages in acquiring more accurate spatial information (road networks, geographic barriers, etc)

[15]. In 2005, Prathumchai and Samarakoon [16] developed the location-allocation strategy for the placement of the evacuation shelters as well as the evacuation assignment based on flood case. Three indicators are considered including the physical provisions, topography, and accessibility. The Decision Support System (DSS) based on GIS to determine the fire evacuation shelters has been suggested by [17]. P-median analysis is conducted by taking into account four criteria; distance, road barriers, fire risk at shelters, and evacuation time. Their studies were examined for the major fires at Coimbra City, Portugal. The extended work of their model by adding secondary (backup) evacuation routes is provided in [18]. Their mixed integer linear programming model determines the evacuation routes, the located facilities, and the evacuation assignment. Similarly, another P-median model in facility location problem by utilizing GIS tool is investigated by Wu et al., [19]. The disaster occurrence accompanied by its second hazard is characterized in their model. The accessibility, safety, and effectiveness are contained in locating-allocating the facilities-number of evacuees.

2.2. Relief Delivery Assignment

Several researchers have sought to formulate the relief routing and assignment planning as a principal guidance to conduct a quick-exact supplies deliveries during the response phase. A two-stage stochastic programming on the last mile distribution problems by addressing the vehicle routing and supply allocation decision was introduced by Barbarosoglu et al., [20]. The uncertain factors; supplies, demands, and network arc capacities are considered to develop a set of transportation scenarios. The examined model is based on the earthquake disaster in Marmara, Turkey. Ozdamar et al., [21] demonstrated the Decision Support System (DSS) based on relief routing by treating deterministic manner. Their DSS model considered the alteration of the demand requests, supplies and transportation modes which may change during the response phase in order to define the suitable periodical routing assignment. Similarly, the deterministic model in delivering relief commodities is contained in [22]. Their model focused on the last mile delivery during the incorporated planning horizon. The authors developed a mixed integer programming model by splitting the demand into two categories and non-homogeneous freight for handling the relief commodities. The fairness concept is represented by charging the associated penalty cost for shortage supplies. The two-phase heuristic method to minimize the total travel time and penalty cost of the unfairness fulfillment was undertaken by Hsueh et al., [23]. The routes are predetermined in the pre-disaster to be further extended in the post-disaster event with consideration to the real-time information after the disaster surges. In their research, the emergency levels of each demand nodes will be counted to decide the nodes that will be visited by each relief vehicle. Similar approach for generating the pre-determined routes and the adjusted routes is provided in the work of Shen et al., [24]. The authors applied their method in the large-scale bioterrorism attack. Their work calculated the effect of demand uncertainties and unknown travel time to design a robust relief distribution strategy. The same authors [25] published the Mixed Integer Programming (MIP) model to minimize the unmet demand under the stochastic situations. They utilized tabu heuristic to solve the relief routing problem under the randomness of demand and travel time. Ultimately, they compared the effectiveness of the deterministic case and the chance constrained model to obtain the best solution.

In recent years, the use of simulation method has been rapidly developed to the field of relief aid distribution. In 2009, the simulation framework for optimizing relief supplies to a number of point of distributions (PODs) was conducted by Lee et al., [26]. Their simulation framework involved the relief supply chain, the distribution activities at PODs, the dynamicity of demand, and the disaster progression. By allowing the cross-leveling among PODs, their analytics simulated the dispatching efforts to various PODs. Barahona et al., [27] studied the simulation-optimization in obtaining the optimal stocking decision and relief supplies delivery during the response phase. Their model accommodates the multi-tier relief supply chain to face catastrophic events. The results of their simulation research generate the optimal policies of stocking the relief goods at the multi stage facilities as well as the relief routing and assignment. Another simulation method by concerning on the uncertain travel time to obtain an appropriate relief routing decision was involved in [28]. The @Risk Simulation software is used to generate the possible route based on the travel time probability between each node. In 2016, a typical characteristic of the information sharing together with the relief delivery activities is portrayed by Miyakita et al., [29]. Their work modeled the epidemic transmission whereas the relief vehicles transporting the commodities receive the information from the shelter to be shared to another shelters. They used the computer simulation to analyze the effect of the additional waiting time for exchanging the information to the delay of relief goods delivery. In their case study of earthquake in Taiwan, Lionardo and Nouaouri [30] proposed simulation approach on the relief distribution strategy by concentrating on the effectiveness and fairness accomplishment. They used the centralization of the relief system through the distribution center in order to avoid the imbalance supply-demand. They concluded that their method can improve the performance of relief delivery as well as the well-organized coordination among the relief supply members. Recent studies by Fikar et al., [31] highlighted an agent-based simulation-optimization for dynamic disaster relief distribution. The uncertain condition in the transportation network during the post-disaster incidents is delivered by interaction between agents (people). This word of mouth information is further processed to select the optimal distribution points and the vehicle type by using bi-objective optimization. Their model is tested on the earthquake case in Nepal.

2.3. Integrated Location-Routing Problem

Recent development in the humanitarian logistics have heightened the need for integrating the strategic decisions with the operational operations. Mete and Zabinsky [32] carried out the stochastic approach to optimize the storage points as well as its inventory level during the preparedness stage as well as vehicle loading and routing decision during the response phase. Their modelling approach considered the delivery of medical supplies under the possibility occurrence of several hazards. The work of Rennemo et al., [33] presented a three-stage integer stochastic programming model by incorporating the location-allocation problem with the last mile delivery decision. Their research considered the availability of relief vehicles, infrastructures, and demand requirements as stochastic elements. The equity considerations were included by providing greater attention to the most needed beneficiaries. The investigation on the multi-depot location-routing problem was assessed by Ahmadi et al., [2]. They firstly built the base case of the location-routing model in deterministic manner to be further extended to the stochastic programming based on the uncertain network disruptions. Their finding claimed that the number of local depots and the relief vehicle significantly affect to the decrement of the unsatisfied demand. In the subsequent work, Patrisina et al., [34] the two-stage location-routing method was depicted for encountering the Sumatra Megathrust hazard. Their deterministic model comprised the three-tier relief distribution supply chain. In the location-allocation stage, they calculated the fixed opening cost, transportation cost, shortage cost and penalty cost to be minimized. Meanwhile, minimizing total routing cost was the objective for their second stage. In their work, they examined two relief distribution strategy; pure strategy and mixed strategy. They argued that the mixed distribution strategy generated better result in term of routing cost.

3. Point of Statement

Due to its severe impacts to the society and environment, the Sumatra Megathrust issue has been becoming a major interest to provide a better effort mainly in the humanitarian logistics activities. Badan Penanggulangan Bencana Daerah (BPBD), the local legitimated authority for disaster countermeasure, has developed the contingency plan for facing the consequences of this future hazard [11]. Despite of its conscientious contents, the recent contingency plan still misses the logistical scheme particularly in the location-routing planning. This lack of consideration may lead to an ineffective response [35]. Recent studies (e.g. [14], [34]) attempted to accomplish this deficiency in order to propose a considerable development. However, improvement should be made through several aspects:

1. Strategic level
    - *Demand characteristic*. The demand characteristic fundamentally affects to the decision-making process in both strategic and operational level. During the emergency period, the demand requirements genuinely depend on the number of evacuees arriving at a shelter. The evacuees' arrival may vary in each day and evolves over the planning horizon [36]. Hence, this tendency will require the need of the dynamic supply chain planning.
    - *Stochastic environment*. The complexities arising in the aftermath of disaster may be generated by several uncertainties in term of demand, road restoration

time, and vehicle velocity. These stochastic elements are significant to be accommodated in designing a robust operational framework.

- *Relief distribution strategy*. Most of the previous research assumed that the relief aid fulfillment will be equal over the planning period. However, the different amount of the demand requirements per day implies to the different relief fulfillment quantity. As a result, this may generate another best-suited distribution strategy.
- *Expected impassable path*. In the post tsunami occurrence, the debris may be resulted along the inundation area which may hamper the relief distribution process. Therefore, designing a safer route by avoiding the road under the inundation area is required.
- *The expected remote areas*. Some demand points may be remote due to no road access connecting to the assigned depot. To face this potential incident, an anticipation plan should be defined in the strategic level, either by restoring the road or utilizing another transportation mode.

2. Operational level
   - *Relief routing.* The strategic plan results in the allocation plan between the selected depot to its recipients. In the location-allocation decision, a depot usually serve its assigned area. However, during the operational stage a demand point can also be served by another depot in order to minimize the total travelling time and relief vehicle utilization.
   - *Time windows*. Due to the safety and security factors, the operational time for distributing the relief aids may be limited. Subsequently, the relief delivery operations should be accomplished within the restricted working hours.

Designing an appropriate logistical framework under the complex environments is challenging to perform an effective and efficient response. This work seeks to construct a strategic-operational logistics planning by taking into account those missing aspects. By integrating the location and routing analysis, this research is expected to yield a better-realistic outcome. However, in the incorporated location-routing literature, the implication of a joint model in the optimization and simulation methods is still absent [37]. With regard to the comprehensiveness of combining the optimization and simulation approach in order to assist the relief stakeholders by the effectiveness of the solution provided, it is important to analyze some different scenarios and to assist the efficacy for analyzing the response plan and policies effectiveness in the relief efforts.

4. Research Objective

This research aims to develop a two-stage humanitarian logistics strategy involving the location-allocation planning during the preparedness phase and the relief routing and assignment planning in the response phase. The integrated strategic-operational framework is intended to be applied for facing the potential hazard, Sumatra Megathrust. The methods occupied in this work consist of the joint model of optimization and simulation techniques. The optimization method is utilized to solve the location-allocation decision by utilizing the Geographic Information System (GIS). Meanwhile, the relief distribution decision is solved by using the simulation method.

5. Research Scope and Assumption

The scope of this study is deliberated as below:

1. The research comprises the humanitarian logistics tasks including the location-allocation problem which prevails in the preparedness phase and relief routing and assignment which is aimed to be implemented in the response phase.
2. This work is prepared to anticipate the consequences of Sumatra Megathrust hazard.
3. Padang City is selected for the study case for at least two reasons: 1) Padang is estimated to be the city with the biggest amount of the affected people [11], 2) Referring to previous major earthquake in 2009, the lack of efficiency due to a large number of affected victims signifies the need of a rapid-appropriate logistical planning in Padang City [14].
4. This work is specified for the fulfillment of the basic needs particularly the consumable commodities.
5. Since the 72 hours is considered as the critical period [4] [2], this takes into account the strategic and operational decisions during this short-term fulfillment.

6. In term of the road recovery efforts, the restoration activities are intended to clean the debris or muds resulted by the tsunami inundation.

6. Research Benefit

This research is proposed to assist contributions in the following terms:

1. The relief aid managers and stakeholders; This research provide a concrete solution by accommodating substantial aspects with the capability to be implemented during the response phase in order to reduce human suffering or death.
2. Research and development; This research proposes the relief location-routing with a comprehensive analysis to the nature of event which result in more realistic solution. Moreover, the analytical framework used in this research can be utilized to face the other type of calamities by modifying some minor assumptions.

CHAPTER 2

THEORITICAL FRAMEWORK

The main issues addressed in the theoretical framework are about terms and activities related to disasters, earthquake and tsunami event, issues in disaster management, humanitarian logistics, and business logistics, the minimum standard fulfillment, and the essence of operations research and computer simulation.

1. Terms and Activities Related to Disaster

Vitoriano et al., [8] defined hazard as a probability occurrence of a threatening event accompanied by its potential damage within a given time period and area which is classified to natural or human-made.

a. *Natural hazard*: Physical phenomena which occurs naturally caused by either rapid or slow onset events such as geophysical, hydrological, climatological, meteorological, or biological (earthquakes, landslides, tsunamis, volcanic activity, avalanches, floods, extreme temperatures, droughts, wildfires, cyclones, storm/wave surges, disease epidemic, animal plagues, etc.).
b. *Human-made* or *technological hazard*: events which occur in (or close to) human settlements with humans as a cause of this incident.

Emergency is described as situation which generates an immediate risk to health, life, property, or environment [8]. The disruption hitting a system or community and affects its normal function, causes a strong impact on people, structures, and environment, and goes beyond the local capacity of response is defined as disaster [8]. In the same vein, Wassenhove [4] determined disaster as ‘a disruption that physically affects a system as whole and threatens its priorities and goals’. Meanwhile, the Indonesian constitution number 24 year 2007 describes disaster as disruptive event causing losses in physical, environmental, psychological, or even losses of life [38]. Another term in disaster is catastrophe which is considered as extremely large-scale disaster [8].

Balcik and Beamon [12] elaborated the activities executed by relief organization after the disaster occurrence:

a. *Assessment*. Survey conducted by the relief organization to assess the impacts generated by disaster in disaster areas for predicting the amount of relief items required by survivors. An off-logistician will receive relief assessment result to be translated into supply requirements.
b. *Procurement*. Within 36 hours after disaster, a preliminary appeal for donations of cash and relief supplies is made. Relief supplies will be mobilized after donors respond and the appeal is funded. Firstly, the logisticians procure the supplies from local sources, or check the available supplies in their warehouse (in case if they own a centralized warehouse). Anything that cannot be fulfilled by themselves, will be procured from global suppliers through competitive bidding because there are usually multiple suppliers supplying a single relief organization for each effort.
c. *Shipping*. The goods are shipped to the disaster site by considering disaster location, the shipping capabilities of the supplier, and the negotiated contract.

2. Earthquake and Tsunami

International Federation of Red Cross (IFRC) defines earthquake as a sudden break within the upper layers of the earth resulted by forces generated by the earth's interior which causes to surface breaking, vibration of the ground, and sometimes may cause to the collapse of building, losses of life, and destruction of properties [39]. **Table 2.1** classified the earthquake frequency based on its magnitude. The modern seismographic networks are utilized to measure millions of earthquakes happening every year, but over 99% of these disasters are small in scale and pose no danger.

Table 2.1 Earthquake Frequency [40]

Description	Magnitude (M)	Energy Released (ergs)
Great	> 8.0	$>5.8 \cdot 10^{23}$
Major	7.0 - 7.9	$2 - 42 \cdot 10^{22}$
Strong	6.0 - 6.9	$8 - 150 \cdot 10^{20}$
Moderate	5.0 - 5.9	$3 - 55 \cdot 10^{19}$
Light	4.0 - 4.9	$1 - 20 \cdot 10^{18}$
Minor	3.0 - 3.9	$1 - 26 \cdot 10^{15}$

Tsunami is caused by rapid displacement of the body of water (ocean, lake) triggering a series of wave which is characterized by very long wavelength and much smaller amplitude offshore [41]. Tsunami velocities may reach hundreds kilometer per hour, depends on the depth of the source under sea level. Meanwhile, the tsunami height increases along with its distance to the coastline. Tsunami can be affected by several disturbances but 90% of them is affected by earthquake. Briefly, tsunami can be originated by such events [42] :

a. *Undersea landslides.* Undersea landslides are described as the occurrence of a big crust movement between the tectonic plates boundary. The cracks between these tectonic plates are called faults. The subductions between ocean plates and continental plates will result in earthquake subduction which effectively trigger tsunami.

b. *Undersea earthquake*. The tectonic earthquake is usually caused by earth's plates movement. In case of undersea occurrence, the water movement above the plates causes displacement from its equilibrium which can generate tsunami. Subsequently, the requirements of tsunami occurrence caused by tectonic earthquake is characterized as follows:
   - The earthquake is centered in the middle of the sea with low depth (0 – 30 km)
   - The magnitude of earthquake is at least 6.5 of Ricther Scale
   - The type of earthquake fault; thrust/reverse fault

c. *Volcanic activities*. The plates movements over the seabed can trigger both earthquake and volcanic activities. In addition, volcanic activities in the ocean floor will also raise tsunami wave.

d. *Cosmic-body impacts*. The cosmic-body impacts occurring in the sea territories will affect to tsunami event. The tsunami triggered by these activities usually happens rapidly and rarely affects to the coastline. Nevertheless, terrible phenomenon of cosmic-body impacts will potentially trigger to mega-tsunami event.

3. Disaster Management, Humanitarian Logistics, and Business Logistics

Disaster risk management is aimed to avoid disaster, reduce its impact, or recover from its losses by summarizing all activities, programs, and measurement which can be taken up before, during, and after disaster occurrence [43]. Based on the disaster occurrence, the disaster management is divided into two phases. The pre-event phase starts from predicting and analyzing the potential hazards in order to prepare the action plans aiming to mitigate the disaster consequences. Meanwhile, locating-allocating, coordinating and managing the available resources for performing the relief aids delivery is conducted during the post-disaster event [3].

The decision-making process of the disaster management changes over time from before and after disaster event. The context related-uncertainties and time pressure as well as the nature of decisions and the criteria of the involved actors may vary from one situation to the other. This has led to distinguish four successive phases of the disaster management as depicted in **Figure 2.1**.

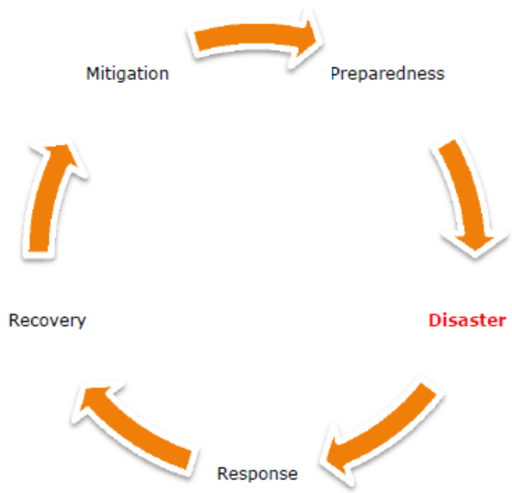


Figure 2.1 Disaster Management Cycle [3] [44]

a. *Mitigation*. This phase is aimed to prevent and mitigate the consequences of a future disaster by performing all the middle and long-term actions and decisions. The tasks in mitigation include the coding and zoning of the vulnerable buildings, analyzing the vulnerability, and conducting the public education.

b. *Preparedness*. Once the upcoming adverse phenomenon has been predicted until it finally strikes, all the short-term interventions are implemented at preparedness phase. It involves setting emergency systems and evacuation plans, the real-time tracking of the hazard, the analysis of the most probable scenarios, the reinforcement of critical infrastructures, etc. Preparedness phase also includes some long-term decisions including inventory prepositioning and network design preparedness which takes place before disaster occurrence after one area has identified by a threatening hazard. Serious problems are considered to be potential impact of lack preparedness as follows [35]:
   - Poor coordination and cooperation in emergency response
   - Difficulties to determine the needs for rehabilitation and reconstruction
   - Importance of having resilience of local government and community
   - Underutilized science and technology in early warning system
   - Unclear assignment to the stakeholders
   - Lack of fairness in disaster relief operation

c. *Response*. High emergency and high uncertainty will be barriers in the response phase in order to save lives in the aftermath of disaster. It is divided into stages including first response phase; rescuing and assisting urgent medical aids for injured and affected people, and middle-term response phase; estimating and mitigating the potential unattended first needs of the affected population as a result of possible damage to the life-line infrastructures and resources. In the mid-term response phase, the delivery of aids from outside of the affected zone is executed during the emergency periods, depends on its nature and magnitude as well as the economic and development circumstances of the affected country.

d. *Recovery*. The recovery activities contain all long-term actions and decisions aimed to restore the normal function of the affected community and the reconstruction of the social fabric, including life-lines resources, services and infrastructures, and other necessary improvements. This phase focuses to achieve efficiency which is associated with the long duration with low emergency and low uncertainty.

In disaster management context, the logistical efforts play a significant role in saving lives. Patrisina [35] illustrated the relationship between disaster management and humanitarian logistics. It shows the main coherence between disaster management and humanitarian logistics in the preparedness and emergency response stage. Establishing facility locations such as warehouses, allocating the required relief items, prepositioning the stock are considered in the preparedness stage. During the emergency response, the relief goods are distributed by considering the shipment size, transportation modes, and relief routing decisions.

The concept of logistics in humanitarian deals with identical activities to fulfill their customers' needs promptly [6]. Rennemo et al., [33] referred the humanitarian logistics to the function dealing with the distribution process of required aid and supplies in disaster relief situations. In humanitarians, activities of mobilizing people, resources, skills, and knowledge are processed systematically to help vulnerable people [4]. Minimizing human suffering and death has to be a truly intention by providing appropriate emergency supplies to the people affected by disaster [22]. Efficiency and effectiveness of people or commodities reaching the victims are necessary to be considered in the time of disaster [7].

Different customers lead to different designs and strategies adapted by stakeholders. The comparison flow between humanitarian logistics and business logistics is shown by **Figure 2.2**. Differ with the business logistics chain, the main contributors for humanitarian logistics come from suppliers, in-kind donation, and relied on available stocks in warehouse. These supplies from various locations worldwide are then shipped to primary hub located usually in harbor or airport [45]. Before its arrival to Local Distribution Centers (tertiary hubs located near evacuation camps), the supplies are stored and sorted in the secondary hub which is usually located in the large city. From Local Distribution Centers (LDCs), supplies are finally delivered to beneficiaries. This final stage is also called as last mile distribution activities. During the last mile delivery, the limitations associated with the availability of the transportation modes as well as the available amount of supplies, the infrastructures disruptions, and the lack of coordination between the related stakeholders become the major factors for providing a quick-decent distribution plans [22].

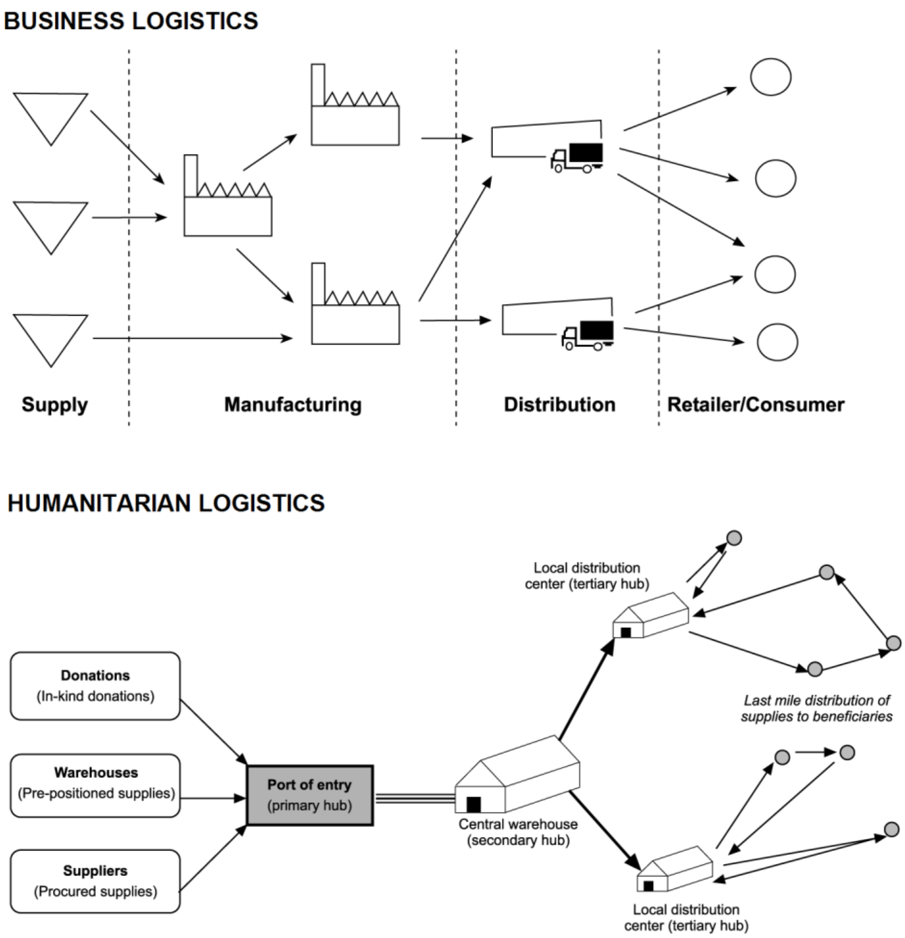


Figure 2.2 Comparison Between Business Logistics and Humanitarian Logistics [45]

Concisely, the performance measurement between humanitarian logistics and business logistics can be stated as follows [45]:

a. *Strategic goals*. The strategic objectives of business logistics are mainly centralized on cost reduction (minimizing costs associated with item movement and storage), capital reduction (maximizing return on logistics assets while minimizing investment in logistics), and service improvement (increasing revenue by maximizing value provided to customers) which corresponds to customers' goals and values. Unlike business logistics, humanitarian logistics are aimed to save lives and reduce human suffering by considering financial constraints. Mission effectiveness and financial sustainability are carried out by humanitarian stakeholders to deliver relief aid to beneficiaries.

b. *Demand characteristics and order fulfillment for quick-onset emergencies*. While the demands needed in business logistics are related to products and services, the required demands in humanitarian logistics are supplies and people. Supply chain model in commercial logistics are relatively stable, predictable in term of demand patterns, fixed locations in set of quantities, and fixed (and often certified) suppliers receiving regular interval orders. Instead, demand requirements in humanitarian logistics should be estimated after they are needed (based on assessment of disaster characteristics) due to the random events regarding to disaster characterized by uncertainty in terms of timing, location, type and size. Type and impacts of disaster take a role as the decisive factors which lead to various supplies' requirements. Regarding to these distinctions, demand patterns become the main difference between humanitarian logistics and business logistics. Moreover, the order fulfillment process of the relief chain and commercial logistics forms unique patterns related to such factors:

- *Lead times*. After the disaster occurrence, the demands are necessary to be fulfilled immediately (zero lead time), while in commercial logistics, customers usually accept the lead time between the time they order to the arrival of the shipment.
- *Reliability of the transportation system*. Unreliability of transportation modes and transportation routes makes it difficult to be established due to demand location uncertainty. In contrast, commercial logistics performs availabilities of the reliable distribution channels to be established and occur constantly.
- *Pricing*. For business logistics, pricing is relatively stable over a reasonable time horizon. Meanwhile, the commodity price increases dramatically due to unpredictable occurrence of disaster.

c. *Customers characteristics.* The difference between humanitarian logistics customers and commercial logistics customers affects to its performance measurement. In commercial logistics, individuals or organizations are expected to be customers receiving the products. In humanitarian, aid recipients or disaster victims used to be beneficiaries of humanitarian assistances.

Humanitarian logistics activities are formed by relationship between various actors with their own heterogeneous cultures, purposes, interests, mandates, capacities, and logistics expertise contributing to its typical tendencies. As shown in **Figure 2.3**, the key actors involved in humanitarian relief chain includes [7]:

a. *Governments*. The governments (host governments, neighboring country governments, and other country governments) are the activators of humanitarian logistics since they have authorities for operating and mobilizing resources after a disaster strikes.
b. *Military*. Soldiers often provide primary assistance in humanitarian logistics such as hospital and camp installations, telecommunications, and route repair. Due to their high planning and logistics capabilities, military becomes one of important actors in humanitarian assistance.
c. *Aid Agencies*. Many aid agencies including global actors (such as World Food Programme) and regional actors are able to collaborate with governments in order to alleviate human suffering caused by disaster.
d. *Donors*. Generally, donations consist of two types which provide the vast funding for major relief activities, including:
   - In-cash donations: giving direct financial supports
   - In-kind donations: providing goods and/or services for free
e. *NGOs*. Some of Non-Governmental Organizations are temporary which is created just to address one particular crisis while some of them are influential and international players, such as CARE (Cooperative for Assistance and Relief Everywhere).
f. *Companies*. In the aftermath of disaster, companies are able to provide technological support, logistics staffs and managers, and also specific services that may no longer be available on the ground such as electricity supply, engineering solutions, banking support, and postal services.
g. *Other companies*. Due to their logistics and supply chain management core capabilities, logistics service providers become excellent contributors at each stage of a disaster-relief operation. In terms of the resources, assets, and knowledge shared with their humanitarian counterparts, they genuinely enhance the speed and

efficiency of relief efforts. Some of them are known as Agility, DHL, FedEx, Maersk, TNT, and UPS.

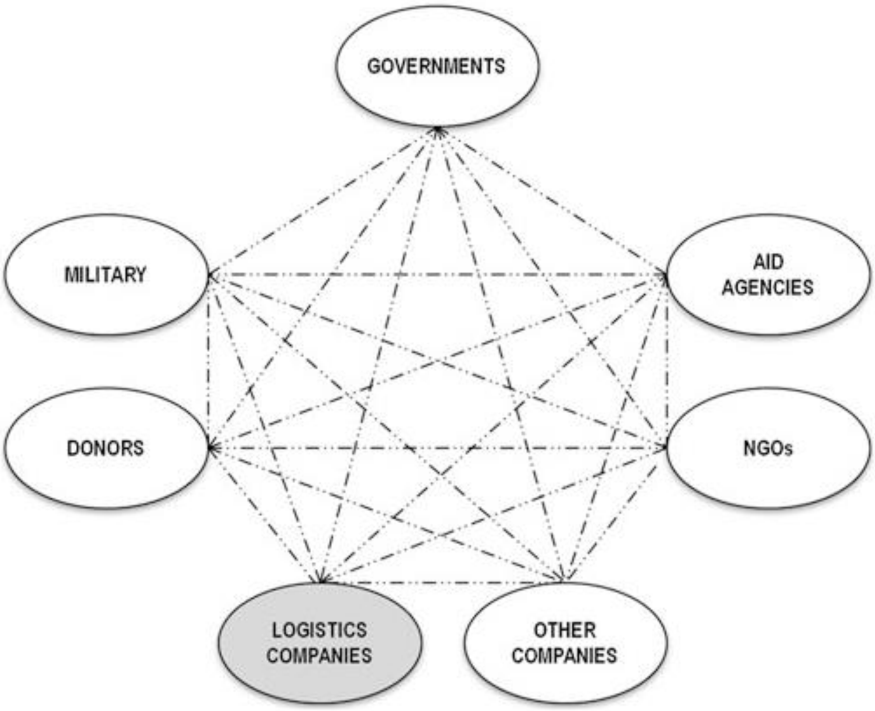


Figure 2.3 Humanitarian Relationships Model [7]

In relation with their involvement in disaster response, there are three levels of actors involved in humanitarian operations [8]:

a. *Local level*. Usually addressed by local agencies, civil societies, organizations, and civil protections in order to address the first response level in disaster. Normally, this level is not declared as a disaster.
b. *National level*. This emergency event is typically defined as disaster which involves participation of many stakeholders such as military, national civil protection, governmental organizations, NGOs. Sometimes, the international organizations with local offices also take part in this level.
c. *International level*. This level is reached when national capacity is not adequate enough to handle such kinds of disasters due to the scale of disaster and/or vulnerability of the country. The host government of affected country authorizes an international humanitarian operation. OCHA (Office for the Coordination of Humanitarian Affairs) and the IASC (Inter-Agency Standing Committee) usually coordinate the other international actors such as foreign governments, inter-

governmental organizations, international NGOs, and the United Nations Agencies to take places for assisting help.

4. The Minimum Standard of Relief Aid Fulfillment

The minimum standards for estimating relief demands are needed to obtain the number of relief supplies to be delivered periodically and to assist equitability among victims. West Sumatra government for disaster countermeasures [11] has identified minimum standards fulfillment involving:

a. Food
   - Rice with side dishes equal to 400 gr/person/day
   - 2 times feeding/person/day
   - Total calories of food equal to 2.100 kcals/person/day

b. Non-Food
   - Cooking set and tableware
   - Stove with fuel and lighting equipment
   - Tools and equipment

c. Clothing
   - Personal clothing
   - Hygiene kits

d. Water supply and sanitation
   - Water supply
     - Water needs 7 liters/person/day (first 3 days), 15 liters/person/day (rest days)
     - Good qualities of water without health impact
   - Sanitation
     - 1 trash can with 100 liters in size for 10 households
     - 1 water closet for 20 persons
     - The distance between water closet and septic tank at least 30 m from water spring
     - The septic tank substructure does not exceed 1.5 m above the water spring and does not leak

- Area for washing clothes and household appliances should be within 100 persons of maximum capacity

5. Victims' Arrival and Demand Characteristic

As the earthquake which potentially triggers the giant tsunami takes place, the local government will announce the evacuation order to the assigned safe place. The safe place belongs to two categories [46]:

a. *Temporary evacuation shelter*. The vertical building or highland which is relatively higher than the expected inundation height.

b. *Final evacuation point*. Usually an area or building which is located outside the expected inundation territory around 3-5 km away from the shorelines.

The evacuation plan designed by BPBD [46] has addressed two consecutive terms in the evacuation assignment, during 20 minutes in aftermath of the earthquake and after the tsunami recedes from inundating the area as illustrated in **Figure 2.4**. The first term, namely escaping period, is designed by utilizing the clustering method whereas the potential affected people are assigned to their relative closest point, either to a temporary evacuation shelter or directly to the final evacuation point. Meanwhile, the post-inundation term is intended to the assignment of the survivors from the temporary evacuation shelter to evacuate themselves to a given final evacuation point. In the post-tsunami inundation, the final evacuation point will act as the demand point which will receive the relief goods from its associated depot.

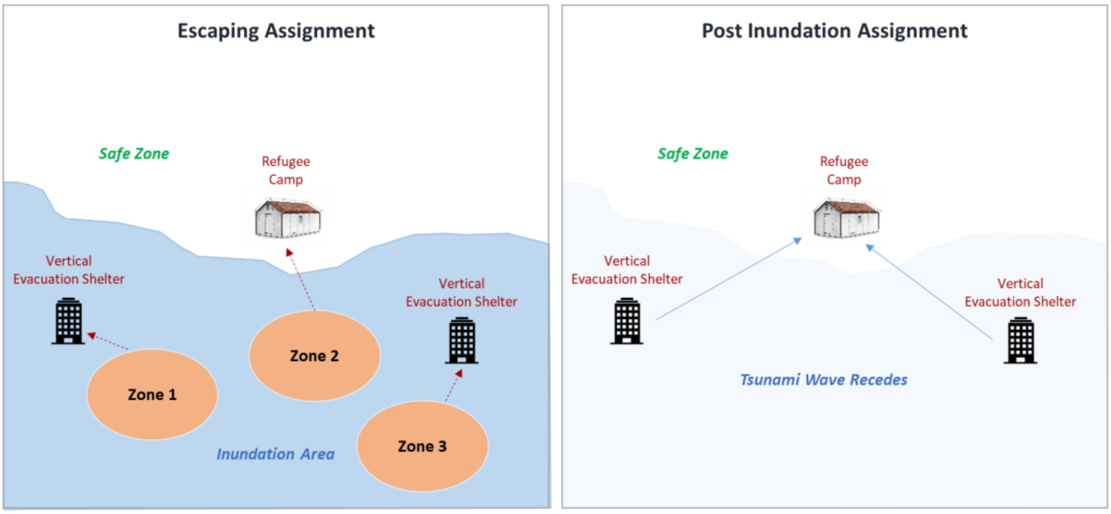


Figure 2.4 The Two Term Evacuation Assignment

During the relief aid fulfillment, the victims' arrival will significantly affect to the number of required demands. As shown in **Figure 2.4**, the number of evacuees assigned straightly to the final evacuation point (e.g. zone 2) during the escaping term will be acknowledged to be a certain amount. The needs of this category will remain constant over the planning period. The number of victims' arrival in the post-inundation assignment, however, will vary and evolve over the emergency periods. In the post-inundation event, the survivors may be required to walk to the designated refugee camps since there may be no available vehicle to fetch them. Moreover, some of survivors may be caught in the wreckages. Another factor, such as the family relationship in the West Sumatra [35] may influence the survivors to postpone their movement since they have to take care their relatives who may be injured or killed as the effect of the tsunami.

The needs of the consumable items can be related to the victims arrival function [36]. Referring to Rawls et al., [36] and Song and Yan [47], the victims' arrival pattern in the post-disaster event follows the S-shaped curve. In this research, however, we adjust the curve to be combined with constant number reflecting to the two term of the victims' arrival at a given demand point. An illustrative example, **Figure 2.5**, describes the combination curve between the S-shaped pattern and the constant pattern. The periodical peak point of the cumulative amount of these pattern will be used to determine the strategic and operational decision that will be implied to deal with the Sumatra Megathrust consequences.

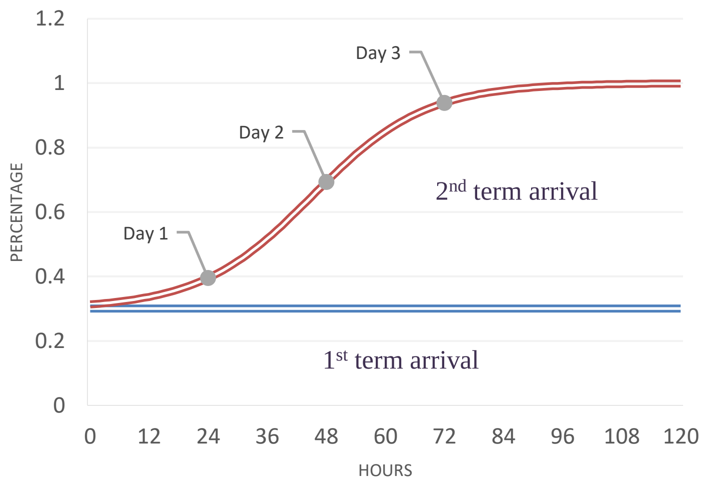


Figure 2.5 Victims Arrival Pattern [48]

In the disaster aftermath, it is crucial to fulfill the beneficiaries' needs during the first three days of the emergency periods [4] [2]. The variation of the required demand in each day will significantly affect to the decision in the strategic and operational level. Providing an appropriate relief aids during these critical days means to saving lives and reducing the human suffering. Therefore, the main focus is concerned to the short-term demand fulfillment.

The aspect ratio of the cumulative victims' arrival at a given demand point in the first three days is presented in **Table 2.2**. As mentioned before, the ratio of the first term arrival will reach its total number of the assigned evacuees. This number will be constant over the planning period.

Table 2.2 Aspect Ratio of the Cumulative Victims' Arrival [47]

Term of Arrival	**Arrival Percentage**		
	24 hrs	**48 hrs**	**72 hrs**
1st term	100%	100%	100%
2nd term	13.588%	56.161%	91.256%

6. Operations Research and Computer Simulation

Operations research (OR) is an interdisciplinary branch of applied mathematics and formal science to arrive at optimal or near optimal solutions to the complex problems by using methods like mathematical modeling, statistics, and algorithms [49]. An OR study can be divided to the following seven phases [49]:

a. *Formulating the problem*. Defining the organization's problem is the first step held by OR analyst. Before solving the problem, the OR analyst should firstly specify the objectives of organization and its parts (or system).
b. *Observing the system*. After the problem has been formulated, the OR analyst should estimate the values of the parameters that affect the organization's problem by collecting data.
c. *Formulating a mathematical model of the problem*. Next, the estimation about the problem will be developed through an idealized representation such as developing mathematical model of the problem.
d. *Verifying the model and using it for prediction*. The mathematical model developed in step 3 will be further verified to ensure that the model represents an accurate

condition of reality. This step observes the parameters of the system assuring the correct parameters used by OR analyst. OR analyst will go back either to step 3 or step 2 if the model does not represent the reality.

e. *Selecting a suitable alternative*. The OR analyst now choose the alternative that best meets the organization's objectives by using given model and set of alternatives.
f. *Presenting the results and conclusions*. The organization's decision-makers will receive the model and recommendations presented by OR analyst. If the decision-makers do not approve the recommendations which may be resulted from incorrect definition of the organization's problems or the parameters or the mathematical model, the OR analyst may go back to step 1, step 2, step 3, depends on where the disagreement lies.
g. *Implementing and evaluating recommendation*. Finally, the OR analyst helps to implement the recommendations after the organization accepted the study with constantly monitor and update dynamically along with the changes of environment.

Simulation tools is one of the OR techniques used to study real-life systems by quantifying the performance of a system under study for various values of its input parameters which can be useful in the managerial decision process [50]. Because it is such a flexible, powerful, and intuitive tool, simulation ranks very high among the other widely used techniques. It is also useful to analyze stochastic systems with randomness of event occurrences [51]. The process is generally preceded and followed by the same steps of operations research. Each step can be evaluated by their earlier steps when the simulator finds obstacles with the current step.

The use of simulation in the disaster relief operations has some advantages which are described as follows:

a. It allows the dynamicity of the tactical and operational development in the disaster relief operations particularly the logistic field [52]
b. Simulation is useful for evaluating the new strategies and policies which would be implemented in the relief efforts by allowing the wide range of the disaster scenario and stressors [53] [27]
c. In simulation, virtual display of the physical environment for developing the analytical model is enabled [53]

d. Since the actual disaster will be too difficult and risky, simulation plays a significant role as the test-bed experiments [53]

7. The Integrated Method of Optimization and Simulation

In the disaster relief supply chain field, the utilization of the optimization methods for the location-allocation decisions and simulation approach for defining the appropriate relief distribution are widely applied [37]. During the post-disaster occurrence, the need of locating an appropriate location of the Distribution Centers (DCs) as well as the allocation of the relief commodities to be shipped are important to be optimally solved. The constraint on the disruptions probabilities of the relief facilities must be taken into account to serve the disaster victims with the minimization of the corresponding operational and logistics costs. Meanwhile, the effectiveness of the associated strategies and policies should be tested and improved by applying the simulation methods. Due to the importance of the disaster relief operations, a proper decision-making effort can be gained through the application of simulation manner. However, the research in the integrated model of the optimization and simulation methods for the location-routing decisions is still absent. Therefore, the development of this joint model is necessary to provide agile solutions.

8. Location-Allocation Model

The location-allocation problem with the maximal coverage analysis is basically developed by Church and Revelle [54]. Referring to Alexandris et al., [55], the maximal covering location problem (MCLP) model is expressed as follows:

7.1. Notation

Indices

i index for demand points

j index for candidate locations

Parameters

d_{ij} distance from i to j

D_i distance standard for demand point i

w_i coefficient reflecting the desirability of covering demand point i

Sets

I set of demand points

J set of all candidate locations

$N_{(i)}$ set of locations that can cover demand point i:

$N_{(i)} = \{j\text{-}d_{ij} \leq D_i\}$

Decisions Variables

x_j = 1 if a server is located in location j, 0 otherwise

y_i = 1 if demand point i is covered by at least one server, 0 otherwise

7.2. Model Formulation

Based on the notation above, the objective function of the model along with its related constraints are formulated as follows:

(**MCLP**) Maximize $z = \sum_{i \epsilon I} w_i y_i$

Subject to $y_i \leq \sum_{j \in N_{(i)}} x_j$ for all $i \in I$, (1)

$\sum_{j \in J} x_j = S,$ (2)

$x_j \in \{0,1\}$ for all $j \in J$,

$y_i \in \{0,1\}$ for all $i \in I$

Where S is the number of the available servers.

The MCLP model aims to select the appropriate number of depots based on the set of depot candidates to serve a given number of demand points. The weighted factor regarding to the importance of demand points is also considered in this model. Constraints (1) oblige the coverage of demand point i by at least one server with its specific distance D_i to the demand point. Meanwhile, the selection of the servers' location to serve the given number of demand points is presented in constraint (2).

9. Capacitated Vehicle Routing Problem (CVRP)

The Capacitated Vehicle Routing Problem (CVRP) is a well-known combinatorial optimization problem in the logistics and distribution systems. The mathematical model representing the CVRP is formulated as follows [56]:

8.1. Notation

Parameters

- n set of customers and the depot (0)
- m number of vehicles
- C capacity of each vehicle
- Di demand of customer *i*
- d_{ij}^{k} distance of a direct travel from customer *i* to customer *j* by vehicle *k*

Decisions Variables

- x_{ij}^{k} = 1 if vehicle *k* travels from customer *i* to *j*, 0 otherwise
- K number of used vehicle

8.2. Model Formulation

The formulated model of CVRP is written as:

(**CVRP**) Minimize $z = \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{k=1}^{m} d_{ij} x_{ij}^{k}$

Subject to

$$\sum_{k=1}^{m} \sum_{i=0}^{n} x_{ij}^{k} = 1 \qquad j = 0, \ldots, i-1, i+1, \ldots, n \qquad (1)$$

$$\sum_{k=1}^{m} \sum_{j=0}^{n} x_{ij}^{k} = 1 \qquad i=0,\ldots, j\text{-}1, j\text{+}1,\ldots, n \qquad (2)$$

$$\sum_{i=0}^{n} x_{it}^{k} - \sum_{j=0}^{n} x_{ij}^{k} = 0 \qquad k=1,\ldots, m,\ i \neq j\ t=0,\ldots, n \qquad (3)$$

$$\sum_{j=0}^{n} D_j \left(\sum_{i=0}^{n} x_{ij}^{k} \right) \leq \text{C} \qquad k=1,\ldots, m,\ i \neq j \qquad (4)$$

$$\sum_{j=0}^{n} x_{0j}^{k} \leq 1 \qquad k=1,\ldots, m \qquad (5)$$

$$\sum_{i=0}^{n} x_{i0}^{k} \leq 1 \qquad k=1,\ldots, m \qquad (6)$$

$$\sum_{i,j \in S} x_{ij}^{k} \leq |S| - 1 \qquad S \subseteq \{2,\ldots,\text{n}\},\ k=1,\ldots, m \qquad (7)$$

The CVRP model assumes that the demand is satisfied by fitting the requirements into the trip by considering the vehicle capacity constraint. The objective function *z* of CVRP attempts to minimize the total traveled distance of the assigned vehicles. The implication of each node to be visited just only once by one vehicle is contained in constraints (1) and (2). The continuity of the vehicles' pathways is described in constraint (3). While constraint (4) specifies the vehicle capacity restriction, constraints (5) and (6) ensure that the assigned vehicles should return to its depot after completing the tour. Subsequently, constraint (7) discards the vehicle sub-tours.

10. GIS Heuristic Methods

The wide application of Geographic Information System (GIS) in the emergency management operations has become a valuable method to spatially analyze and provide proper solutions with relatively short computational time [57]. During the preparedness stage, GIS is utilized as the decision-support tool for analyzing the hazard probability and organizing the potential countermeasure [58]. In the response phase, GIS application is useful for determining the relief routing decisions.

To solve many practical spatial problems, GIS tool is equipped by the compatible heuristic methods [59]. In this review, the associated heuristic methods are categorized based on the strategic and operational stage:

a. Strategic stage

   The location-allocation problem under the strategic stage is firstly conquered by generating the origin-destination (OD) matrix for each depot candidates-demand points counterparts. The Hillsman editing method is then used to enable the edited version of the OD matrix to obtain a variety of different problem types. Furthermore, the Teitz and Bart heuristic is employed to generate a group of good solutions refined from the edited solutions. In order to create better result, a metaheuristic is applied to combine the group of good solutions. The best solution will be selected when there is no more additional improvement. Ultimately, the combination of these heuristics will generate near-optimal solutions [59].

b. Operational stage

The operational stage covers the relief routing decisions under the response phase. This research exploits the Capacitated Vehicle Routing Problem (CVRP) to yield the routes of the relief distribution. In GIS software, the CVRP is notably solved by generating the Dijkstra shortest path algorithm. The initial solutions are then constructed by inserting orders to the most appropriate route to be further improved by resequencing and exchanging the orders on each route to obtain the optimal solution. In this process, tabu search metaheuristic is utilized due to the scale of the optimization. The tabu search metaheuristic has advantages to obtain the local optima solution by the use of tabu list and neighborhood generation with reasonable computation time [56].

11. Model Verification and Validation

In modelling a system, the performance measurement should be evaluated in order to obtain a proper representation of system. To ascertain whether the model represents the correct assumptions and whether these assumptions correspond to its real system, the right approximation must be achieved by verifying and validating the model. Verification is described as the process of ensuring the intended sequences of a model running. On the other hand, validation is often defined as the process of determining whether the model accurately represents the actual system [60].

There are several techniques used to verify the model, as elaborated below [60]:

a. *Reviewing model code*. This activity is usually conducted by the modeler in order to check whether there are errors or inconsistencies happening in the model. The model can be tested by using bottom-up or top-down techniques. In bottom-up testing, it is started by checking from the lowest modules to finally review the complex model. Meanwhile, the top-down approach begins with testing the main module to the lower modules.

b. *Checking for reasonable output*. The reasonable output means to the predictable values resulted during the model running. By replacing the stochastic input will allow the modeler to investigate if the outcomes match with the input values.

c. *Animation*. Particularly in the simulation model, by watching the animation of the model, the modeler can visually analyze and detect whether there are errors occurring during the running time.

d. *Trace and debugging*. In the simulation, the trace and debugging feature provides information of the detailed textual feedback on each step of the process. This allows the modeler to inspect if the following logic is coded correctly.

Validation is recognized as the inductive process to measure the accuracy of the model. The commonly used techniques in the model validation are contained in the following lists:

a. *Watching the animation*. The dynamic visual feedback can be encountered from the dynamic plots provided by visual animation. The operational behavior of the designed model can be compared with one's knowledge about how the real system behaves.

b. *Comparing with the actual system*. The model and the actual system can be compared as long as the model is run using the same conditions and inputs with the actual system.

c. *Comparing with other models.* The output of the model can also be compared to the outcome of the other valid model which is already exist in order to investigate its results.

d. *Conducting degeneracy and extreme condition tests.* The known situations of the model behavior can be degenerated to check the growth of the particular response variable. Another way is by running the under the extreme conditions to see if it behaves as expected.

e. *Checking for face validity*. The face validity is conducted by asking the knowledgeable people if the model behaves reasonably. More specifically, this technique determines if the logic of the conceptual model is correct and if the relationship of the model input-output is reasonable.

f. *Testing against historical data*. This is also called as the "as-once-was" comparison technique. The step involved is accomplished by comparing the operating and performance data of the existed historical information to the developed model.

g. *Performing sensitivity analysis*. By using the sensitivity analysis, the modeler changes the input values to determine how the model behaves as well as the resulted outcomes.
h. *Traces*. In order to see if the specific entities or sequence of events follows the system behavior, the modeler can use the traces technique to determine the model correctness.
i. *Turing tests*. In this test, the knowledgeable person particularly in the operational level is asked to discriminate between the real system and the model outcomes.

The validation test can be organized through the objective approach by using the mathematical procedure or statistical test such as hypothesis tests and confidence interval tests. However, validation process becomes more sophisticated when the real system does not exist yet. In their book, Harrel et al., [60] suggested the collaboration among the modeler with the experts who have a good understanding of how the actual system should work. In this case, animation technique is commonly applied to validate whether the model mimic the ideal behavior of the proposed system under the various treatments.

CHAPTER 3

RESEARCH METHODOLOGY

This study consists of six main stages of structured methodology including the review on the recent contingency plan, problem identification, reviewing the previous relevant research, analyzing the gap fulfillment, developing new study, and proposing the new logistical framework to face Sumatra Megathrust, as described in **Figure 3.1**.

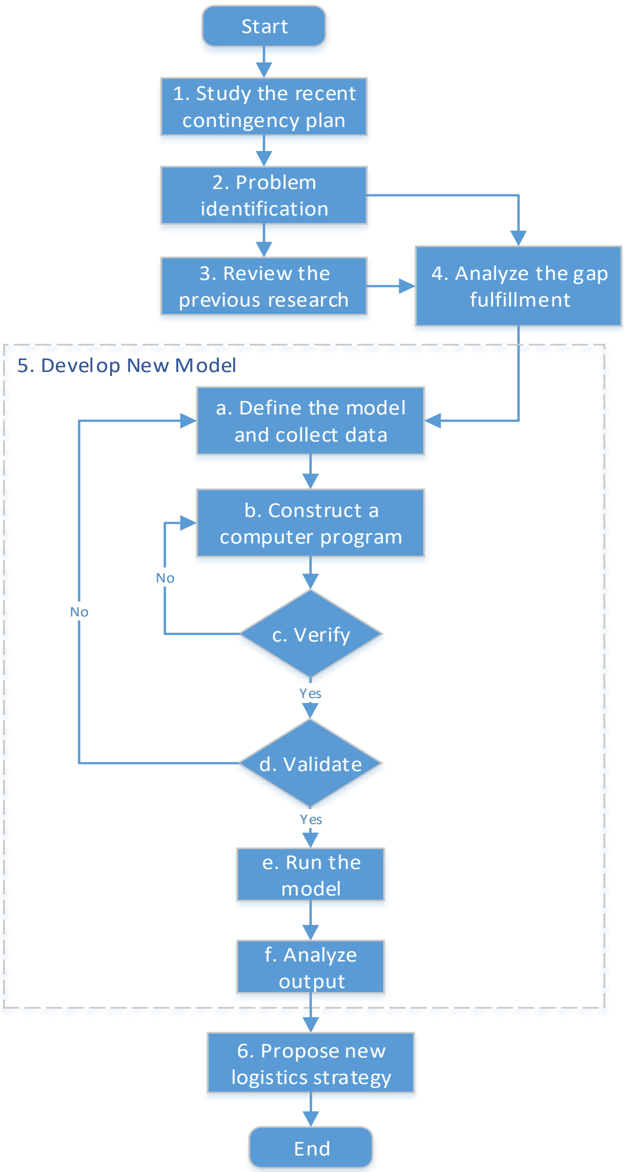


Figure 3.1 Research Methodology Framework

1. Contingency Plan Review

The first step of this study is reviewing the recent framework developed by the local government to face the potential consequences of the earthquake triggering tsunami, Sumatra Megathrust. The first consideration comprises the prediction of the magnitude and effect of this potential calamities to the society, infrastructures, and environment. The strategies and policies developed by the local government are also analyzed in order to capture the countermeasure efforts which is going to be used to enhance the early recovery process. Subsequently, the analysis of the sectoral division which is basically determined by its qualification is carried out to the review discussion. The contents included in the sectoral planning consist of the main tasks of each sector, the objective that would be achieved, and the estimated requirements.

2. Problem Identification

Due to the significance of humanitarian logistics in the disaster response, it is important to enclose these necessary activities as principal substances of the contingency plan [35]. Hence, the implementation of the basic concept of humanitarian logistics is investigated in the problem identification. The missing consideration on the logistical application will be further improved by using the well-organized methods.

3. Previous Research

The previous research is inquired to capture the accomplishment of the related research to the deficiency in the recent contingency plan, particularly in the logistical planning. The relevant terms and methods in the disaster management, humanitarian logistics, and the correspondent manners are discussed to obtain the comprehensive reference in developing the robust logistical strategy.

4. The Gap Fulfillment Analysis

Due to the intention of the contingency plan that will be activated as operation plan in the post event of disaster, it is required to ensure that the contingency plan contains an accurate program to save lives and reduce human suffering. The previous works related to the logistical planning are carried out to be further analyzed in order to find out if the gap existed in the recent contingency plan has been completely solved. The analysis about the significant aspects which are not considered in the previous research will be taken into account as the gap to be complemented in this research.

5. The Development of New Model for Logistical Operations

The next stage of this methodology is developing the new study handling out the remaining gaps which are still missing. Since most of the real-world systems contain complexities [61], the development of the new study must encompass the essence of the observed environment. The analytical phases of the formulized probe contain six sequenced orders.

5.1. Defining Model and Collecting Data

The moderate model is depicted and will be made to be more sophisticated if necessary. The model in this step contains only enough detailed information to capture the essence of the system for purposes for which the model is intended. A model with excessive detail may affect to the difficulties to be performed. In the same vein, the collection of information and data is necessary to portray the system of interest and used to specify operating procedures and probability distributions of the random variables used in the model.

5.2. Constructing the Computer Program

In programming a model, there are several techniques for generating random variates on a computer with a specified probability distribution. The development of the new logistics model consists of two levels:

a. *The strategic level*. In the strategic level, all terms related to the location-allocation decision are performed. This phase firstly considers the spatial data on the demand points and the LDCs candidates. Next, the demand requirements are quantified based on the victims' arrival to the given shelter per day. The quantity of the required demands per day is computed to generate its weight and volume which will be utilized as the weighted factor of each demand points, the opening cost, and the transportation cost. In the same vein, the road networks and the network barriers (based on the expected inundation scenario) are provided to select the appropriate access from each depot to its recipients.

The defined inputs are incorporated to solve the location-allocation problem using Geographic Information System (GIS) with maximal coverage analysis in order to obtain the alternative number of LDCs which would be established. The selection of the appropriate LDCs is assessed by calculating the minimum total opening cost and transportation cost. The fixed opening cost is spent to establish the temporary LDCs such as tent with its certain capacity. The transportation cost belongs to the cost associated with loading unloading, shipment, and labor utilization for delivering a certain amount of relief items. In addition, this research assumes the sustainable utilization of the LDCs. Hence, the selected LDCs in the particular day will be used as the required LDCs in the next day without any charge for the fixed opening cost. However, if for instance, the total volume of the stored commodities exceeds the available volume of the recent LDC, it will be charged for another fixed cost to open another storage.

b. *The operational level*. The output of the strategic level, the depot-recipient counterparts, will be used as input in the operational level. In this stage, the Capacitated Vehicle Routing Problem (CVRP) is required to optimize the daily routing for the individual vehicle. During this stage, two different delivery strategy is tested. The first strategy is applied by synchronizing the delivery tasks to the daily required demand. Meanwhile, the second strategy performs the equalized shipment over the planning period.

   To determine the appropriate routes from the selected LDCs to its demand points, the CVRP solver in GIS application requires the existence of the allocated number of commodities resulted from the strategic solutions. Moreover, the state of the road networks and the expected network barriers are reused as inputs of this step. Furthermore, to specify the vehicle capacity constraint GIS tool allows the setting of the capacity restriction in the CVRP analysis.

   Despite of its usefulness for the geographical modelling, GIS owns several limitations in solving more complex situations. Hence, the presence of another application is required to be combined with GIS in order to obtain more tangible solutions [15]. Therefore, in this research the simulation approach is chosen to generate the relief routing and assignment under the complex environment.

In the simulation programming, the output of the CVRP obtained from GIS will be extended by treating the stochastic instruments by considering the limited operational working hours through the dynamic environment. Moreover, the set of multi-vehicle and the loading-unloading time are applied in order to simulate the real-complex system. In the simulation approach this work compares two relief distribution strategy, the equalized strategy and the synchronized strategy. The output of this simulation computation, the assignment of each vehicle to delivery relief goods through a particular route, the shortage fulfillment, and the exceeded fulfillment, are calculated to obtain the total operational cost. The most appropriate strategy will be proposed to be applied in the actual efforts.

Figure 3.2 illustrates the flow of the model development consisting the tasks to be accomplished during the strategic level and operational level.

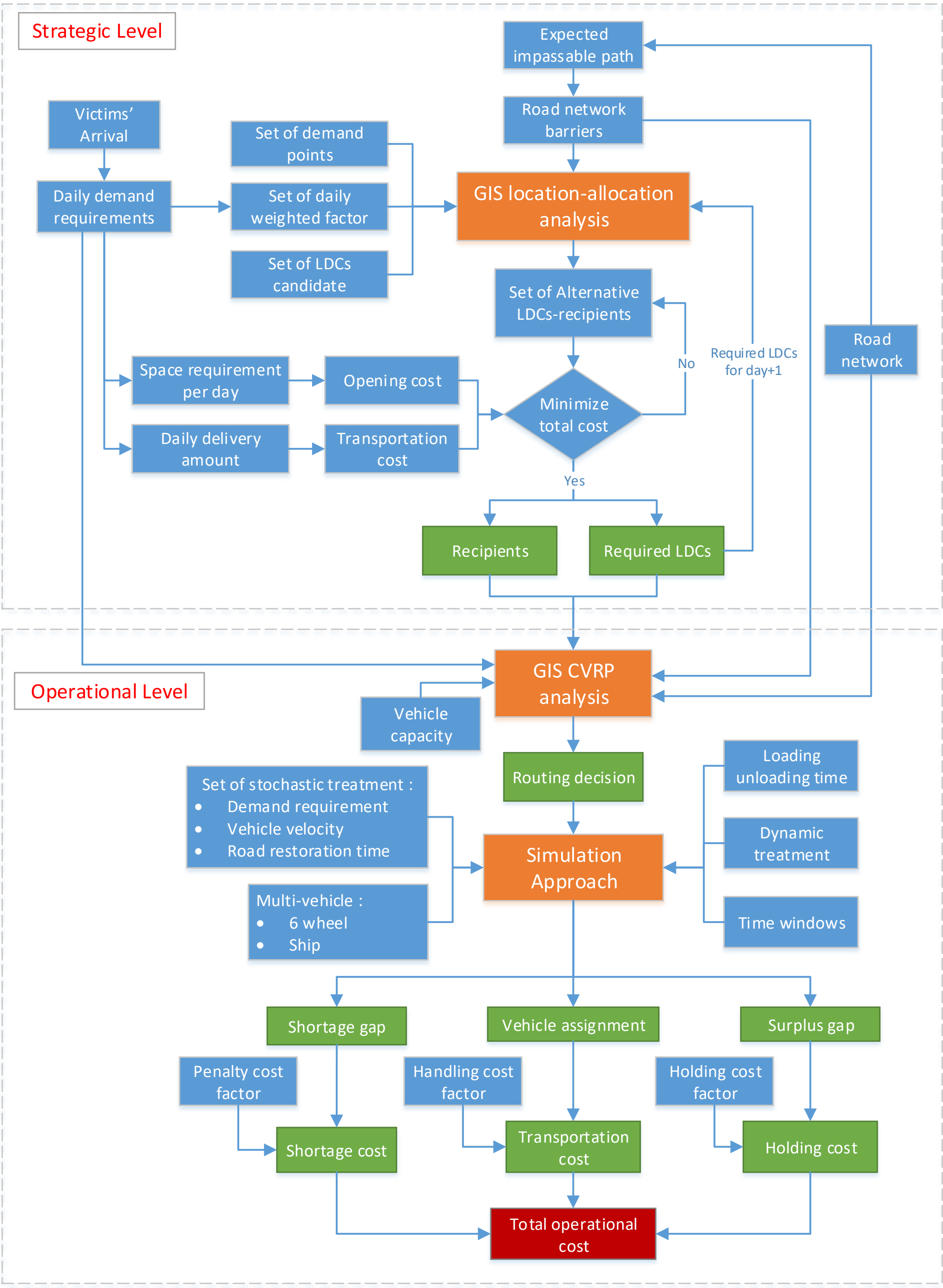


Figure 3.2 Model Development Flow Chart

5.3. Verification

Verification is needed to assure that the developed model complies the correct implementation. In the computerized model using the simulation language, verification is aimed to check errors occurring during coding process. There are basically two approaches for testing the simulation software, either by statically or dynamically [62]. In the static testing, several techniques such as structured walkthroughs, proofing correctness, and testing the structure properties are used. Meanwhile, the common techniques used in dynamic testing is by tracing, investigating the input-output relations, checking the internal consistency, and reprogramming the critical components.

5.4. Validation

In building the model, the validity and the credibility of the model will increase along with the involvement of the people who are intimately familiar with the operations of the actual system and interaction with the decision maker (or the model's intended user) on a regular basis. In addition, it is also necessary to test the adequacy of the specified probability distributions for generating the variates of the random input.

5.5. Running the Model

The system designs which would be simulated should be decided if there are more alternatives than one can reasonably simulate. Decisions have to be made on such issues including the initial conditions for the simulation run(s), the length of the warmup period (if any), the length of the simulation run(s), and the number of independent simulation runs (replications) to make for each alternative.

5.6. Analyzing Output

In order to construct confidence interval for a measurement of performance for one particular system design or to decide which simulated system is relatively best, the output of the resulted calculation should be analyze to identify the affective factors.

6. Proposing the New Logistics Strategy

The analyzed output will lead to concrete solutions on the proper strategic and operational decisions. Finally, the results of a joint model of optimization and simulation approach are proposed to be implemented in the humanitarian logistics activities to face Sumatra Megathrust.

CHAPTER 4

RESULTS AND ANALYSIS

1. The Recent Contingency Plan

The Sumatra megathrust issue is one of the most threatening hazard in the future. Regarding to the potential fatalities resulted by this tremendous hazard, the Indonesian government through their constitution number 24 year 2007, guarantees the protection and sheltering for the citizens from disaster to provide welfare among victims [38]. Moreover, the local government of West Sumatra for disaster affairs (BPBD) [11] [63] has formulated the countermeasure procedure to face the consequences of this high impact catastrophe, namely contingency plan.

The contingency plan for encountering tsunami in the West Sumatra Province mainly discusses six major contents. In the first section, it discusses about the general description of the affected area, including geographical condition, administration territory, and demography, topography circumstances, climate, potential hazards, and the existence of BPBD Sumatra Barat as an authorized institution for organizing emergency activities in the West Sumatra Province. Hazards assessment based on the probability occurrences and depiction of the potential tsunami event are discussed in the second section. The third chapter further estimates the effect of tsunami to residents in the coastal areas, the number of infrastructures failures (roads, bridges, airports, etc), and the natural environments (mangroves, coral reefs, coastal areas, etc). the forth section contains the strategies and policies treated in order to hasten the early recovery phase. In the fifth chapter, establishing five clusters according to the activities being performed in the aftermath of disaster is elaborated. Meanwhile, the last section reveals the recent situation about the potential affected area and the future preparation to face the tsunami hazard.

There are three policies contained in the contingency plan inclusive with its strategies which should be performed by the local government to enhance the early recovery process [11]:

a. Optimizing all of the available resources in order to fulfill the basic needs of victims and giving protection to the vulnerable people, involving:
   - Organizing the Memorandum of Understanding (MoU) with the private sectors for the resources allocation
   - Mobilizing personnel, facilities, and infrastructures
   - Activating contingency plan becomes the operational plan
   - Assigning rapid assessment team
   - Optimizing data management and information for donations approval
   - Preparing transportation modes for relief distribution activities
   - Seeking for international assistances (if necessary)
   - Optimizing main and secondary posts for relief aid donations
   - Assisting security service for donors
   - Declaring the information access through the main post
   - Prioritizing vulnerable people including elderly, pregnant, children, and people with disabilities
b. Coordinating the disaster emergency management with the related stakeholders, including:
   - Activating the command and control system
   - Utilizing the information and communication system
   - Mobilizing volunteers according to their proficiencies
c. Establishing decentralization authorities to every districts affected by tsunami by following the commands and instructions from the main organizational structures, consisting:
   - Dividing affected areas based on their geographic conditions
   - Establishing command systems in order to facilitate the relief distribution access

In the contingency plan, the decision on the establishment of the emergency sectors for handling and organizing humanitarian relief activities are basically assigned by the corresponding objectives of the disaster countermeasures. Six clusters to be established include [11]:

a. *Management and coordination sector*. As the governor establishes the disaster emergency status, management and coordination sector will be responsible for coordinating activities among the involved sectors as well as conducting the daily evaluation in the operation plan and ensuring that every sectors implements their own objectives into their daily activities.

b. *Search, rescue, and evacuation sector.* The search and rescue activities should be optimized by mobilizing personnel and adequate equipment in order to minimize casualties. Evacuation process is held simultaneously to anticipate the fatalities.

c. *Health sector.* In order to anticipate death and casualties, the health sector will assist treatment to person with minor injuries and avoid the infectious diseases among evacuees. Meanwhile, victims with serious injuries will be treated in the hospital or emergency facilities.

d. *Transportation, information, and communication sector*. This sector primarily focusses on the transportation, information, and communication procurement and restoration in order to fulfill the needs during emergency periods especially for victims search and rescue as well as the basic needs fulfillment.

e. *Emergency facilities and infrastructures repair and recovery sector*. In the post-disaster event, public facilities and infrastructures such as hospitals, schools, airports, governmental buildings, and telecommunication network will be potentially damaged. Hence, repairing and recovering should be immediately held to restore the main function of these facilities.

f. *Logistics, aid approval and distribution sector*. This sector will coordinate all approval and distribution activities including basic needs, communication network, and personnel from the other areas such as other districts, province, national, or even international donors.

2. Problem Identification

The definition of the contingency plan is declared as “a forward planning process, in a state of uncertainty, in which scenarios and objectives are agreed, managerial and technical actions defined, and potential response systems put in place in order to prevent, or better response to an emergency or critical situation” [64]. The International Federation of Red Cross and Red Crescent Societies (IFRC) described the contingency plan as the guideline for a proper respond to an emergency as well as its humanitarian impact [65]. A well design of a contingency plan should contain all terms and conditions in the management of human and financial resources, coordination and communication procedures, and the *awareness of a range of technical and logistical responses*.

With regard to the significance of the logistical activities in the disaster relief operations, the logistical planning must take into account the following functional actions:

a. Mobilizing and storing the standby stocks
b. Identifying and preparing the appropriate warehousing and the stock control management
c. Pre-agreements with the involved stakeholders and ensuring the readiness of the vehicles fleets
d. Preparing and storing the equipment which will be rapidly utilized in the aftermath of disaster occurrence
e. Assuring the readiness of IT and communications equipment

The recent contingency plan basically contains the essence of the logistical planning actions. However, the effort of mobilizing and storing the available stocks as well as identifying the appropriate warehousing and stocking decisions are still missing in the content of the recent contingency plan. Therefore, the detailed planning on optimizing these missing lines are encouraged in order to provide a quick-decent assistance.

3. Previous Research in the Humanitarian Logistics Planning to Face the Sumatra Megathrust Hazard

The lack of consideration in the detailed logistical planning contained in the recent contingency plan calls for development of a comprehensive study to fulfill the deficiency. Ariyana [14] proposed the strategic planning on the locating the buffer post as well as allocating the adequate number of relief aids to respond for the major catastrophes. Liperda [57] implemented the last mile distribution model for the fulfillment planning to face the potential consequences of Sumatra Megathrust hazard. Recently, the work of Patrisina [35] proposed an analytical method in designing the location-routing planning to deal with the effects of this future hazard. In their work, Patrisina formulated the three-tier supply chain by firstly defining the location allocation strategy to select the suitable Local Distribution Centers (LDCs) during the preparedness stage. In the response phase, their work designed the relief distribution plan by taking into account the relief aid delivery started from the warehouse to the selected LDCs and finally received by the refugees in each demand point. In their research, they compared the effectiveness of two relief distribution strategy, the pure strategy and mixed strategy. subsequently, they claimed that the mixed strategy is appropriate to be applied in the response phase.

4. The Gap Fulfillment Analysis

Despite of its major contribution for assisting the preference in designing the appropriate logistical planning, the previous works have not deliberate the following aspects:

a. *The dynamic increment of demand*. The sudden change in the demand requirements during the emergency periods immensely affects to the decision-making of the strategic and operational level. The previous researches assume the identical quantity of the relief aid delivery over the planning period. This may lead to the excessive shipment and affect to the additional cost for holding the number of commodities.
b. *The damaged path networks*. The consideration on the expected damaged paths caused by debris piles as a result of the tsunami inundation is not under the consideration of the previous works. The wrong decision on the road utilization which has the disruption probability may result in an ineffective planning.
c. *The expected remote areas.* As an effect of the damaged paths, some areas may be remote due to no road access connecting between its original point to the designated depot. The anticipative manner should be made if this incident happens in order to ensure the possible access for delivering the relief aids.
d. *Relief routing*. During the response phase, the decision on the routing and assignment may change compared to the location-allocation result. Hence, the design of a flexible routing which aims to optimize the routing cost is crucial.

e. *Uncertain conditions.* Disaster is considered as a complex phenomenon with high uncertainties. These significant factors need to be considered in order to generate more realistic results.
f. *Restrictions in the delivery working hours.* In the effort of relief delivery, the safety and security factors should be prioritized. Therefore, the relief distribution plan must be designed to prevail under the limited working hours.
g. *Relief strategy*. The different amount of the daily required demand may require a different location-routing assignment per day. The suitable strategy is needed to properly fit this tendency.

The attempt of designing a rigorous work by accommodating those mentioned aspects is necessary. Therefore, this research aims to fulfill the missing gap in order to promptly meet the beneficiaries' necessities.

5. Model Development

This section discusses the methodical steps on designing a new logistical model by firstly defining the model characteristics and preparing the required data. Afterwards, the model is constructed to be further verified and validated. Subsequently, the output of the will be analyzed after running the model.

5.1. Defining the Model and Data Preparation

In defining a model, this research initially refers to the nature of the system to be later modeled through the scientific program. The involved data is compromised to obtain the scrupulous outcomes.

5.1.1. System Description

The system description encompasses the state of the study area and the schematic manner in the strategic and operational level.

5.1.1.1. The Study Area

Padang City is geographically located on 00° 44' 00" - 01° 08' 35" of South latitude and 100° 05' 05" - 100° 34' 09" of East longitude, with territory area approximately reaches 694.96 km^2. The coastal area of Padang City extends through 68,126 km. In addition, there are 19 small islands alongside Padang territory. The contour of the mainland varies in height from 0 to 1,853 km above the sea level. Meantime, the demographic information about Padang administrative area is shown in **Table 4.1**. Koto Tangah is the district with the widest area, meanwhile the population density in Padang Timur becomes the highest number of the inhabitants per km^2.

Table 4.1 Demographic Information of Padang City [63]

District	Area (km^2)	Density (Inhabitant/km^2)
Bungus Teluk Kabung	100.78	227
Lubuk Kilangan	85.99	568
Lubuk Begalung	30.91	3,443
Padang Selatan	10.03	5,755
Padang Timur	8.15	9,554
Padang Barat	7	6,483
Padang Utara	8.08	8,554
Nanggalo	8.07	7,097
Kuranji	57.41	2,207
Pauh	146.29	405
Koto Tangah	232.25	698

5.1.1.2. The Schematic Manner in the Strategic and Operational Level

In the preparedness stage, all efforts in the strategic decisions for obtaining the suitable location of the LDCs along with the allocation incorporated with the dynamic increment of demands must be accomplished. Since the requirements vary over the planning period, GIS is utilized to provide the alternative number of LDCs per day by using maximal coverage analysis. The analysis on the expected impassable path and the expected remote area is provided. The countermeasure plan related to the remote access must be determined in this phase, either by restoring the road or utilizing another transportation method. Subsequently, based on these comprehensive deliberations, the alternative solution is then assessed to select the LDCs with the minimum opening cost and transportation cost. The selected LDCs in a particular day will be used as the required LDCs in the next day, as long as its capacity is sufficient enough to accommodate the relief commodities without any charge for opening cost. The additional cost will be spent to open another capacity if the stored items exceed the available capacity. Finally, the decisions on the selected LDCs per day will be used to be input in the operational level.

In order to obtain the delivery route between the depots to their recipients during the operational level, the CVRP analysis by utilizing GIS is solved by assuming the employment the individual vehicle. Two delivery strategy, equalized delivery and synchronized strategy, are examined to determine most appropriate relief distribution strategy. The result obtained from GIS is developed through more complex treatments including the stochastic elements (demand, vehicle velocity, road restoration time), multi-vehicle, the loading-unloading activities, and the restricted time windows under the dynamic environment. As shown in **Figure 4.1**, the equalized delivery takes into consideration an identical amount of the relief delivery per day by dividing the sum of demand in the consecutive planning period to the total period in the planning horizon. On the other hand, the synchronized delivery refers to the distribution strategy which suits to the required demand on each day. The equalized delivery may have advantages in term of fulfilling a sudden additional demand by supplying more than the predicted needs. However, exceeding the supplies may affect to additional holding cost. The synchronized delivery, conversely, may not be able to accommodate the sudden-extra need which yield to the penalty charge due to the unsatisfied demand but will generate minimum holding cost. The effectiveness of these two strategy is compared to obtain the proper distribution strategy with the least total transportation cost.

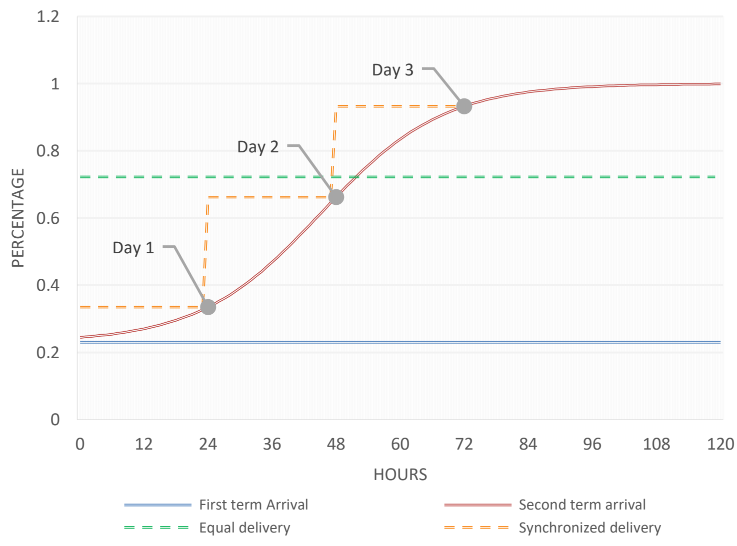


Figure 4.1 The Relief Distribution Strategy

5.1.2. Data Preparation

This section comprises the data preparation in terms of general data, moving assignment, and the vehicle availability.

5.1.2.1. General Data

Referring to the evacuation plan developed by the local authority for disaster countermeasure [46], there are 12 final evacuation points which will prevail as refugee camps in the aftermath of disaster event. In this research, these refugee camps are also utilized as the LDC candidates. Furthermore, this work considers three kind of consumable goods to be shipped during the relief response including rice, noodle, and preserved food, as can be shown in **Table 4.2**.

Table 4.2 Type of Relief Items [34]

Item	Standard Fulfillment per Person per Day (gr)	Unit per Pack	Weight per Unit	Volume (cm^3)
Rice	400 gr	Sack (30 kg)	30 kg	31
Noodle	95 gr	Box (40 packs)	80 gr	20.35
Preserved Food	200 gr	Box (12 cans)	155 gr	5.31

The temporary LDC is assumed as a tent with volume capacity 168 m^3 and fixed opening cost 500 USD [35]. The excessive storage volume will turn to the establishing of new capacity which will be charged to another 500 USD. To assess the handling cost, it contains three indicators including loading and unloading cost, shipment cost, and labor cost. The loading and unloading cost per ton will be charged 2.56 USD with the loading and unloading time takes 10 minutes per ton. The cost for shipping one ton of relief aids per kilometer is 0.313 USD. Meanwhile, 3 USD will be spent to hire the labor per one trip. These cost factors are obtained from the transportation and cargo company [57]. Therewith, the penalty cost factor are set to be 6 USD, 5 USD, and 8 USD respectively for each unsatisfied fulfillment of rice, noodle, and preserved food [35]. On the other hand, the holding costs of each item per kg are 0.0394 USD (rice), 0.0575 USD (noodle), and 0.7175 (preserved food) which is calculated from the work of Rawls et al., [36]. In term of supply, this work assumes the sufficient stocks for fulfilling demand needs during the short term period, as adopted by the previous research [14] [34]. The operational working hours is expected to be 16 hours a day, started from 07.00 am to 11.00 pm.

Table 4.3 shows the information of the handling cost factors involved in this research. It consists of loading-unloading cost, shipment cost, and labor cost.

Table 4.3 Handling Cost Factors [57]

Handling Cost Factor		
Loading Unloading Cost	**Shipment Cost**	**Labor Cost**
2.56 USD/ton	0.313 USD/ton/km	3 USD/trip

As shown in **Table 4.4**, it can be known the cost charged for holding a certain amount of entities and the penalty spent for each unsatisfied fulfillment.

Table 4.4 Penalty Cost [35] and Holding Cost Factor [66]

Commodities	Penalty Cost (USD)	Holding Cost (USD/kg)
Rice	6	0.0394
Noodle	5	0.0575
Preserved Food	8	0.7175

5.1.2.2. The Moving Assignment

The calculation on the moving assignment to each designated refugee camps is computed based on the tsunami evacuation plan of Padang City [46]. The summary of the moving assignments for each sequent are shown in **Table 4.5**. The enumeration on the detailed information are provided in **Appendix A**. From the table below, it is estimated that 437,860 affected victims are going to require a number of relief goods to alleviate them from suffering. The classification on the arrival term refers to the zoning method developed by the BPBD. The zones assigned to directly escape to the final evacuation points are categorized to the first term arrival. Meanwhile, the second term arrival belongs to the zones assigned to move after the inundation recedes. This estimation will be further utilized as the basic data for determining the appropriate strategic-operational decision.

Table 4.5 The Moving Assignment to Each Refugee Camp

Sector	Refugee Camp	Location	Expected Victims	Moving Assignment	
				1st Term	2nd Term
A	A1	Batipuh Panjang	19,978	10,154	9,824
	A2	Bukit Anak Aia	24,797	5,473	19,324
B	B1	Koto Pulai	21,233	7,668	13,565
	B2	Balai Gadang	6,603	1,101	5,503
C	C1	Koto Panjang Ikua Koto	12,614	3,806	8,808
D	D1	Municipality office, By Pass	18,801	18,801	-
	D2	TVRI office, by pass	56,398	17,967	38,431
E	E1	Gunung Pangilun	80,684	11,254	69,431
F	F1	Sungai Sapih	32,625	13,242	19,383
G	G1	Kubu Marapalam	106,327	32,414	73,913
H	H1	Teluk Kabung Utara	16,411	1,144	15,267
I	I1	Banuaran nan XX	41,389	3,854	37,536
		Total	437,860		

5.1.2.3. The Relief Vehicle Availability

The data on the available number of relief vehicles is presented in **Table 4.6** [57]. As shown from the table, the total 28 multi-vehicles including 6 wheeler truck and boat are acquired from four institutions. The velocity of each type of vehicle is set to be stochastic with normal distribution. Due to its significance to be utilized in the humanitarian logistics [67], the land transportation modes are considered as the initial preference. However, the road disruptions as an impact of the tsunami may require another transportation mode with capability to transport the relief aids. Hence, in this research we consider the ship as alternative solution to deal with the inaccessible roads.

Table 4.6 Relief Vehicle [57]

Vehicle Type	Owner	Capacity (Ton)	Amount	Velocity (Meters per Minute)
6 Wheeler	Indonesian Army	4	23	N (666.66, 138.33)
6 Wheeler	BPBD	4	2	N (666.66, 138.33)
6 Wheeler	Social Agency	4	3	N (666.66, 138.33)
Ship	Indonesian National Police	4.7	2	N (617.33, 92.61)
	Total		30	

5.2. Numerical Experiments

In the numerical experiments, the analytical computation on the spatial analysis of the study area, the required demands, the location-allocation decision, and the relief routing assignment to face the tremendous impacts of Sumatra Megathrust are elaborated

5.2.1. Spatial Analysis

The spatial analysis is encompassed to portray the geographic location of the demand points, the existing facilities, and the probability of the inaccessible path caused by the tsunami inundation. The scenario developed by the local government basically classifies the inundation area to be three zones. Conversely, this work considers all possibility of the impassable path under the inundation area. Moreover, the buffer area is set to be 500 m around the inundated river since the wave may spread into the river during inundation, similar to [68]. As illustrated in **Figure 4.2**, the developed plot based on GIS application is constructed to generate the safe road access by avoiding the expected impassable path. However, there are four refugee camps (A1, A2, B1, and H1) which are predicted to be remote. **Figure 4.3** explains more detail about the expected road closures. The length of each expected impassable roads (A1-A2; 406.85 m), (B1; 557.80 m), (H1; 10,915.85 m) is measured by GIS. Due to its relative-short length, the restoration is assumed to be prior for the roads connecting to A1-A2 and B1 with the cleaning ability 250 m^3/hour [69] [70] [71]. In order to reach refugee camp H1, it may require another transportation mode since restoring the road may not be effective. To deal with this matter, this research assumes the utilization of ship by defining the ship loading point and its line access through the river. The assigned truck will deliver the relief goods to the ship loading point then it is continued by transporting the commodities with ship to refugee camp H1.

Unlike the other disasters, the debris volume produced by tsunami inundation may vary throughout the inundation area. This happening will strongly affect to the road restoration time which causes another challenge in the emergency assistance efforts. This obvious incident is simulated through the operational stage in order to delineate the severities which potentially occur in the immediate aftermath of tsunami. However, the simplification is made by presuming that the debris volume as a triangular prism shape. The length of the road to be recovered represents the prism base length. The base width of the prism is set to be 2.6 m referring to the truck width standard [72]. Meanwhile, for the height of the prism we refer to the height of previous tsunami piles in Japan 2011 [73]. In order to portray the uncertainties in the debris height, this study assumes that the debris height follows the triangular distribution with smallest height 1.36 m, largest height 8.16 m, and average 4.01 m.

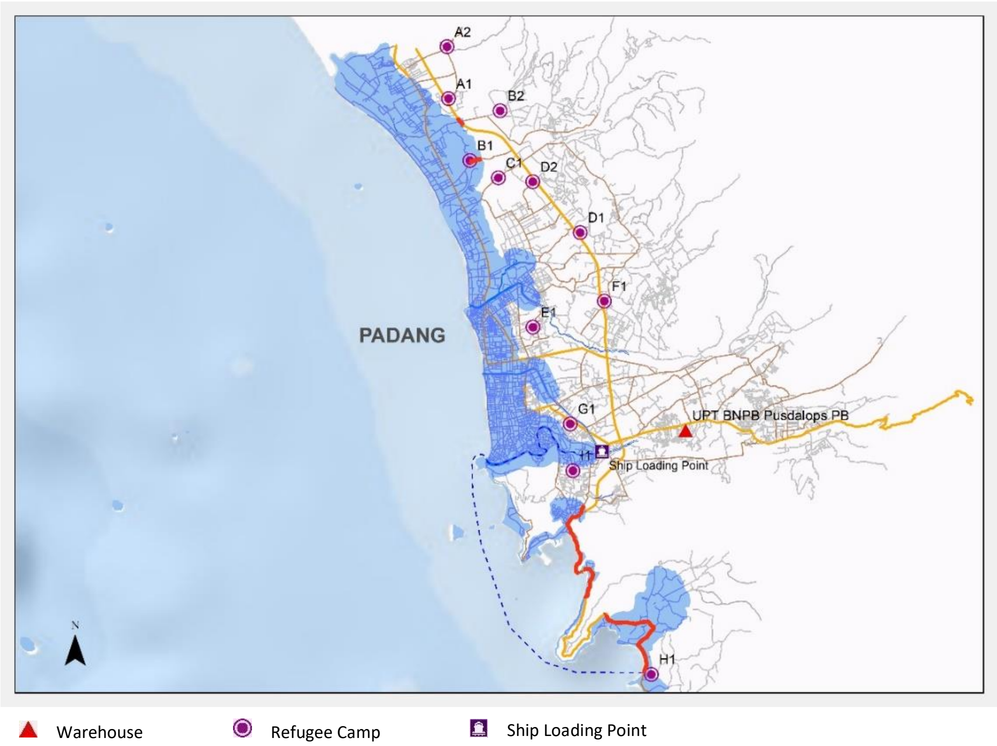
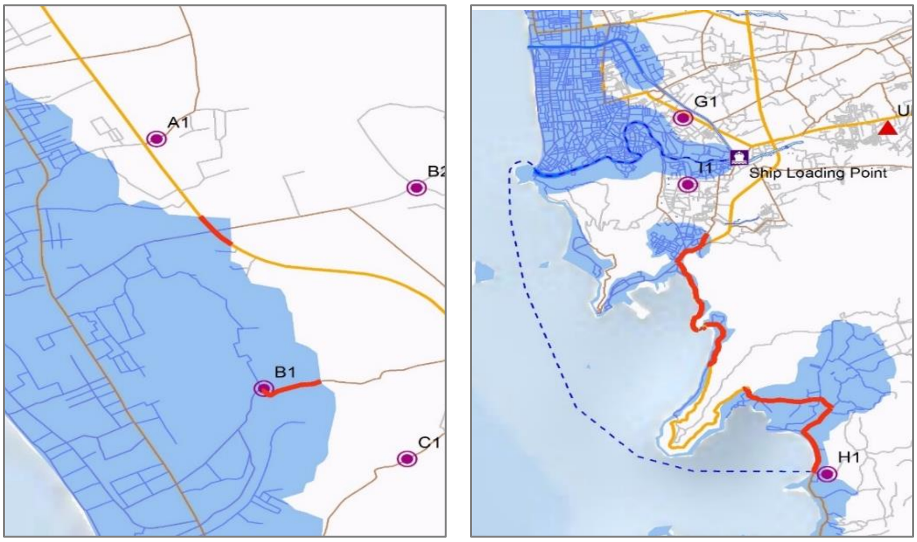


Figure 4.2 Spatial Analysis of Study Area



(a) (b)

Figure 4.3 Expected Road Closures

5.2.2. The Expected Victims' Arrival and The Demand Requirements

In order to obtain the daily required demand, this work firstly define the number of victims arriving at a given refugee camp per day by multiplying the aspect ratio in **Table 2.2** to the number of assigned victims of each term (**Table 4.5**). The calculation sample for refugee camp A1 in the first day is provided in the equation below.

The expected victims' arrival in the first day

- Victims arriving in the 1st term = Aspect ratio in the 1st term * Moving assignment in the 1st term

  Victims arriving in the 1st term = 100% * 10,154

  Victims arriving in the 1st term = 10,154

- Victims arriving in the 2nd term = Aspect ratio in the 2nd term * Moving assignment in the 2nd term

  Victims arriving in the 2nd term = 13.588% * 9,824

  Victims arriving in the 2nd term = 1,335

- Total victims' arrival in day 1 = Victims arriving in the 1st term + Victims arriving in the 2nd term

  Total victims' arrival in day 1 = 10,154 + 1,335

Total victims' arrival in day 1 = 11,489

Table 4.7 shows the summary of the cumulative victims' arrival to a given refugee camp per day. As can be seen from the table, the number of the victims staying at a refugee camp varies in each day and evolves over the planning horizon. The total cumulative arrival in the second day increases 72.28% from the first day. Interestingly, the value in the third day does not show significant difference comparing to its previous day since in this period the quantity of the expected victims almost reaches its peak point.

Table 4.7 Expected Victims' Arrival per Day

Refugee Camp	Location	Expected Victims Arrival		
		24 Hrs	48 Hrs	72 Hrs
A1	Batipuh Panjang	11,489	15,672	19,119
A2	Bukit Anak Aia	8,099	16,326	23,107
B1	Koto Pulai	9,511	15,286	20,047
B2	Balai Gadang	1,848	4,191	6,122
C1	Koto Panjang Ikua Koto	5,003	8,753	11,844
D1	Municipality office, By Pass	18,801	18,801	18,801
D2	TVRI office, by pass	23,189	39,550	53,038
E1	Gunung Pangilun	20,688	50,247	74,614
F1	Sungai Sapih	15,876	24,128	30,930
G1	Kubu Marapalam	42,458	73,925	99,864
H1	Teluk Kabung Utara	3,219	9,718	15,076
I1	Banuaran nan XX	8,954	24,934	38,107
Total		169,135	301,530	410,670

From **Table 4.8**, the amount of the required demand per type as well as its volume are computed according to the item specification in **Table 4.2**. **Table 4.8** enumerates the quantity of the daily demand needs per type based on its standard fulfillment. Next, the space requirements are counted in **Table 4.9** based on the relative volume of each type. The demand amount is later used to determine the daily weighted factor for each demand point and to define the transportation expense. In the meantime, the required space is utilized as the decisive indicator to set the amount of the fixed opening cost.

Table 4.8 Daily Demand Requirements

Refugee Camp	Location	Relief Aid Requirement (kg)									Total Amount (Tons)		
		24 hrs			48 hrs			72 hrs					
		Rice	Noodle	Preserved Food	Rice	Noodle	Preserved Food	Rice	Noodle	Preserved Food	24 Hrs	48 Hrs	72 Hrs
A1	Batipuh Panjang	4,595.73	1,091.49	2,297.86	6,268.68	1,488.81	3,134.34	7,647.78	1,816.35	3,823.89	7.99	10.89	13.29
A2	Bukit Anak Aia	3,239.59	769.40	1,619.79	6,530.30	1,550.95	3,265.15	9,243.00	2,195.21	4,621.50	5.63	11.35	16.06
B1	Koto Pulai	3,804.43	903.55	1,902.22	6,114.47	1,452.19	3,057.24	8,018.75	1,904.45	4,009.38	6.61	10.62	13.93
B2	Balai Gadang	739.39	175.61	369.70	1,676.44	398.16	838.22	2,448.90	581.61	1,224.45	1.28	2.91	4.25
C1	Koto Panjang Ikua Koto	2,001.27	475.30	1,000.64	3,501.17	831.53	1,750.59	4,737.61	1,125.18	2,368.80	3.48	6.08	8.23
D1	Municipality office, By Pass	7,520.54	1,786.13	3,760.27	7,520.54	1,786.13	3,760.27	7,520.54	1,786.13	3,760.27	13.07	13.07	13.07
D2	TVRI office, by pass	9,275.50	2,202.93	4,637.75	15,820.06	3,757.26	7,910.03	21,215.05	5,038.57	10,607.52	16.12	27.49	36.86
E1	Gunung Pangilun	8,275.16	1,965.35	4,137.58	20,098.71	4,773.44	10,049.35	29,845.43	7,088.29	14,922.71	14.38	34.92	51.86
F1	Sungai Sapih	6,350.34	1,508.21	3,175.17	9,651.05	2,292.12	4,825.53	12,371.98	2,938.35	6,185.99	11.03	16.77	21.50
G1	Kubu Marapalam	16,983.05	4,033.47	8,491.52	29,569.85	7,022.84	14,784.92	39,945.76	9,487.12	19,972.88	29.51	51.38	69.41
H1	Teluk Kabung Utara	1,287.48	305.78	643.74	3,887.27	923.23	1,943.64	6,030.40	1,432.22	3,015.20	2.24	6.75	10.48
I1	Banuaran nan XX	3,581.54	850.62	1,790.77	9,973.58	2,368.73	4,986.79	15,242.85	3,620.18	7,621.43	6.22	17.33	26.48
Total		67,654.03	16,067.83	33,827.02	120,612.15	28,645.38	60,306.07	164,268.06	39,013.66	82,134.03	117.55	209.56	285.42

Table 4.9 Space Requirements of Relief Commodities

Refugee Camp	Location	Space Requirement (m^3) 24 hrs Rice			48 hrs			72 hrs			Total Space Requirement (m^3)		
		Rice	Noodle	Preserved Food	Rice	Noodle	Preserved Food	Rice	Noodle	Preserved Food	24 Hrs	48 Hrs	72 Hrs
A1	Batipuh Panjang	4.77	6.96	6.57	6.48	9.48	8.96	7.91	11.56	10.92	18.30	24.92	30.39
A2	Bukit Anak Aia	3.35	4.90	4.63	6.76	9.87	9.33	9.58	13.98	13.20	12.88	25.96	36.76
B1	Koto Pulai	3.94	5.76	5.44	6.32	9.24	8.73	8.31	12.13	11.45	15.13	24.30	31.89
B2	Balai Gadang	0.78	1.12	1.06	1.74	2.54	2.40	2.54	3.70	3.50	2.95	6.68	9.75
C1	Koto Panjang Ikua Koto	2.08	3.03	2.86	3.63	5.29	5.00	4.90	7.16	6.77	7.97	13.92	18.83
D1	Municipality office, By Pass	7.78	11.38	10.74	7.78	11.38	10.74	7.78	11.38	10.74	29.90	29.90	29.90
D2	TVRI office, by pass	9.61	14.02	13.25	16.37	23.91	22.60	21.95	32.05	30.30	36.88	62.88	84.30
E1	Gunung Pangilun	8.56	12.52	11.82	20.77	30.36	28.71	30.85	45.10	42.63	32.89	79.84	118.57
F1	Sungai Sapih	6.57	9.61	9.07	9.98	14.59	13.79	12.80	18.70	17.67	25.25	38.36	49.18
G1	Kubu Marapalam	17.58	25.66	24.26	30.57	44.67	42.23	41.29	60.34	57.06	67.50	117.47	158.69
H1	Teluk Kabung Utara	1.33	1.95	1.84	4.03	5.88	5.55	6.26	9.12	8.62	5.13	15.46	24.00
I1	Banuaran nan XX	3.72	5.41	5.12	10.32	15.08	14.25	15.78	23.04	21.77	14.25	39.65	60.59
Total		70.06	102.32	96.65	124.74	182.30	172.29	169.94	248.25	234.64	269.03	479.33	652.83

5.2.3. The Location-Allocation Problem

The dynamic increment of the required demand over the planning period implies the need of suitable strategic planning. The decision on the location-allocation for selecting the proper LDCs is conducted by developing scenarios containing a set of alternative LDCs. The scenarios are generated by utilizing ArcMap 10.2 software with the maximal coverage analysis. The mathematical formulation of the maximal coverage analysis can be seen in **Chapter 2**. Subsequently, the determination on the number of selected LDCs per day is assessed by calculating the minimum total fixed opening cost and transportation cost.

5.2.3.1. The Location-Allocation Parameters

The detailed setting of the parameters involved in the location-allocation using GIS tool can be seen in **Appendix B**. The parameters engaged in defining the location-allocation problem consist of set of refugee camps, weighted factors, set of facilities, and set of road barriers, as defined below:

a. *Set of Refugee Camps*. Regarding to the scenario developed by the local government [46], there are 12 final evacuation points that will prevail as the refugee camps to receive the relief aids from its assigned depot. This number is used as input of demand points in GIS. In the location-allocation decision, the location of refugee camp H1 is deputized by ship loading point. During the response phase this dropped point will be used by ship to continue transferring the relief commodities to the refugee camp H1.
b. *Set of Weighted Factors*. The weighted factors are utilized to portray the importance of each demand point to be served. These factors are set based on the total amount of the required demand per day, which is contained in **Table 4.8**. The relative weighted factor of each demand point will over the planning period is calculated from the percentage of the total demand amount, as can be seen from **Table 4.10**.
c. *Set of Facilities*. In this research, it is assumed that the refugee camps are also used as the LDC candidates. Therefore, the number of LDCs candidates will be similar to the number of demand points.

d. *Set of Road Barriers*. To model the expected impassable roads due to the disruptions affected by tsunami, these restrictions are set in the line barriers feature. There are 3,868 line barriers which represent the expected impassable roads under the tsunami inundation area.

Table 4.10 The Relative Weighted Factors

Refugee Camp	Location	Total Required Demand per Day (Tons)			Weighted Factors		
		24 Hrs	48 Hrs	72 Hrs	24 Hrs	48 Hrs	72 Hrs
A1	Batipuh Panjang	7.99	10.89	13.29	6.79%	5.20%	4.66%
A2	Bukit Anak Aia	5.63	11.35	16.06	4.79%	5.41%	5.63%
B1	Koto Pulai	6.61	10.62	13.93	5.62%	5.07%	4.88%
B2	Balai Gadang	1.28	2.91	4.25	1.09%	1.39%	1.49%
C1	Koto Panjang Ikua Koto	3.48	6.08	8.23	2.96%	2.90%	2.88%
D1	Municipality office, By Pass	13.07	13.07	13.07	11.12%	6.24%	4.58%
D2	TVRI office, by pass	16.12	27.49	36.86	13.71%	13.12%	12.91%
E1	Gunung Pangilun	14.38	34.92	51.86	12.23%	16.66%	18.17%
F1	Sungai Sapih	11.03	16.77	21.50	9.39%	8.00%	7.53%
G1	Kubu Marapalam	29.51	51.38	69.41	25.10%	24.52%	24.32%
H1	Teluk Kabung Utara	2.24	6.75	10.48	1.90%	3.22%	3.67%
I1	Banuaran nan XX	6.22	17.33	26.48	5.29%	8.27%	9.28%
Total		117.55	209.56	285.42	100%	100%	100%

5.2.3.2. The Location-Allocation Decisions

This research considers the effect of the dynamic increment of demand over the planning periods to the location-allocation decisions to select the suitable Local Distribution Centers (LDCs). An LDC, such as tent, is assumed to have a certain capacity and will be built in the post-occurrence of disaster. By using GIS tool with maximal coverage analysis, the set of alternative LDCs is generated. These alternative LDCs are later assessed to select the appropriate LDCs with the least total fixed opening cost and transportation cost. With regard to the different amount of the daily required demand, the decision on the selected LDCs will be calculated for each day. In this work, we assume the sustain-utilization of LDCs with the fixed opening cost 500 USD for unit capacity 168 m^3. The selected LDCs in a given day will be used as the required LDCs in the next day without any charge as long as its capacities are still sufficient to hold the arriving commodities. However, overcapacities will lead to the establishment of another unit of storage with additional fixed opening cost. Meanwhile, the consideration of the transportation cost for the three-tier relief distribution chain consisting warehouse, LDCs, and refugee camps are computed by calculating the loading-unloading cost, shipment cost, and labor cost, which is basically calculated from **Table 4.3**. As mentioned in the setting of location-allocation parameters, the LDCs candidates also use the same location with the available demand points. This means there will be no charge spent for transportation cost from the selected LDCs to its original demand point.

Table 4.11 presents the calculation for obtaining the fixed opening cost during the three days of emergency periods. In each day, the set of alternative LDCs as well as its recipients are acquired by utilizing the location-allocation solver in the network analysis feature. The total delivery amount of the required demand (**Table 4.8**) and the total space requirements (**Table 4.9**) of the LDCs' recipients are enumerated in order to determine the unit to be built by comparing to the unit capacity. In the second day and the third day, the establishment of LDC D2 and LDC G1 will not be charged since these two LDCs are selected in the first day. However, overcapacities will require the establishment of new unit by spending additional 500 USD.

Table 4.11 Fixed Opening Cost

Day	Scenario	Alternative LDCs	Capacity/ Unit (m^3)	Recipients	Total Delivery Amount (Tons)	Total Space Requirements (m^3)	Unit to build	Opening Cost (USD)	Total Opening Cost (USD)
1	1 Depot	LDC F1	168	A1, A2, B1, B2, C1, D1, D2, E1, F1, G1, Ship Loading Point, I1	117.549	243.782	2	1000	1000
	2 Depot	LDC D2	168	A1, A2, B1, B2, C1, D1, D2, F1	65.203	112.382	1	500	1000
		LDC G1	168	E1, G1, Ship Loading Point, I1	52.346	52.272	1	500	
	3 Depot	LDC D2	168	A1, A2, B1, B2, C1, D1, D2	54.169	87.130	1	500	1500
		LDC E1	168	E1, F1	25.412	25.252	1	500	
		LDC G1	168	G1, Ship Loading Point, I1	37.968	19.380	1	500	
2	2 Depot	LDC D2	168	A1, A2, B1, B2, C1, D1, D2, F1	99.181	164.033	1	0*	0
		LDC G1	168	E1, G1, Ship Loading Point, I1	110.382	134.953	1	0*	
	3 Depot	LDC D2	168	A1, A2, B1, B2, C1, D1, D2	82.413	125.673	1	0*	500
		LDC E1	168	E1, F1	51.690	38.360	1	500	
		LDC G1	168	G1, Ship Loading Point, I1	75.461	55.115	1	0*	
	4 Depot	LDC A1	168	A1, A2, B2	25.151	57.553	1	500	1000
		LDC D2	168	B1, C1, D1, D2	57.261	68.120	1	0*	
		LDC E1	168	E1, F1	51.690	38.360	1	500	
		LDC G1	168	G1, Ship Loading Point, I1	75.461	55.115	1	0*	
3	2 Depot	LDC D2	168	A1, A2, B1, B2, C1, D1, D2, F1	127.191	206.693	2	500**	1000
		LDC G1	168	E1, G1, Ship Loading Point, I1	158.224	203.151	2	500**	
	3 Depot	LDC D2	168	A1, A2, B1, B2, C1, D1, D2	105.695	157.517	1	0*	500
		LDC E1	168	E1, F1	73.353	49.176	1	500	
		LDC G1	168	G1, Ship Loading Point, I1	106.368	84.584	1	0*	
	4 Depot	LDC A1	168	A1, A2, B2	33.603	46.509	1	500	1000
		LDC D2	168	B1, C1, D1, D2	72.092	80.621	1	0*	
		LDC E1	168	E1, F1	73.353	49.176	1	500	
		LDC G1	168	G1, Ship Loading Point, I1	106.368	84.584	1	0*	

* No charge spent for opening cost

** Requires to build additional unit with additional charge

The cost resulted from delivering assigned LDCs to its recipients is divided to be two echelons. As shown in **Table 4.12**, the first echelon constitutes to the transportation cost from warehouse to each alternative LDCs. Meanwhile, the second echelon belongs to the cost spent for delivering the relief aids from the alternative LDCs to its demand points, which is explained in **Table 4.13**. The relative distance between the depot and its recipients is portrayed in **Appendix C**. The total quantity of relief goods which will be delivered from the depot to its demand points is originated from the cumulative amount of each recipients, which is basically calculated from **Table 4.8**.

the trip required for transporting the commodities is calculated by dividing the amount of demand with the capacity of the land vehicle (**Table 4.6**). Based on **Table 4.3**, the computation of the handling cost including the loading-unloading cost, shipment cost, and labor cost is enumerated. The loading-unloading cost is charged for the loading-unloading activities per ton. The shipment cost is spent for carrying the amount of relief goods per ton per km. Meanwhile, the labor cost, the cost spent for hiring the driver is charged per trip. Subsequently, the transportation cost is obtained by summarizing the total handling cost for each alternative decision.

Table 4.12 Transportation Cost First Echelon

Day	Warehouse	Scenario	Alternative LDCs	Distance (Km)	Total Delivery Amount (Tons)	Trip	Loading-Unloading Cost (USD)	Shipment Cost (USD)	Labor Cost (USD)	Total Transportation Cost (USD)
1	UPT BNPB Pusdalops PB	1 Depot	LDC F1	8.928	117.549	30	300.93	329.011	90	719.94
		2 Depot	LDC D2	15.146	65.203	17	166.92	309.601	51	796.84
			LDC G1	5.686	52.346	14	134.01	93.310	42	
		3 Depot	LDC D2	15.146	54.169	14	138.67	257.210	42	801.71
			LDC E1	10.405	25.412	7	65.05	82.892	21	
			LDC G1	5.686	37.968	10	97.20	67.680	30	
2	UPT BNPB Pusdalops PB	2 Depot	LDC D2	15.146	99.181	25	253.90	470.939	75	1363.19
			LDC G1	5.686	110.382	28	282.58	196.763	84	
		3 Depot	LDC D2	15.146	82.413	21	210.98	391.317	63	1389.93
			LDC E1	10.405	51.690	13	132.33	168.612	39	
			LDC G1	5.686	75.461	19	193.18	134.514	57	
		4 Depot	LDC A1	20.603	25.151	7	64.39	162.452	21	1435.95
			LDC D2	15.146	57.261	15	146.59	271.893	45	
			LDC E1	10.405	51.690	13	132.33	168.612	39	
			LDC G1	5.686	75.461	19	193.18	134.514	57	
3	UPT BNPB Pusdalops PB	2 Depot	LDC D2	15.146	127.191	32	325.61	603.939	96	1832.65
			LDC G1	5.686	158.224	40	405.05	282.045	120	
		3 Depot	LDC D2	15.146	105.695	27	270.58	501.868	81	1880.41
			LDC E1	10.405	73.353	19	187.78	239.274	57	
			LDC G1	5.686	106.368	27	272.30	189.608	81	
		4 Depot	LDC A1	20.603	33.603	9	86.02	217.041	27	1940.90
			LDC D2	15.146	72.092	19	184.56	342.314	57	
			LDC E1	10.405	73.353	19	187.78	239.274	57	
			LDC G1	5.686	106.368	27	272.30	189.608	81	

Table 4.13 Transportation Cost Second Echelon

Day	Scenario	Alternative LDCs	Recipients	Distance (Km)	Total Delivery Amount (Tons)	Trip	Loading-Unloading Cost (USD)	Shipment Cost (USD)	Labor Cost (USD)	Total Transportation Cost (USD)
1	1 Depot	LDC F1	A1	11.830	7.985	2	20.442	29.614	6	615.007
			A2	14.703	5.629	2	14.410	25.945	6	
			B1	9.924	6.610	2	16.922	20.565	6	
			B2	11.292	1.285	1	3.289	4.548	3	
			C	8.346	3.477	1	8.902	9.098	3	
			D1	3.472	13.067	4	33.451	14.223	12	
			D2	6.372	16.116	5	41.257	32.194	15	
			E1	5.167	14.378	4	36.808	23.290	12	
			F	0	11.034	0	0.000	0.000	0	
			G1	6.853	29.508	8	75.541	63.396	24	
			LP	7.142	2.237	1	5.727	5.009	3	
			I	9.455	6.223	2	15.931	18.446	6	
	2 Depot	LDC D2	A1	5.663	7.985	2	20.442	14.176	6	369.047
			A2	8.537	5.629	2	14.410	15.065	6	
			B1	3.757	6.610	2	16.922	7.786	6	
			B2	5.125	1.285	1	3.289	2.064	3	
			C	1.986	3.477	1	8.902	2.165	3	
			D1	3.239	13.067	4	33.451	13.269	12	
			D2	0	16.116	0	0.000	0.000	0	
			F	6.372	11.034	3	28.246	22.041	9	
		LDC G1	E1	7.155	14.378	4	36.808	32.251	12	
			G1	0	29.508	0	0.000	0.000	0	
			LP	2.108	2.237	1	5.727	1.478	3	
			I	4.421	6.223	2	15.931	8.625	6	

Table 4.13 Transportation Cost Second Echelon (Con't)

Day	Scenario	Alternative LDCs	Recipients	Distance (Km)	Total Delivery Amount (Tons)	Trip	Loading-Unloading Cost (USD)	Shipment Cost (USD)	Labor Cost (USD)	Total Transportation Cost (USD)
1	3 Depot	LDC D2	A1	5.663	7.985	2	20.442	14.176	6	283.820
			A2	8.537	5.629	2	14.410	15.065	6	
			B1	3.757	6.610	2	16.922	7.786	6	
			B2	5.125	1.285	1	3.289	2.064	3	
			C	1.986	3.477	1	8.902	2.165	3	
			D1	3.239	13.067	4	33.451	13.269	12	
			D2	0	16.116	0	0.000	0.000	0	
		LDC E1	E1	0	14.378	0	0.000	0.000	0	
			F	5.167	11.034	3	28.246	17.873	9	
		LDC G1	G1	0	29.508	0	0.000	0.000	0	
			LP	2.108	2.237	1	5.727	1.478	3	
			I	4.421	6.223	2	15.931	8.625	6	
2	2 Depot	LDC D2	A1	5.663	10.892	3	27.883	19.337	9	669.852
			A2	8.537	11.346	3	29.047	30.367	9	
			B1	3.757	10.624	3	27.197	12.513	9	
			B2	5.125	2.913	1	7.457	4.680	3	
			C	1.986	6.083	2	15.573	3.788	6	
			D1	3.239	13.067	4	33.451	13.269	12	
			D2	0	27.487	0	0.000	0.000	0	
			F	6.372	16.769	5	42.928	33.498	15	
		LDC G1	E1	7.155	34.922	9	89.399	78.332	27	
			G1	0	51.378	0	0	0	0	
			LP	2.108	6.754	2	17.291	4.464	6	
			I	4.421	17.329	5	44.363	24.018	15	

Table 4.13 Transportation Cost Second Echelon (Con't)

Day	Scenario	Alternative LDCs	Recipients	Distance (Km)	Total Delivery Amount (Tons)	Trip	Loading-Unloading Cost (USD)	Shipment Cost (USD)	Labor Cost (USD)	Total Transportation Cost (USD)
2	3 Depot	LDC D2	A1	5.663	10.892	3	27.883	19.337	9	468.787
			A2	8.537	11.346	3	29.047	30.367	9	
			B1	3.757	10.624	3	27.197	12.513	9	
			B2	5.125	2.913	1	7.457	4.680	3	
			C	1.986	6.083	2	15.573	3.788	6	
			D1	3.239	13.067	4	33.451	13.269	12	
			D2	0	27.487	0	0	0	0	
		LDC E1	E1	0	34.922	0	0	0	0	
			F	5.167	16.769	5	42.928	27.163	15	
		LDC G1	G1	0	51.378	0	0	0	0	
			LP	2.108	6.754	2	17.291	4.464	6	
			I	4.421	17.329	5	44.363	24.018	15	
	4 Depot	LDC A1	A1	0	10.892	0	0	0	0	390.510
			A2	2.873	11.346	3	29.047	10.220	9	
			B2	3.034	2.913	1	7.457	2.771	3	
		LDC D2	B1	3.757	10.624	3	27.197	12.513	9	
			C	1.986	6.083	2	15.573	3.788	6	
			D1	3.239	13.067	4	33.451	13.269	12	
			D2	0	27.487	0	0	0	0	
		LDC E1	E1	0	34.922	0	0	0	0	
			F	5.167	16.769	5	42.928	27.163	15	
		LDC G1	G1	0	51.378	0	0	0	0	
			LP	2.108	6.754	2	17.291	4.464	6	
			I	4.421	17.329	5	44.363	24.018	15	

Table 4.13 Transportation Cost Second Echelon (Con't)

Day	Scenario	Alternative LDCs	Recipients	Distance (Km)	Total Delivery Amount (Tons)	Trip	Loading-Unloading Cost (USD)	Shipment Cost (USD)	Labor Cost (USD)	Total Transportation Cost (USD)
3	2 Depot	LDC D2	A1	5.663	13.288	4	34.017	23.591	12	922.725
			A2	8.537	16.060	5	41.113	42.981	15	
			B1	3.757	13.933	4	35.667	16.410	12	
			B2	5.125	4.255	2	10.893	6.836	6	
			C	1.986	8.232	3	21.073	5.125	9	
			D1	3.239	13.067	4	33.451	13.269	12	
			D2	0	36.861	0	0	0	0	
			F	6.372	21.496	6	55.031	42.942	18	
		LDC G1	E1	7.155	51.856	13	132.752	116.319	39	
			G1	0	69.406	0	0.000	0	0	
			LP	2.108	10.478	3	26.823	6.924	9	
			I	4.421	26.484	7	67.800	36.707	21	
	3 Depot	LDC D2	A1	5.663	13.288	4	34.017	23.591	12	626.533
			A2	8.537	16.060	5	41.113	42.981	15	
			B1	3.757	13.933	4	35.667	16.410	12	
			B2	5.125	4.255	2	10.893	6.836	6	
			C	1.986	8.232	3	21.073	5.125	9	
			D1	3.239	13.067	4	33.451	13.269	12	
			D2	0	36.861	0	0	0	0	
		LDC E1	E1	0	51.856	0	0	0	0	
			F	5.167	21.496	6	55.031	34.821	18	
		LDC G1	G1	0	69.406	0	0	0	0	
			LP	2.108	10.478	3	26.823	6.924	9	
			I	4.421	26.484	7	67.800	36.707	21	

Table 4.13 Transportation Cost Second Echelon (Con't)

Day	Scenario	Alternative LDCs	Recipients	Distance (Km)	Total Delivery Amount (Tons)	Trip	Loading-Unloading Cost (USD)	Shipment Cost (USD)	Labor Cost (USD)	Total Transportation Cost (USD)
3	4 Depot	LDC A1	A1	0	13.288	0	0	0	0	525.619
			A2	2.873	16.060	5	41.113	14.465	15	
			B2	3.034	4.255	2	10.893	4.047	6	
		LDC D2	B1	3.757	13.933	4	35.667	16.410	12	
			C	1.986	8.232	3	21.073	5.125	9	
			D1	3.239	13.067	4	33.451	13.269	12	
			D2	0	36.861	0	0	0	0	
		LDC E1	E1	0	51.856	0	0	0	0	
			F	5.167	21.496	6	55.031	34.821	18	
		LDC G1	G1	0	69.406	0	0	0	0	
			LP	2.108	10.478	3	26.823	6.924	9	
			I	4.421	26.484	7	67.800	36.707	21	

Table 4.14 summarizes the total cost of the location-allocation decision for each alternative LDCs consisting total fixed opening cost and total transportation cost of the three-tier relief chain. In the first day and second day, the minimum total cost is yielded by establishing two depots, LDC D2 and LDC G1. Interestingly, no opening cost charged for establishing both LDCs in the second day since their capacities are still sufficient to storage the relief items. However, in the third day, the minimum cost is gained by adding one more LDC, LDC E1. The total location-allocation cost for three consecutive day reaches 7,205.869 USD.

Table 4.14 Total Location-Allocation Cost

Day	Scenario	Alternative LDCs	Total Opening Cost (USD)	Total Transportation Cost (USD)		Total Cost (USD)
				1st Echelon	2nd Echelon	
1	1 Depot	LDC F1	1000	719.936	615.007	2334.943
	2 Depot	LDC D2 LDC G1	1000	796.836	369.047	**2165.883**
	3 Depot	LDC D2 LDC E1 LDC G1	1500	801.707	283.820	2585.527
2	**2 Depot**	LDC D2 LDC G1	0	1363.186	669.852	**2033.038**
	3 Depot	LDC D2 LDC E1 LDC G1	500	1389.925	468.787	2358.712
	4 Depot	LDC A1 LDC D2 LDC E1 LDC G1	1000	1435.953	390.510	2826.463
3	2 Depot	LDC D2 LDC G1	1000	1832.648	922.725	3755.373
	3 Depot	LDC D2 LDC E1 LDC G1	500	1880.414	626.533	**3006.948**
	4 Depot	LDC A1 LDC D2 LDC E1 LDC G1	1000	1940.901	525.619	3466.520

The spatial information of the selected LDCs in the first day and the second day, LDC D2 and LDC G1 is presented in **Figure 4.4**. The linear transformation is used to depict the stream line between the selected depots to its recipients. LDC D2 is assigned to serve eight demand points including the location itself. At the same time refugee camp E1, G1, the ship loading point, and I1 are employed as demand point of LDC G1.

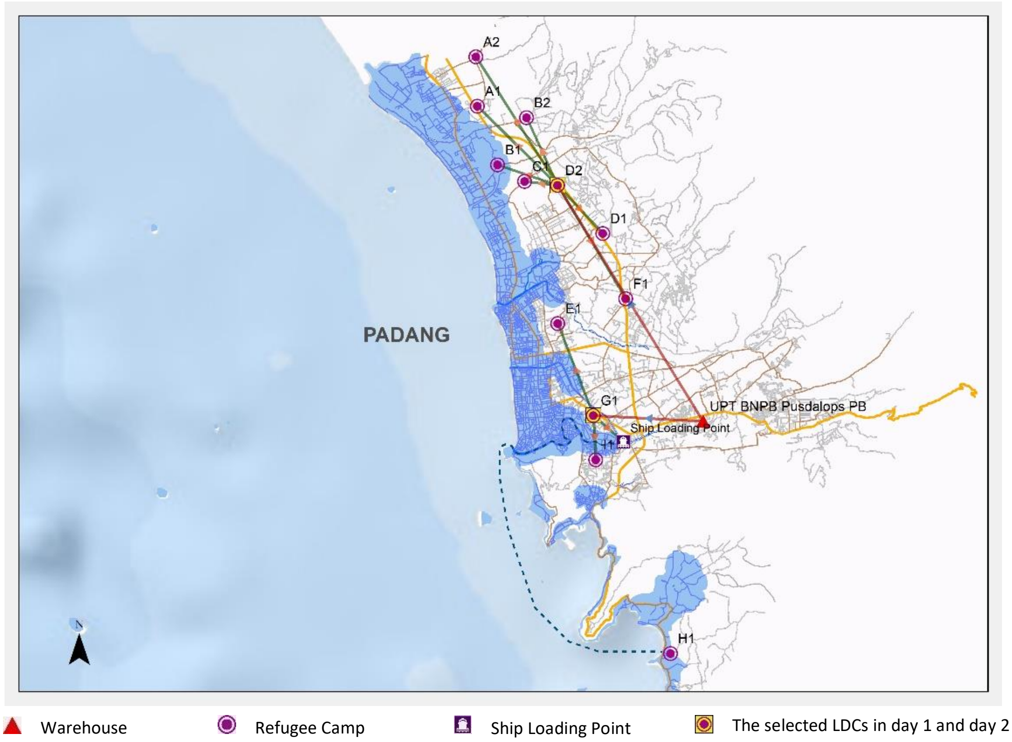


Figure 4.4 The Selected LDCs-Recipients Day 1 and Day 2

The spatial information of the selected LDCs and its demand points in the third day is provided by **Figure 4.5**. The assigned demand points of LDC D2 becomes seven refugee camps. LDC G1, on the other hand, has three demand points. Meanwhile, the LDC E1 is required to serve refugee camp F1 and the demand occurring in its own point.

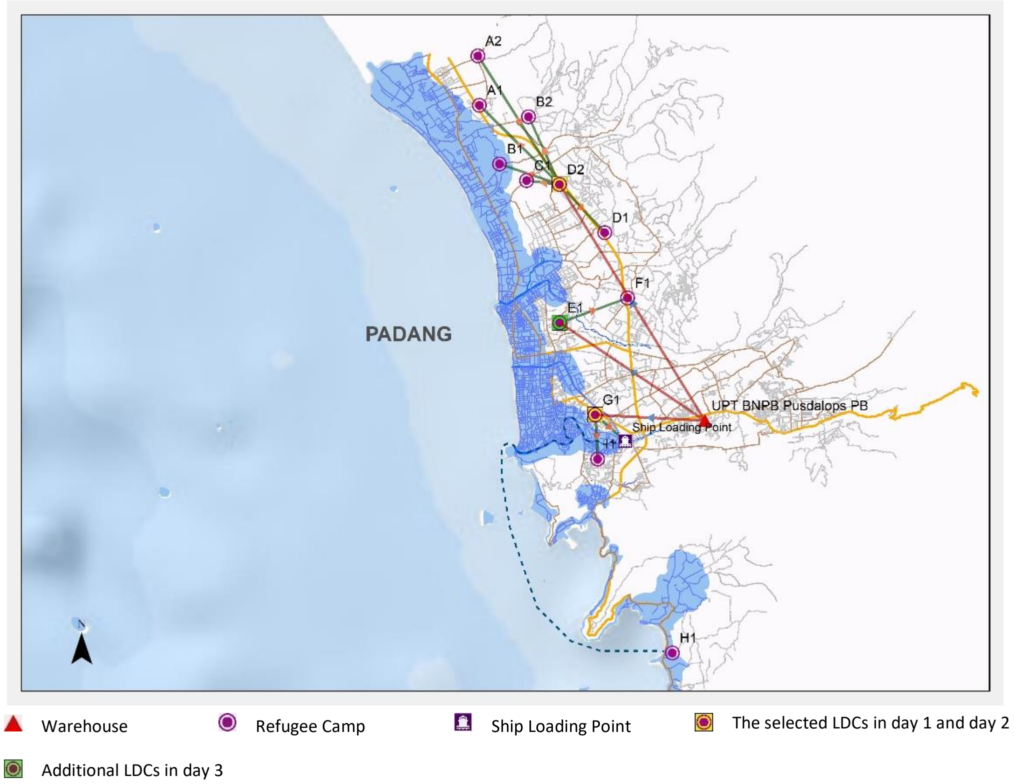


Figure 4.5 The Selected LDCs-Recipients Day 3

5.2.4. The Relief Routing and Assignment

As the response phase begins, the implementation of the integrated strategic-operational level must be activated. The selected LDCs during the response phase will receive the relief aids from the warehouse to be continued to send to its recipients. During the operational stage, this work attempts to compare the effectiveness of two distribution strategies, the equalized strategy and the synchronized strategy, as mentioned in sub-section **5.1.1.2**. In this section, firstly the use of GIS application to solve the Capacitated Vehicle Routing Problem (CVRP) is occupied by using the individual vehicle. The mathematical formulation of the CVRP model can be seen in **Chapter 2**. Afterwards, more complex models are exploited to be later assessed to propose an appropriate distribution strategy with the least operational cost.

5.2.4.1. Capacitated Vehicle Routing Problem (CVRP)

The CVRP analysis solved by GIS is applied for two relief distribution strategies, the equalized strategy and the synchronized strategy. Three-tier distribution started from the warehouse, LDCs, and refugee camps is executed. The individual vehicle with capacity 4 tons is enclosed to deliver the relief commodities. The expected impassable road barriers are added to avoid the expected damage roads. Based on the allocation result in the strategic level, the route and its delivery quantities are solved by suiting to the capacity of vehicle.

The setting of CVRP Parameters includes the number of orders, depots, routes (vehicle), route renewals, and line barriers. The detailed information of this setting can be seen in **Appendix D**. The CVRP setting is explained in the following steps:

a. *Adding Orders*. In ArcGIS application, orders belong to the demand points requesting the relief aids to its assigned depots. The number of orders is adjusted according to the required demands of each depots' recipients.
b. *Adding Depots*. The number of added depots is customized based on the existing warehouse and the selected LDCs during the location-allocation problem. This research allows the joint fulfillment between two or more depots to distribute one demand point as long as the routing assignment results in an optimum distance.
c. *Adding Routes*. ArcGIS defines routes as the number of vehicle utilized to transport the goods. In this work, the individual vehicle is employed to obtain the suitable distribution routes. In the properties setting, the originated depot of the relief vehicle is set. The capacity of the vehicle is assigned to be 4 Tons.
d. *Route Renewals*. The route renewals are purposed to generate the revisit and reload activities of the defined vehicles to its designated depot. By setting the route renewals' properties, the associated depot and its route is determined.
e. *Line Barriers*. As done in the location-allocation problem, the line barriers are included to delineate the expected damage roads after the tsunami inundation. There are 3,868 line barriers which represent the predicted impassable paths based on the scenario developed by the local government.

5.2.4.2. CVRP Results

The route assignments generated by GIS are conducted per day during 72 hours of emergency periods. The path network between the depots and its service area can be seen in **Appendix C**. This research enables the flexibility in the routing decisions in the CVRP analysis by allowing two LDCs to fulfill the relief aids in a given refugee camp in order to optimize the travel distance. The first set of equalized routing analysis given by **Figure 4.6** presents the spatial information of the routing decision day 1 and day 2. The solutions signify the identical routing decisions utilized in these two days due to the similarity in the delivery amount and the number of depots. Interestingly, the refugee camp E1 which originally belongs to the LDC D2 service area during day 1 and day 2 is supplied by two LDCs in the operational stage. In **Figure 4.7**, it can be seen that the additional LDC (LDC E1) causes a different routing solution for day 3. On the other hand, the routing decisions of the synchronized strategy vary in each day due to the different quantity of the allocated relief commodities. The representation of the daily routing decisions of the synchronized distribution can be seen in **Figure 4.8**, **Figure 4.9**, and **Figure 4.10**.

The detailed information about the amount shipped from the depots to its recipients including the number of relief goods, trip for each route, and the amount carried for each trip is provided in **Table 4.15** and **Table 4.16** respectively for both equalized strategy and synchronized strategy. The table contains the three-tier routing decisions per day started from the warehouse UPT BNPB Pusdalops PB to the selected LDCs, continued by the LDCs to their demand points.

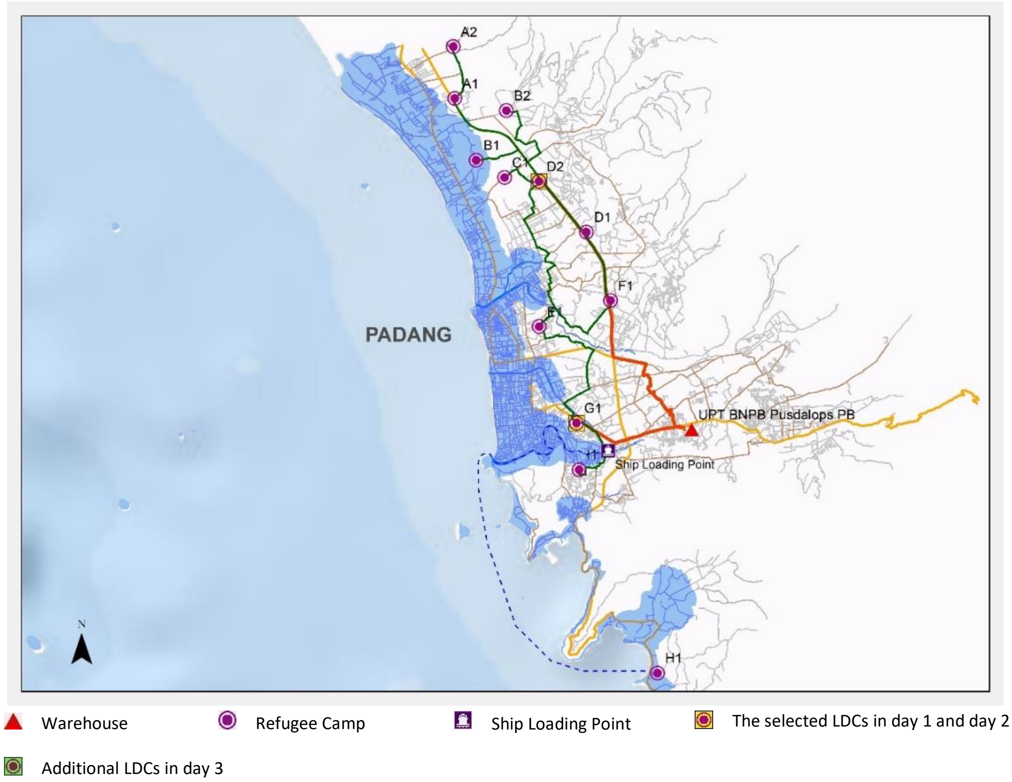


Figure 4.6 Spatial Information of Equalized Strategy Day 1 and Day 2

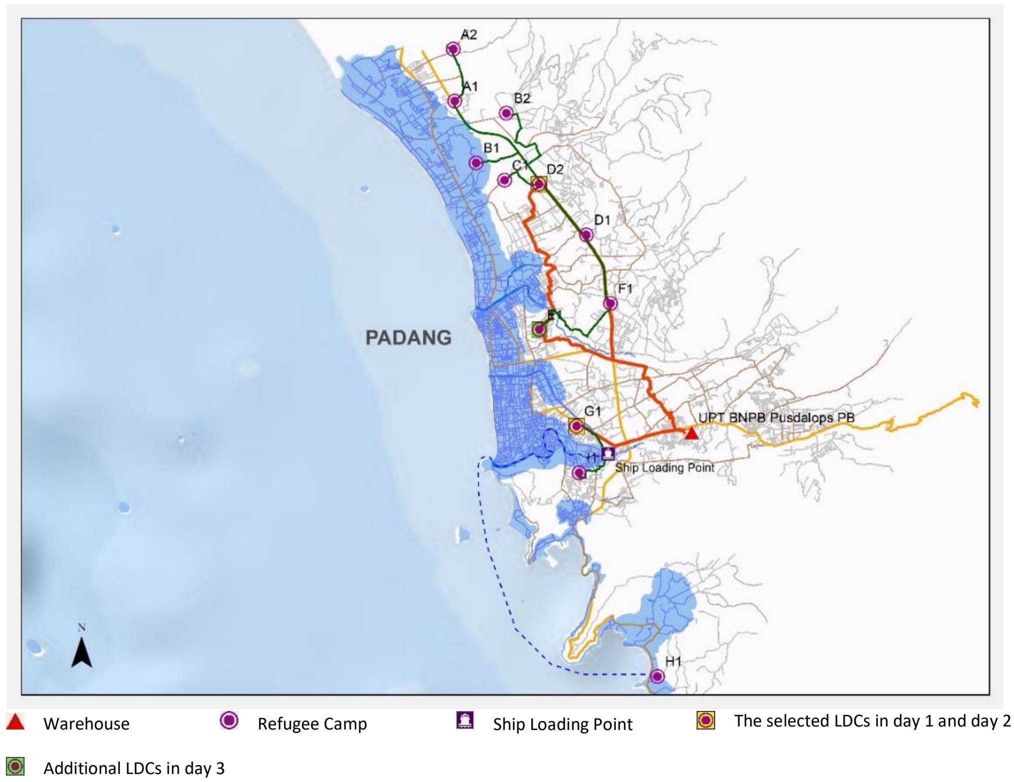
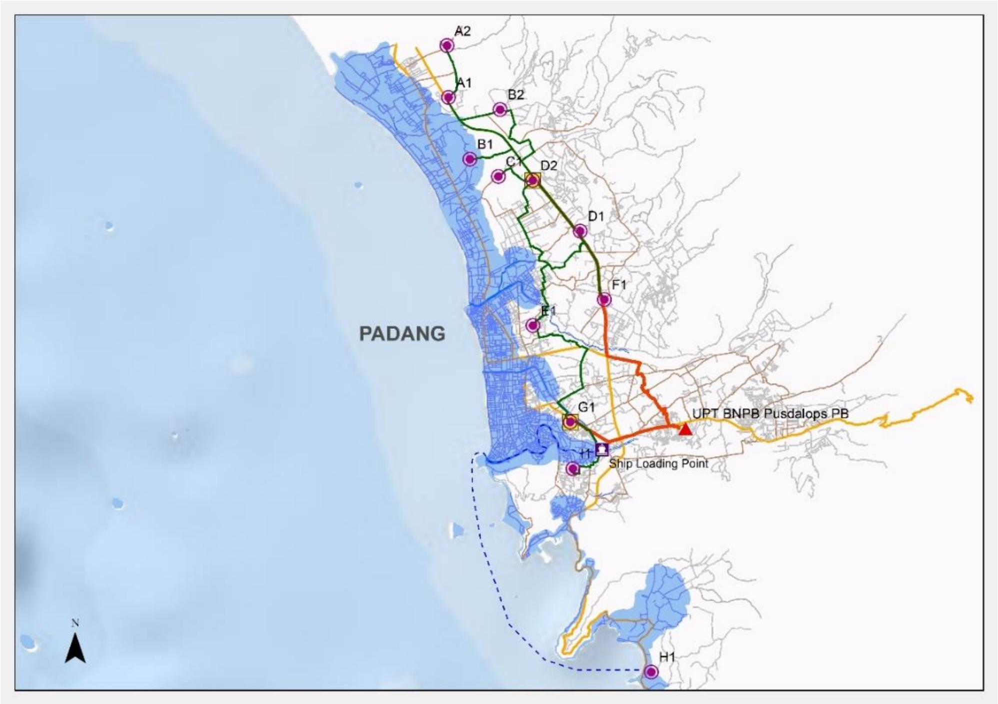


Figure 4.7 Spatial Information of Equalized Strategy Day 3

Table 4.15 Routing Decisions of the Equalized Strategy

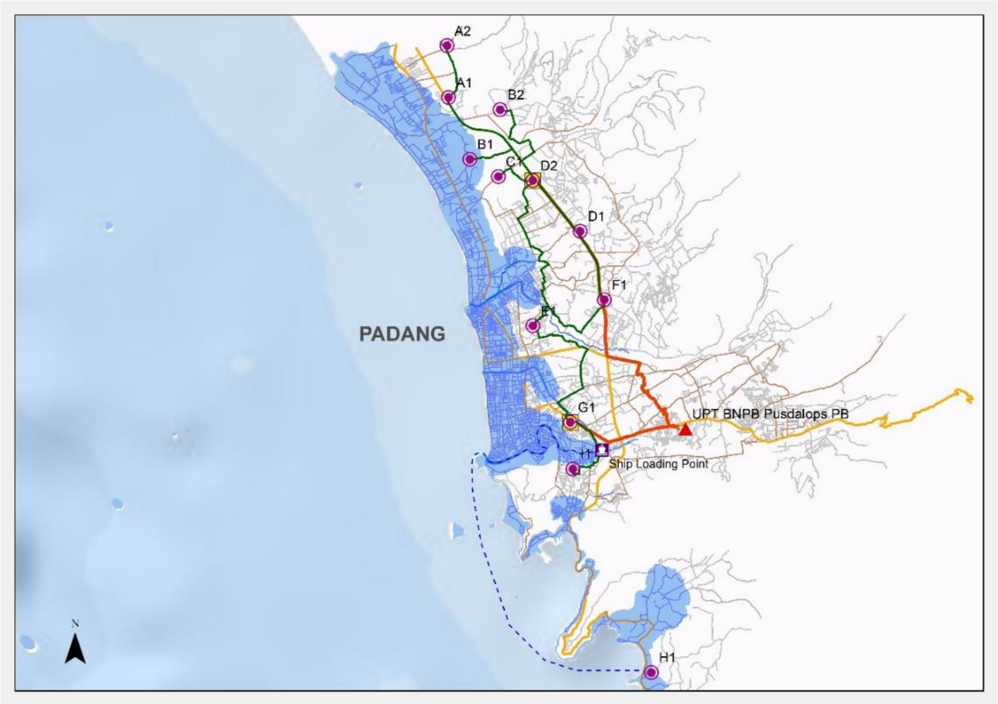
Day	Depot	No	Recipient	Delivery Amount (Tons)	Trip	Total Amount (Tons)	Distribution Cost (USD)
1	UPT BNPB Pusdalops PB (Warehouse)	1	LDC D2	2.910	1	2.910	16.582
		2	LDC D2	4	24	96	522.120
		3	LDC G1	1.266	1	1.266	3.293
		4	LDC G1	4	26	104	212.345
	LDC D2	1	F1	4	4	16	36.610
		2	D1	4	3	12	13.957
		3	E1, F1, D1	3.219	1	3.219	7.176
		4	B1	2.389	1	2.389	3.499
		5	A1	2.722	1	2.722	5.865
		6	A1	4	2	8	16.268
		7	A2	3.012	1	3.012	9.617
		8	A2	4	2	8	24.524
		9	B2	2.817	1	2.817	5.461
		10	B1	4	2	8	10.793
		11	C1	1.931	1	1.931	1.564
		12	C1	4	1	4	2.853
	LDC G1	1	E1	4	8	32	82.217
		2	I1	4	4	16	25.400
		3	I1, LP	3.168	1	3.168	3.266
		4	LP	4	1	4	3.028
2	UPT BNPB Pusdalops PB (Warehouse)	1	LDC D2	2.910	1	2.910	16.582
		2	LDC D2	4	24	96	522.120
		3	LDC G1	1.266	1	1.266	3.293
		4	LDC G1	4	26	104	212.345
	LDC D2	1	F1	4	4	16	36.610
		2	D1	4	3	12	13.957
		3	E1, F1, D1	3.219	1	3.219	7.176
		4	B1	2.389	1	2.389	3.499
		5	A1	2.722	1	2.722	5.865
		6	A1	4	2	8	16.268
		7	A2	3.012	1	3.012	9.617
		8	A2	4	2	8	24.524
		9	B2	2.817	1	2.817	5.461
		10	B1	4	2	8	10.793
		11	C1	1.931	1	1.931	1.564
		12	C1	4	1	4	2.853
	LDC G1	1	E1	4	8	32	82.217
		2	I1	4	4	16	25.400
		3	I1, LP	3.168	1	3.168	3.266
		4	LP	4	1	4	3.028
3	UPT BNPB Pusdalops PB (Warehouse)	1	LDC D2	4	20	80	435.100
		2	LDC E1	4	12	48	179.343
		3	LDC D2, LDC E1	2.910	1	2.910	12.279
		4	LDC G1	1.266	1	1.266	3.293
		5	LDC G1	4	18	72	147.008
	LDC D2	1	D1	4	3	12	13.957
		2	C1	1.931	1	1.931	1.564
		3	C1	4	1	4	2.853
		4	A2	3.012	1	3.012	9.617
		5	A2	4	2	8	24.524
		6	F1, D1, B1	3.889	1	3.889	7.797
		7	A1	2.722	1	2.722	5.865
		8	A1	4	2	8	16.268
		9	B2	2.817	1	2.817	5.461
		10	B1	4	2	8	10.793
	LDC E1	1	F1	4	4	16	29.687
	LDC G1	1	I1	4	4	16	25.400
		2	I1, LP	3.168	1	3.168	3.266
		3	LP	4	1	4	3.028
Total Distribution Cost (USD)							**2949.979**



Warehouse Refugee Camp Ship Loading Point The selected LDCs in day 1 and day 2

Additional LDCs in day 3

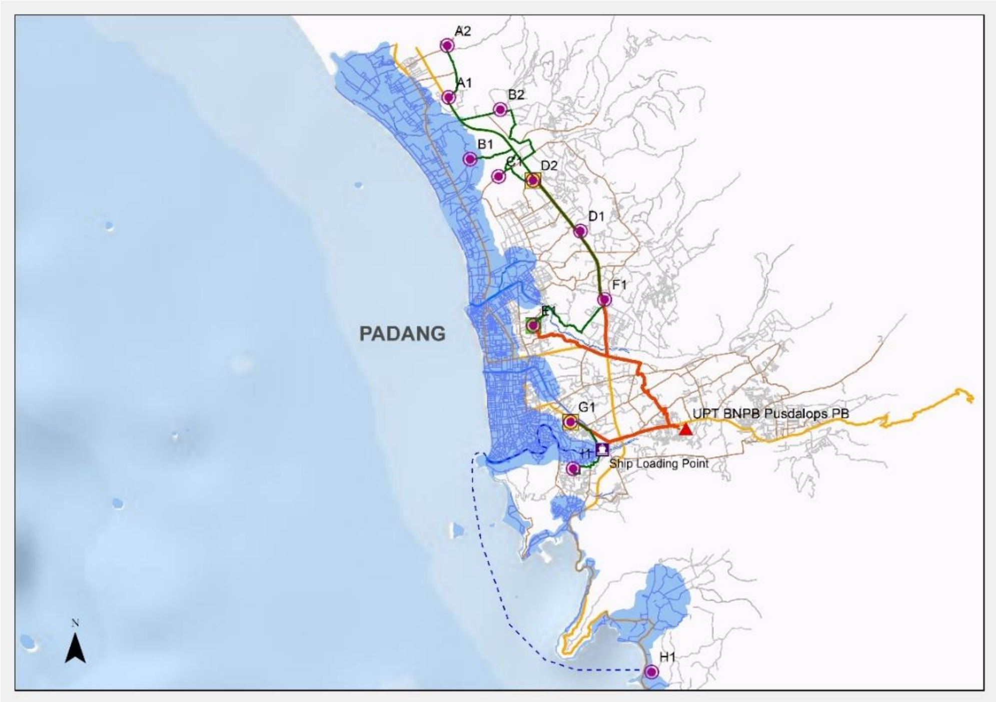
Figure 4.8 Spatial Information of Synchronized Strategy Day 1



Warehouse Refugee Camp Ship Loading Point The selected LDCs in day 1 and day 2

Additional LDCs in day 3

Figure 4.9 Spatial Information of Synchronized Strategy Day 2



Warehouse
Refugee Camp
Ship Loading Point
The selected LDCs in day 1 and day 2
Additional LDCs in day 3

Figure 4.10 Spatial Information of Synchronized Strategy Day 3

Table 4.16 Routing Decisions of the Synchronized Strategy

Day	Depot	No	Recipient	Delivery Amount (Tons)	Trip	Total Amount (Tons)	Distribution Cost (USD)
1	UPT BNPB Pusdalops PB (Warehouse)	1	LDC D2	3.581	1	3.581	19.765
		2	LDC D2	4	16	64	348.080
		3	LDC G1	1.968	1	1.968	4.545
		4	LDC G1	4	12	48	98.005
	LDC D2	1	F1	4	2	8	18.305
		2	F1	3.034	1	3.034	7.222
		3	D1	4	3	12	13.957
		4	A1	3.985	1	3.985	8.108
		5	A1	4	1	4	8.134
		6	A2	4	1	4	12.262
		7	E1, D1	3.445	1	3.445	9.404
		8	A2, B2	2.913	1	2.913	7.673
		9	B1	2.610	1	2.610	3.759
		10	B1	4	1	4	5.396
		11	C1	3.477	1	3.477	2.527
	LDC G1	1	E1	4	3	12	30.831
		2	I1	2.223	1	2.223	3.887
		3	I1	4	1	4	6.350
		4	LP	2.237	1	2.237	1.863
2	UPT BNPB Pusdalops PB (Warehouse)	1	LDC D2	2.103	1	2.103	12.746
		2	LDC D2	4	25	100	543.875
		3	LDC G1	3.461	1	3.461	7.206
		4	LDC G1	4	26	104	212.345
	LDC D2	1	F1	4	4	16	36.610
		2	D1	4	3	12	13.957
		3	E1, F1	3.690	1	3.690	10.436
		4	C1	2.083	1	2.083	1.659
		5	D1, A1	3.959	1	3.959	10.001
		6	A1	4	2	8	16.268
		7	A2	3.346	1	3.346	10.513
		8	A2	4	2	8	24.524
		9	B2	2.913	1	2.913	5.615
		10	B1	2.624	1	2.624	3.776
		11	B1	4	2	8	10.793
		12	C1	4	1	4	2.853
	LDC G1	1	E1	4	8	32	82.217
		2	I1	1.329	1	1.329	2.648
		3	I1	4	4	16	25.400
		4	LP	2.754	1	2.754	2.204
		5	LP	4	1	4	3.028
3	UPT BNPB Pusdalops PB (Warehouse)	1	LDC D2	3.191	1	3.191	17.915
		2	LDC D2	4	26	104	565.630
		3	LDC E1	3.856	1	3.856	14.477
		4	LDC E1	4	17	68	254.069
		5	LDC G1	2.368	1	2.368	5.258
		6	LDC G1	4	26	104	212.345
	LDC D2	1	B2, A1, A2, B1, C1	3.767	1	3.767	7.647
		2	F1, D1	2.563	1	2.563	4.741
		3	D1	4	3	12	13.957
		4	C1	4	2	8	5.705
		5	A2	4	4	16	49.049
		6	A1	4	3	12	24.402
		7	B2	4	1	4	7.361
		8	B1	4	3	12	16.189
	LDC E1	1	F1	4	5	20	37.108
	LDC G1	1	I1	2.484	1	2.484	4.250
		2	I1	4	6	24	38.101
		3	LP	2.478	1	2.478	2.022
		4	LP	4	2	8	6.056
			Total Distribution Cost (USD)				**2935.029**

5.2.4.3. Relief Vehicle Allocation

The routing decisions resulted from GIS with the utilization of the individual vehicle are expanded to more complex treatments by allowing the enforcement of a fleet of vehicles. Based on the available number of vehicles in **Table 4.6**, there are 28 units of 6 wheeler truck and 2 units of ship which are consigned to run the relief delivery activities. Due to the distinct solutions yielded from the location-allocation decisions per day as an effect of the dynamic increment of demands, allocating an appropriate number of vehicle in each depot is necessary. This part conducts the daily allocation for the land transportation vehicle for both equalized strategy and synchronized strategy. The ratio of the shipment amount for each depot to the total shipment amount per day is used as the multiplier for deciding the vehicle allocation.

As given by **Table 4.17**, the equalized strategy which is fundamentally based on the identic amount of shipment generates similar allocation for day 1 and day 2. However, the ratio of the vehicle allocation in the third day is fitted to the additional LDC which will be established in day 3.

Table 4.17 Vehicle Allocation per Day for the Equalized Strategy

Depot	Shipment Amount (Tons)			Vehicle Allocation (Truck		
	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3
UPT BNPB Pusdalops PB	204.176	204.176	204.176	17	17	19
LDC D2	72.089	72.089	54.370	6	6	5
LDC E1	-	-	16.000	-	-	2
LDC G1	55.168	55.168	23.168	5	5	2
Total	331.433	331.433	297.715	28	28	28

From **Table 4.18** there is clear trend of increasing demand amount per day which significantly affects to the allocation of relief vehicles. Comparing to the equalized strategy, the daily vehicle allocation of the synchronized strategy will vary in each day over the three days of planning period.

Table 4.18 Vehicle Allocation per Day for the Synchronized Strategy

Depot	Shipment Amount (Tons)			Vehicle Allocation (Truck)		
	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3
UPT BNPB Pusdalops PB	117.549	209.564	285.416	17	17	19
LDC D2	51.465	74.615	70.330	8	6	5
LDC E1	-	-	20	-	-	1
LDC G1	20.460	56.083	36.962	3	5	3
Total	189.474	340.262	412.708	28	28	28

5.2.4.4. Simulation Modelling

Simulation is considered to play a prominent role in the development of the strategic tactical and operational decisions to obtain the dynamicity of the logistics problems in the disaster relief operations [52]. In this study, ProModel® 2016 simulation software is encompassed to construct the simulation modelling. Two dynamic-stochastic models, the equalized strategy and the synchronized strategy are developed to generate the least-cost relief distribution strategy measured by the total cost spent for the relief delivery activities. Similar to the location-allocation analysis, the handling cost involves the loading-unloading cost, shipment cost, and labor cost. However, the change in the routing decisions may significantly affect to the handling cost result. Therefore, in the simulation modelling, it is important to reconsider the amount of handling cost. Afterwards, the calculation of the holding cost for stockpiling a number of items and the penalty cost due to the shortage fulfillment are enclosed based on **Table 4.4**.

In this work, the stochastic instruments involving demand requirements, vehicle velocity, and the road restoration time are treated in both distribution strategies. The dynamic environment is also included to reflect the relief fulfillment efforts during the three days of emergency periods. In addition, the time needed for the loading-unloading activities is included. Moreover, the time windows are considered to be another challenge with 16 hours of the operational working hours per day. Subsequently, the allocated vehicles in each depot per day are assigned to performs the relief distribution operations.

To convert a conceptual model into a simulation formula, the research composes the methodical programming which is also portrayed in **Appendix E**. Meanwhile, the simulation coding can be seen in **Appendix F**. The following stages include:

a. *Build entities*. Entities represents the inputs which will be processed in the model to be later routed as outputs of the system. The entities may have special characteristic such as speed, size, condition, etc. In this research, entities are time windows, relief aids, demands, and truck freight.

b. *Build locations*. The locations belong to the place where the entities arrive for processing, waiting, or decision making. The locations involved in this research include the location of warehouse, LDCs, refugee camps, and ship loading point.

c. *Layout*. The layout setting is aimed to visualize the relief routing efforts. The layout design of this research involves the map of Padang City containing facilities and road network, the information about the gap between the delivered commodities and the actual demand amount, and the resource assignment.

d. *Build resources*. The resources are used to process the entities throughout the system. This research uses the dynamic resources which move from its depots to the designated recipients.

e. *Build paths*. The paths network developed in this research is built based on the spatial measurement from GIS. During the process, the path network is used by the resources as the course of travel to transport the relief aids.

f. *Build arrivals*. The time, quantity, frequency, and location of entities when entering the system are engaged in the entities arrivals. In the arrival box, the scheduled arrivals during the three days of emergency periods are composed.

g. *Arrival cycles*. In this research, the arrival cycle is designed to depict the uncertainties in term of the stochastic demand occurring during the 2^{nd} term arrival.

h. *Build variables*. The variables contained in this research consist of decision variables, response variables, and state variables. These variables are used for making decisions and gathering the intended result.

i. *Build process and routing*. The operation logic for each type of entity in each location is defined in the processing. The outputs of the process are routed to define the next process. In this work the three-tier relief distribution flow during three days of the emergency periods is demonstrated.

j. *Macros*. This work specifies the often-used expressions and function in macros. In macros, the what-if analysis is also conducted by setting up some parameters.

5.2.4.5. The Equalized Strategy

The equalized strategy aims to provide an identical amount of the relief aids shipped to the demand points over the planning period. Most of the previous cited research (e.g. [20], [22], [2], [34]) assumed that the demand requests are similar in each day. In this research, the effectiveness of this relief distribution strategy is examined by measuring the total cost including holding cost, shortage cost, and handling cost.

In ProModel®, the state of the SimRunner as the evolutionary algorithms can be used to analyze the appropriate replications. The number of replication for the equalized strategy is shown in **Figure 4.11**. The confidence level is set to be 0.95 and with significant level (α) 1. With the initial test 20 replications, the result denotes 45 replications for running the equalized strategy.

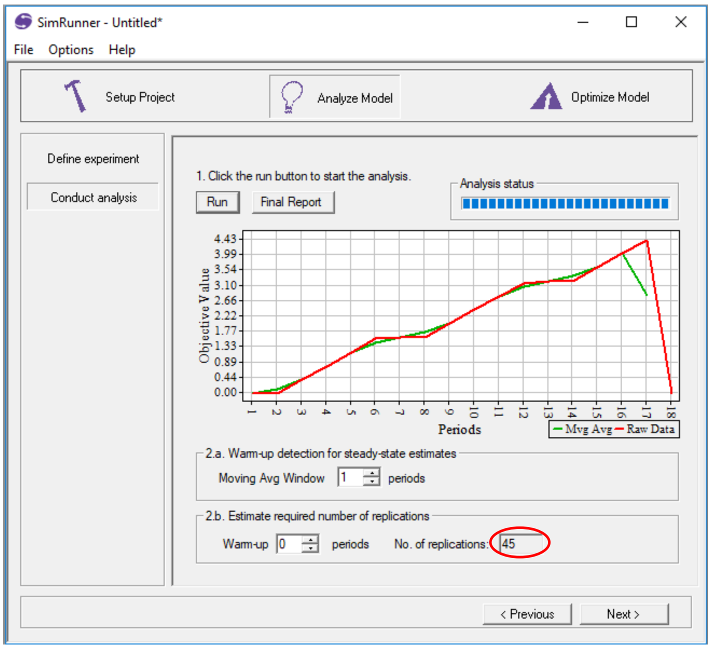


Figure 4.11 Model Replication of the Equalized Strategy

From 45 replications, as given by **Table 4.19**, the average total cost obtained to run the equalized strategy for three consecutive days is 47,256.30 USD. Interestingly, 43.47% of the total cost is spent for holding the relief aids in the first day. Meanwhile, the average holding cost in the second day reaches 19,274.11 USD which is apparently 40.79% of the total distribution cost. However, this strategy has advantages for tackling the shortage of relief demands by treating zero cost particularly in the first day and second day.

Table 4.19 Total Distribution Cost of the Equalized Strategy

Replication	Total Holding Cost (USD)			Total Shortage Cost (USD)			Total Handling Cost (USD)			Total Cost (USD)
	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3	
1	20,520.23	19,228.38	35.56	-	-	1,416.55	2,180.48	2,180.48	1,997.83	47,559.50
2	20,541.57	19,261.57	73.79	-	-	1,416.55	2,180.48	2,180.48	1,997.83	47,652.25
3	20,515.49	19,233.13	23.78	-	-	1,352.16	2,180.48	2,180.48	1,997.83	47,483.33
4	20,551.05	19,335.05	87.17	-	-	128.78	2,180.48	2,180.48	1,997.83	46,460.82
5	20,510.75	19,209.42	21.10	-	-	1,738.49	2,180.48	2,180.48	1,997.83	47,838.54
6	20,551.05	19,290.01	82.96	-	-	726.62	2,180.48	2,180.48	1,997.83	47,009.42
7	20,524.97	19,244.98	54.52	-	-	1,144.96	2,180.48	2,180.48	1,997.83	47,328.21
8	20,562.90	19,323.20	109.04	-	-	441.37	2,180.48	2,180.48	1,997.83	46,795.28
9	20,553.42	19,292.38	79.14	-	-	901.44	2,180.48	2,180.48	1,997.83	47,185.16
10	20,548.68	19,299.50	54.29	-	-	321.94	2,180.48	2,180.48	1,997.83	46,583.18
11	20,562.90	19,311.35	87.70	-	-	492.09	2,180.48	2,180.48	1,997.83	46,812.82
12	20,541.57	19,282.90	67.29	-	-	965.83	2,180.48	2,180.48	1,997.83	47,216.36
13	20,567.64	19,280.53	67.29	-	-	837.05	2,180.48	2,180.48	1,997.83	47,111.29
14	20,529.71	19,282.90	73.48	-	-	657.55	2,180.48	2,180.48	1,997.83	46,902.43
15	20,551.05	19,275.79	68.74	-	-	896.76	2,180.48	2,180.48	1,997.83	47,151.12
16	20,565.27	19,342.16	112.93	-	-	579.50	2,180.48	2,180.48	1,997.83	46,958.64
17	20,487.05	19,173.87	35.56	-	-	2,653.60	2,180.48	2,180.48	1,997.83	48,708.85
18	20,588.97	19,375.35	147.57	-	-	257.55	2,180.48	2,180.48	1,997.83	46,728.23
19	20,539.20	19,306.61	101.93	-	-	919.78	2,180.48	2,180.48	1,997.83	47,226.29
20	20,560.53	19,304.24	99.56	-	-	703.60	2,180.48	2,180.48	1,997.83	47,026.70
21	20,553.42	19,294.75	80.59	-	-	446.04	2,180.48	2,180.48	1,997.83	46,733.59
22	20,551.05	19,313.72	104.30	-	-	657.55	2,180.48	2,180.48	1,997.83	46,985.40
23	20,548.68	19,311.35	97.18	-	-	528.78	2,180.48	2,180.48	1,997.83	46,844.77
24	20,553.42	19,301.87	67.90	-	-	386.33	2,180.48	2,180.48	1,997.83	46,668.29
25	20,567.64	19,325.57	95.43	-	-	386.33	2,180.48	2,180.48	1,997.83	46,733.75
26	20,534.45	19,266.31	85.33	-	-	1,582.01	2,180.48	2,180.48	1,997.83	47,826.89
27	20,541.57	19,297.13	72.94	-	-	772.66	2,180.48	2,180.48	1,997.83	47,043.08
28	20,501.27	19,214.16	45.04	-	-	1,526.62	2,180.48	2,180.48	1,997.83	47,645.87
29	20,522.60	19,244.98	75.85	-	-	2,014.39	2,180.48	2,180.48	1,997.83	48,216.60
30	20,551.05	19,280.53	75.85	-	-	915.11	2,180.48	2,180.48	1,997.83	47,181.32

Table 4.19 Total Distribution Cost of the Equalized Strategy (Con't)

Replication	Total Holding Cost (USD)			Total Shortage Cost (USD)			Total Handling Cost (USD)			Total Cost (USD)
	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3	
31	20,536.83	19,278.16	80.59	-	-	896.76	2,180.48	2,180.48	1,997.83	47,151.12
32	20,524.97	19,247.35	68.74	-	-	1,540.65	2,180.48	2,180.48	1,997.83	47,740.49
33	20,543.94	19,266.31	82.96	-	-	1,453.24	2,180.48	2,180.48	1,997.83	47,705.23
34	20,536.83	19,271.05	65.83	-	-	1,416.55	2,180.48	2,180.48	1,997.83	47,649.04
35	20,517.86	19,214.16	45.04	-	-	1,931.65	2,180.48	2,180.48	1,997.83	48,067.50
36	20,546.31	19,247.35	47.71	-	-	965.83	2,180.48	2,180.48	1,997.83	47,165.97
37	20,551.05	19,290.01	90.07	-	-	1,094.60	2,180.48	2,180.48	1,997.83	47,384.52
38	20,532.08	19,223.64	35.56	-	-	1,287.77	2,180.48	2,180.48	1,997.83	47,437.83
39	20,534.45	19,252.09	45.04	-	-	763.31	2,180.48	2,180.48	1,997.83	46,953.67
40	20,484.68	19,188.09	23.70	-	-	1,567.99	2,180.48	2,180.48	1,997.83	47,623.24
41	20,539.20	19,252.09	43.89	-	-	965.83	2,180.48	2,180.48	1,997.83	47,159.78
42	20,548.68	19,280.53	53.98	-	-	772.66	2,180.48	2,180.48	1,997.83	47,014.63
43	20,541.57	19,252.09	56.89	-	-	1,020.86	2,180.48	2,180.48	1,997.83	47,230.19
44	20,539.20	19,278.16	87.70	-	-	1,135.97	2,180.48	2,180.48	1,997.83	47,399.81
45	20,534.45	19,290.01	83.57	-	-	965.83	2,180.48	2,180.48	1,997.83	47,232.65
Average	**20,540.25**	**19,274.11**	**71.00**	**-**	**-**	**1,012.17**	**2,180.48**	**2,180.48**	**1,997.83**	**47,256.30**

5.2.4.6. The Synchronized Strategy

Differs from the equalized strategy, the synchronized strategy takes into account the daily increment of the demand amount over the emergency periods. The result showed by SimRunner in **Figure 4.12** signifies 34 required replications for the synchronized strategy. The replication used the confidence level 0.95 and significant level (α) 1. Furthermore, the initial running is treated by 25 tests.

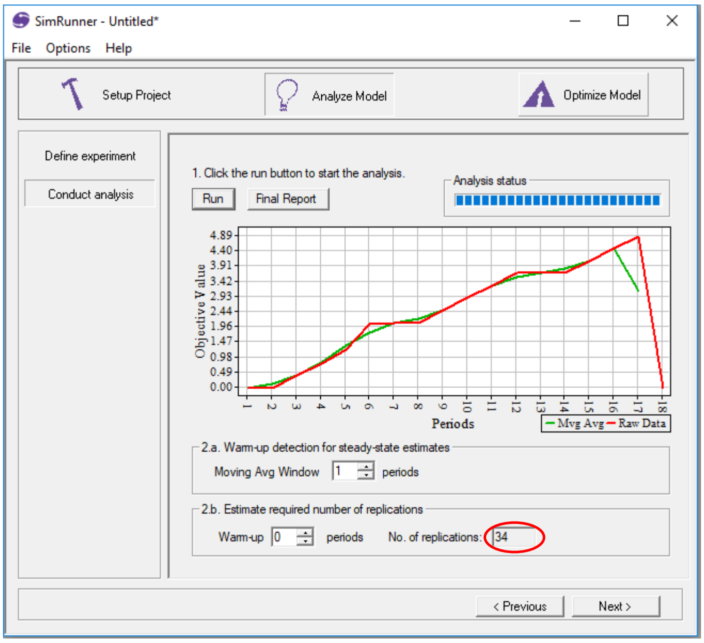


Figure 4.12 Model Replication Synchronized Strategy

As a result, **Table 4.21** elaborates the total distribution cost for the synchronized strategy. The average total cost from 34 replications generates lower price than the equalized strategy, spending 7,716.94 USD. Comparing to the equalized strategy, the obtained result saves almost 83.67% of the total cost resulted from the equalized strategy. 17.77% of the total cost of the synchronized strategy is spent for the loading and unloading activities in day 3. Since this strategy does not adopt an excessive delivery, the total holding cost results in relatively low charge. On the other hand, the shortage cost due to the unsatisfied demand particularly in the first two day increases compared to the equalized strategy. The average shortage cost in the first day ascends 95.45% from its holding cost. Meanwhile, the average value of the cost spent due to the unsatisfied demand in the second day is counted 87.80% from its average holding cost.

Table 4.20 Total Distribution Cost of the Synchronized Strategy

Replication	Total Holding Cost (USD)			Total Shortage Cost (USD)			Total Handling Cost (USD)			Total Cost (USD)
	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3	
1	21.33	37.93	48.02	965.83	837.05	0	1,270.50	2,243.54	2,765.42	8,189.61
2	11.85	23.70	47.71	1287.77	708.27	0	1,270.50	2,243.54	2,765.42	8,358.76
3	16.59	23.70	49.78	1352.16	772.66	0	1,270.50	2,243.54	2,765.42	8,494.35
4	37.93	90.07	106.97	515.11	257.55	0	1,270.50	2,243.54	2,765.42	7,287.08
5	35.56	61.63	79.14	772.66	579.50	0	1,270.50	2,243.54	2,765.42	7,807.93
6	18.96	56.89	61.70	837.05	321.94	0	1,270.50	2,243.54	2,765.42	7,576.00
7	23.70	56.89	63.16	1480.94	643.88	0	1,270.50	2,243.54	2,765.42	8,548.02
8	35.56	85.33	98.10	321.94	450.72	0	1,270.50	2,243.54	2,765.42	7,271.10
9	33.19	56.89	73.48	965.83	321.94	0	1,270.50	2,243.54	2,765.42	7,730.78
10	9.48	37.93	66.37	901.44	386.33	0	1,270.50	2,243.54	2,765.42	7,681.00
11	49.78	85.33	101.93	386.33	386.33	0	1,270.50	2,243.54	2,765.42	7,289.15
12	90.07	168.30	174.87	193.17	0.00	0	1,270.50	2,243.54	2,765.42	6,905.86
13	45.04	66.37	92.44	386.33	837.05	0	1,270.50	2,243.54	2,765.42	7,706.68
14	52.15	111.41	125.63	450.72	386.33	0	1,270.50	2,243.54	2,765.42	7,405.69
15	30.81	45.04	55.13	515.11	772.66	0	1,270.50	2,243.54	2,765.42	7,698.20
16	52.15	99.56	120.89	257.55	579.50	0	1,270.50	2,243.54	2,765.42	7,389.09
17	18.96	37.93	56.89	708.27	450.72	0	1,270.50	2,243.54	2,765.42	7,552.22
18	21.33	64.00	83.57	515.11	708.27	0	1,270.50	2,243.54	2,765.42	7,671.74
19	35.56	68.74	74.70	257.55	321.94	0	1,270.50	2,243.54	2,765.42	7,037.95
20	18.96	28.44	45.04	1094.60	1158.99	0	1,270.50	2,243.54	2,765.42	8,625.49
21	28.44	49.78	68.74	708.27	515.11	0	1,270.50	2,243.54	2,765.42	7,649.80
22	28.44	47.41	71.11	450.72	450.72	0	1,270.50	2,243.54	2,765.42	7,327.85
23	30.81	45.04	55.13	837.05	643.88	0	1,270.50	2,243.54	2,765.42	7,891.37
24	16.59	37.93	59.26	1030.22	386.33	0	1,270.50	2,243.54	2,765.42	7,809.78
25	42.67	66.37	83.57	450.72	901.44	0	1,270.50	2,243.54	2,765.42	7,824.22

Table 4.20 Total Distribution Cost of the Synchronized Strategy (Con't)

Replication	Total Holding Cost (USD)			Total Shortage Cost (USD)			Total Handling Cost (USD)			Total Cost (USD)
	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3	Day 1	Day 2	Day 3	
26	52.15	87.70	113.78	579.50	321.94	0	1,270.50	2,243.54	2,765.42	7,434.52
27	26.07	64.00	51.99	1802.88	708.27	0	1,270.50	2,243.54	2,765.42	8,932.67
28	28.44	59.26	81.20	901.44	128.78	0	1,270.50	2,243.54	2,765.42	7,478.57
29	66.37	116.15	110.64	450.72	515.11	0	1,270.50	2,243.54	2,765.42	7,538.43
30	42.67	92.44	109.34	579.50	579.50	0	1,270.50	2,243.54	2,765.42	7,682.90
31	28.44	59.26	75.85	579.50	708.27	0	1,270.50	2,243.54	2,765.42	7,730.78
32	18.96	47.41	61.63	708.27	772.66	0	1,270.50	2,243.54	2,765.42	7,888.39
33	21.33	40.30	59.26	1030.22	386.33	0	1,270.50	2,243.54	2,765.42	7,816.89
34	37.93	87.70	94.28	450.72	193.17	0	1,270.50	2,243.54	2,765.42	7,143.24
Average	**33.19**	**64.91**	**80.04**	**727.21**	**532.15**	**-**	**1,270.50**	**2,243.54**	**2,765.42**	**7,716.94**

5.2.4.7. Model Verification

An attempt of translating the conceptual model into a simulation model requires an effort of reducing and eliminating errors which may occur during building the model [60]. This can be achieved by verifying the model to trace whether the simulation model decently reflects the conceptual model. By using the trace and debugging analysis, as illustrated by **Figure 4.13**, the information provided from the textual feedback during the simulation allows the modeler to inspect the flow of simulation running.

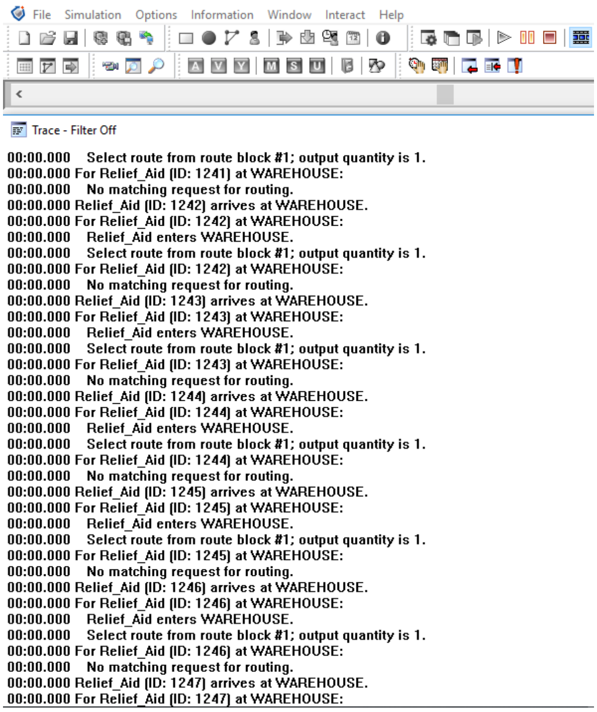


Figure 4.13 Trace and Debugging Analysis

To observe the changing value during the simulation run, the dynamic plot provides a tracking feature by allowing the selection of the certain metrics to be inspected. In this research, the demand amount originated from the second term arrival to a given refugee camp is treated as a dynamic value which will evolve over the planning horizon. As illustrated in **Figure 4.14**, this trend follows the S-shape curve.

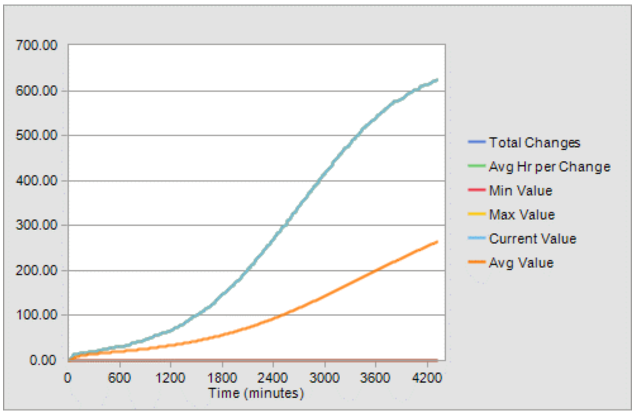


Figure 4.14 Dynamic Plot Tracking

5.2.4.8. Model Validation

This research considers the efforts of minimizing the lost and suffering resulted from the potential earthquake triggering tsunami, the Sumatra Megathrust hazard. Since the actual system does not earnestly exist, the validation process of the proposed model becomes challenging. As discussed in chapter two, the proper way to validate the model is by consolidating the development of the intended model to the related persons who have expertise about how the actual system should work. Therefore, in order to validate this research, the author has intensively discussed with the associated stakeholders in order to gather the specific information which will immensely affect to the system performance. Among the related stakeholders, the instances who are persistently involved in the humanitarian logistics operations which assist to the validation of this model are elaborated as follows:

a. Badan Penanggulangan Bencana Daerah (BPBD). BPBD is a part of the Indonesian disaster management authority which has responsibility to coordinate the preparedness and implementation of the disaster management activities in regional level [74]
b. Social Agency. The social agency is the governmental authority for the coordination and the implementation of the policies and strategies in the social affair [75]. During the disaster, the social agency plays a significant role in the supply of the basic needs through the collaborative actions with the other agencies.
c. Disaster Risk Reduction Indonesia (DRRI). DRRI is the disaster management consultant which focuses on the development of system, mechanism, and methods

to be implemented in the disaster management effort in order to reduce the consequences resulted by disaster [76].

In order to adequately mimic the proposed system, the model utilizes the data originated from the evacuation plan [46] and the contingency plan [63] for facing the Sumatra Megathrust. This work also model the policies and strategies contained in both plan, particularly in the humanitarian logistics operations.

6. Output Analysis

This section discusses the efficacy of the proposed model in terms of the resulted outcomes. The analysis comprises the related aspects which significantly influence the model performance, including:

a. The effect of the dynamic increment of demand to the humanitarian logistics decisions.

   The current study found that the dynamic increment of demand requirements distinctly affects to the logistical planning mainly in the strategic-operational decisions. In the first two days, LDC D2 and LDC G1 are chosen to serve eight and four demand points, respectively. By adding one additional LDC in the third day, LDC E1 is selected to serve two demand points. Furthermore, this output is incorporated to be input in the operational stage. In the routing assignment, the alteration of the depot-recipient may occur in order to optimize the routing decision. In this work, refugee camp E1 which is previously assigned as the demand point of LDC G1 in the strategic decision, is served by both LDC D2 and LDC G1 during the operational stage.

b. The consideration on various aspects

   In order to properly mimic the actual conditions in the efforts of providing an adequate relief assistance, this research takes into account several affective factors including the demand increment, the analysis of the potential impassable roads, the use of multi-vehicle, the consideration on the road restoration, and the dynamic-stochastic treatments. Along with the variable increment, the use of exact methods may not be efficient due to the large volume of data storage and processing. Therefore, a joint model of optimization and simulation approach is proposed by using Geographic Information System (GIS) heuristics solver and the simulation programming.

c. The cost involved

During the strategic planning, the analysis of the best fitted LDCs is measured by calculating the fixed opening cost and the handling cost. In the operational stage, the cost involved consists of handling cost, holding cost, and penalty cost. The total location-allocation cost for three days spends 7,205.869 USD. In the meantime, the total costs comparison between the equalized strategy and synchronized strategy in both deterministic and stochastic treatment can be seen in **Figure 4.15**. In the deterministic treatment both strategies are relatively similar to each other. However, in the stochastic treatment these strategies differ due to some factors, such as holding cost, handling cost, and shortage cost. The excessive delivery in the equalized delivery yields more cost for holding the inventory which contributes to almost 84.4% of the total cost. Hence, the implementation of the synchronized strategy is preferable due to the lower cost resulted. This strategy allows the flexibility in adjusting the tendency of the required demand into the suitable relief distribution assignment. The implementation of this strategy may lead to a rapid-effective relief aid fulfillment.

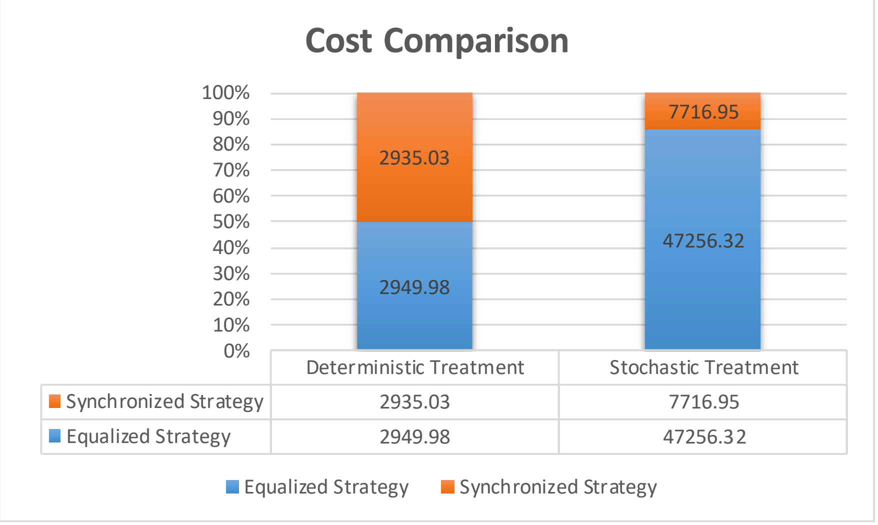


Figure 4.15 Cost Comparison

CHAPTER 5

CONCLUSIONS

This research was designated to determine a systematic manner for providing a rapid-appropriate relief assistance. Since the disaster is characterized by uncertainties and complexities, the development of a comprehensive study on minimizing the human suffering and death is crucial. During the disaster relief operations, the logistical efforts particularly in the preparedness and the response phase have been considered as the substantial element which contribute approximately 80% of the total relief cost. In the preparedness stage, the strategic decisions on the location of the suitable facilities as well as the allocation related to the relief aid fulfillment become the main task to be constructed. Meanwhile, the relief routing and assignment are obligated to be accomplished through the operational planning.

The potential hazard of the earthquake triggering tsunami, Sumatra Megathrust, has become a serious concern due to its tremendous effects to the human life and surroundings. The local government for the disaster countermeasure (BPBD) has issued the contingency plan attempting to incorporate the set of relief activities among the related stakeholders in order to enhance the capabilities of the relief response. However, the deliberation on the detailed logistical activities is still missing.

In this study, an integrated location-allocation and relief routing decision by considering the dynamic-stochastic elements is developed. The selection on the proper Location Distribution Centers (LDCs) as the transit points for managing the large inflow and outflow of the relief commodities is conducted in the strategic level. The selected LDCs in the strategic phase are then utilized to generate the relief routing assignment which prevails in the operational stage. A typical characteristic of the evacuees' arrival at each refugee camps which encompasses two evacuation terms is taken into consideration in order to formulate a compatible humanitarian logistics framework. The consumable goods including rice, noodle, and preserved food are determined as the relief items to be delivered with the standard relief fulfillment 400 gr, 95 gr, and 200 gr, respectively. Moreover, the expected impassable paths due to the inundation impacts are under the scope of this research to model the safest access from the assigned facilities to each designated recipient. Since the 72 hours after the disaster occurrence belong to the critical periods, the dynamic treatments are developed to acquire the short-term relief aids fulfillment. Furthermore, the stochastic components are carried out to portray the uncertain conditions regarding to the demand requirements. In the preparedness stage, the total cost which involves the fixed-opening cost and the shipment cost is employed to select a strategic number of LDCs per day. With regards to the change of the circumstances during the response phase, the relief delivery cost is measured by calculating the transportation cost for handling an amount of the commodities, the holding cost of the exceeded delivery, and the shortage cost for the unsatisfied fulfillment.

The strategic planning on the location-allocation problem in the preparedness stage is conducted by selecting the appropriate LDCs suited to the variation of the demand requirements over the emergency periods. The state of the Geographic Information Systems (GIS) with the maximum coverage analysis is applied to generate the possible scenarios of the alternative LDCs per day. The set of alternative LDCs are assessed to obtain the decent LDCs with the minimum fixed opening cost and the transportation cost. In addition, this work assumes the sustain utilization of the selected LDCs in the particular day to be utilized as the required LDCs in the next day as long as the associated capacities are still sufficient to storage the relief commodities. The analysis of the remote areas due to the unavailable paths are enclosed to define an anticipation plan either by restoring the damaged roads or utilizing another transportation mode. As a result, two LDCs, LDC D2 and LDC G1 are selected to be established in the first day with the total cost 2,165.883 USD. the same LDCs are required to be opened in the second day with total cost 2,033.038 USD. However, along with the increment of demand the use of three LDCs, LDC D2, LDC E1, and LDC G1 yields to the minimum total cost in the third day, 3,006.948 USD. The total location-allocation cost for three consecutive days spends 7,205.869 USD.

The efforts of providing a quick-decent assistance in the aftermath of the disaster occurrence are organized through the operational stage. In this stage, the Capacitated Vehicle Routing Problem (CVRP) by using GIS software is solved to find the optimal delivery routes between the assigned facilities to the destination points. The effectiveness of two relief distribution strategies consisting the equalized strategy and the synchronized strategy is examined. Besides, a joint fulfillment from different LDCs to satisfy the needs of a demand point is presented to gain the flexible delivery with minimum routing cost. In order to depict the actual conditions during the post-disaster event, the stochastic elements (the daily demand requirements, vehicle velocity, and the road restoration time), multi-vehicle utilization (6 wheeler truck and ship), the dynamic span and time windows are allowed to be modeled in the simulation approach. The findings show that the total operational cost gained from the implementation of the synchronized strategy obtains better result with average total cost 7,716.94 USD. Meanwhile, the equalized strategy produces the higher cost with average total cost 47,256.30 USD. Despite of the advantage yielded from the equalized strategy which generates the lower shortage cost, the excessive delivery leads to an ineffective outcome which contributes to higher holding cost, spending 43.47% of its total cost. Therefore, this research recommends the application of the synchronized strategy in the response phase.

This study encompasses a precise and comprehensive plan for the humanitarian logistics operations to deal with the future Sumatra Megathrust hazard. The integrated strategic-operational solutions contained in this research is useful to be applied by the relief aid managers in order to obtain the appropriate decisions aiming to alleviate human suffering or losses. However, more complex model by taking into account the delivery of the non-consumable items is encouraged. In addition, the uncertain range of the inundation width may also affect to the location-routing decisions. Furthermore, an extreme change in the actual demand requirements in each refugee camps may also complicate the decision-making process. This may be caused by some factors such as the survivors may no longer stay in the refugee camp since their relatives offer the settlement. Another factor, a sudden change may also be affected by the refugees who may move from their assigned refugee camps to the other refugee camps in order to gather with their families. Subsequently, the design of a Decision Support Systems (DSS) is significant to track the real-time conditions to obtain more tangible solutions.

References

[1] D. G. Sapir, P. Hoyois and R. Below, Annual Disaster Statistical Review 2015 : The Number and Trends, Brussels : CRED: Ciaco Imprimerie, 2016.

[2] M. Ahmadi, A. Seifi and B. Tootooni, "A humanitarial logistics model for disaster relief operation considering network failure and standard relief time : A case study on san fransisco district," *Transportation Research Part E,* vol. 75, pp. 145 - 163, 2015.

[3] N. Altay and W. G. Green III, "OR/MS research in disaster operations management," *European Journal of Operational Research,* vol. 175, pp. 475 - 493, 2006.

[4] L. N. Van Wassenhove, "Blacket memorial lecture. Humanitarian aid logistics: Supply chain management in high gear," *Journal of the Operational Research Society,* vol. 57, no. 5, pp. 475 - 489, 2006.

[5] A. Cozzolino and S. Rossi, "Agile and lean principles in the humanitarian supply chain ; The case of the united nations world food programme," *Journal of Humanitarian Logistics and Supply Chain Management,* vol. 2, no. 1, pp. 16 - 33, 2012.

[6] A. S. Thomas and L. R. Kopczak, From logistics to supply chain management : The path forward in humanitarian sector, vol. 15, Fritz Institute, 2005, pp. 1 - 15.

[7] A. Cozzolino, Humanitarian logistics : Cross - sector cooperation in disaster relief management, SpringerBriefs in Business, 2012.

[8] B. Vitoriano, M. T. Ortuno, P. Cristobal, J. M. Ferrer, F. J. Martin-Campo, S. Munoz and G. Tirado, "Decision aid models for disaster management and emergencies, atlantis computational intelligence system 7," in *Decision aid models and systems for humanitarian logistics. a survey,* Spain, Atlantis Press, 2013, pp. 17 - 44.

[9] M. Garschagen, M. Comes, M. Dubbert, u. Y. J. Lee, L. Grunewald, M. Lanzendorfer, P. Mucke, O. Neuschafer, S. Pott, J. Post, S. Schramm, D.

Schumann-Bolsche, B. Vandemeulebroecke, T. Welle and J. Birkmann, WorldRiskReport 2016, Berlin: Bundnis Entwicklung Hilft and United Nations University, 2011.

[10] K. Sieh, "Sumatran megathrust earthquakes ; From sciences to saving lives," *Philosopical Transactions of the Royal Society of London A : Mathematical, Phsycal, and Engineering Sciences,* vol. 364, no. 1845, pp. 1 - 16, 2006.

[11] B.P.B.D Sumatera Barat, Contingency plan ; encountering tsunami in west sumatra, Padang: BPBD West Sumatra, 2013.

[12] B. Balcik and B. M. Beamon, "Facility location in humanitarian relief," *International Journal of Logistics : Research and Applications,* vol. 11, no. 2, pp. 101 - 121, 2008.

[13] H. Jia, F. Ordonez and M. M. Dessouky, "Solution approaches for facility location of medical supplies for large-scale emergencies," *Computers & Industrial Engineering,* no. 52, pp. 257-276, 2007.

[14] N. Ariyana, "Model lokasi-alokasi bantuan logistik catastrophic berbasis masjid di kota padang," *Jurnal Optimasi Sistem Industri,* vol. 11, no. 2, pp. 235-242, 2012.

[15] G. Galindo and R. Batta, "Review of recent development in OR/MS research in disaster operations management," *European Journal of Operational Research,* no. 230, pp. 201-211, 2013.

[16] K. Prathumchai and L. Samarakoon, "Application of remote sensing and GIS techniques for flood vulnerability and mitigation planning in munshiganj district of bangladesh," in *25th Asian Conference on Remote Sensing,* Hanoi, Vietnam, 2005.

[17] L. Alcada-Almeida, L. Tralhao, L. Santos and J. Coutinho-Rodrigues, "A multiobjective approach to locate emergency shelters and identify evacuation routes in urban areas," *Geographical Analysis,* vol. 41, pp. 9-29, 2009.

[18] J. C. Rodrigues, L. Tralhao and L. A. Almeida, "Solving a location-routing problem with a multiobjective approach: the design of urban evacuation plans," *Journal of Transport Geography,* vol. 22, pp. 206-218, 2012.

[19] P. Wu, H. Shao, K. Wu and B. Cai, "The study on optimization location-allocation of emergency shelter for earthquake," in *FIG Working Week 2015,* Sofia, Bulgaria, 2015.

[20] G. Barbarosoglu and Y. Arda, "A two-stage stochastic programming framework for transportation planning in disaster response," *Journal of the Operational Research Society,* vol. 55, pp. 45-53, 2004.

[21] L. Ozdamar, E. Ekinci and B. Kucukyazici, "Emergency logistics planning in natural disasters," *Annals of Operations Research,* vol. 129, pp. 217-245, 2004.

[22] B. Balcik, B. M. Beamon and K. Smilowitz, "Last mile distribution in humanitarian relief," *Journal of Intelligent Transportation Systems,* vol. 12, no. 2, pp. 51 - 63, 2008.

[23] C.-F. Hsueh, H.-K. Chen and H.-W. Chou, "Dynamic vehicle routing for relief logistics in natural disasters," *Vehicle Routing Problem,* p. 142, 2008.

[24] Z. Shen, M. M. Dessouky and F. Ordonez, "A two-stage vehicle routing model for large-scale bioterrorism emergencies," *Networks,* vol. 54, pp. 255-269, 2009a.

[25] Z. Shen, F. Ordonez and M. M. Dessouky, "The stochastic vehicle routing problem for minimum unmet demand," *Springer,* vol. 30, pp. 1-25, 2009b.

[26] Y. M. Lee, S. Ghosh and M. Ettl, "Simulating distribution of emergency relief supplies for disaster response operations," in *Proceedings of the 2009 Winter Simulation Conference,* New York, 2009.

[27] F. Barahona, M. Ettl, M. Petrik and P. M. Rimshnick, "Agile logistics simulation and optimization for managing disaster responses," in *Proceedings of the 2013 Winter Simulation Conference*, New York, 2013.

[28] C. A. Bayles, "Uncertainty in relief supply distribution," Industrial Enggineering Undergraduate Honors Theses, Callaghan, 2014.

[29] K. Miyakita, K. Nakano, M. Yamashita and H. Tamura, "Simulation study of relief goods delivery and information sharing by epidemic transmission in disaster areas," *J. Adv. Simulat. Sci. Eng.,* vol. 3, no. 1, pp. 114 - 135, 2016.

[30] T. F. Lionardo and I. Nouaouri, "A simulation study of emergency logistic in case of disaster," in *World Congress on Engineering and Computer Science*, San Fransisco, 2017.

[31] C. Fikar, P. Hirsch and P. C. Nolz, "Agent-based simulation optimization for dynamic disaster relief distribution," *CEJOR*, vol. 26, pp. 423-442, 2017.

[32] H. O. Mete and Z. B. Zabinsky, "Stochastic optimization of medical supply location and distribution in disaster management," *Int. J. Production Economics*, vol. 126, pp. 76 - 84, 2010.

[33] S. J. Rennemo, K. F. Ro, L. M. Hvattum and G. Tirado, "A-three stage stochastic facility routing model for disaster response planning," *Transportation Research Part E*, vol. 62, pp. 116 - 135, 2014.

[34] R. Patrisina, N. Sirivongpaisal and S. Suthummanon, "A logistical relief distribution preparedness model : responses to a probable tsunami case study in west sumatra, indonesia," *Industrial Engineering & Management Systems*, pp. 1-37, In Press.

[35] R. Patrisina, Humanitarian logistics planning in Indonesia, Songkhla: Prince of Songkhla University, 2016.

[36] C. G. Rawls and M. A. Turnquist, "Pre-positioning and dynamic delivery planning for short term response following a natural disaster," *Socio-Economic Planning Sciences*, vol. 46, pp. 46 - 54, 2012.

[37] K. Feng, E. Bizimana, D. D. Agu and T. T. Issac, "Optimization and simulation modeling of disaster relief supply chain: a literature review," *MPRA*, no. 58204, 2014.

[38] Undang-undang Republik Indonesia No. 24 Tahun 2007, "Penanggulangan Bencana".

[39] International Federation of Red Cross (IFRC), "Geophysical hazards : Earthquakes," [Online]. Available: http://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/definition-of-hazard/geophysical-hazards-earthquakes/. [Accessed 8 May 2017].

[40] L. Juan and C. Yong, "Geological hazards : Earthquakes, landslides, and tsunamis," *Natural and Human Induced Hazards,* vol. 1, pp. 224 - 232, 2011.

[41] International Federation of Red Cross (IFRC), "Tsunamis," [Online]. Available: http://www.ifrc.org/en/what-we-do/disaster-management/about-disasters/definition-of-hazard/tsunamis/. [Accessed 8 May 2017].

[42] N. T. Sugito, Tsunami, Bandung: Universitas Pendidikan Indonesia, 2008.

[43] L. G. Vasilescu, H. Khan and A. Khan, "Disaster management cycle - a theoretical approach," *Management & Marketing,* vol. 6, no. 1, pp. 43 - 50, 2008.

[44] H. Khan, L. G. Vasilescu and A. Khan, "Disaster management cycle-a theoritical approach," *Journal of Management and Marketing,* vol. V1, no. 1, pp. 43-50, 2008.

[45] B. M. Beamon and B. Balcik, "Performance measurement in huanitarian relief chains," *International Journal of Public Sector Management,* no. 21, pp. 4 - 25, 2008.

[46] B. P. B. D. Kota Padang, "Rencana Evakuasi Tsunami Padang," BPBD Kota Padang, Padang, 2013.

[47] Y. Song and X. Yan, "A method for formulizing disaster evacuation demand curves based on SI model," *International Journal of Environment Research and Public Health,* vol. 13, no. 986, pp. 1-21, 2016.

[48] R. I. Liperda and N. Sirivongpaisal, "The location-allocation decision under the dynamic increment of demand for selecting the Local Distribution Centers to face Sumatra Megathrust: Study case of Padang City," *IJASEIT,* vol. 9, no. 1, pp. 293-299, 2019.

[49] T. Sottinen, Operations research with GNU linear programming kit, Vaasa: University of Vaasa, 2009.

[50] H. Perros, Computer simulation techniques : The definitive introduction!, Raleigh: NC State University, 2009.

[51] F. S. Hillier and G. J. Lieberman, Introduction to operations research, New York: McGraw-Hill, 2001.

[52] A. D'Uffizi, M. Simonetti, G. Stecca and G. Confessore, "A simulation study of logistics for disaster relief operations," *Procedia CIRP*, vol. 33, pp. 157 - 162, 2015.

[53] L. V. Green and P. J. Kolesar, "Improving emergency responsiveness with management science," *Journal of Management Science*, vol. 50, no. 8, pp. 1001-1014, 2004.

[54] R. Church and C. Revelle, "The maximal covering location model," *Regional Science Association*, no. 32, pp. 101-118, 1974.

[55] G. Alexandris and I. Giannikos, "A new model for maximal coverage exploiting GIS capabilities," *European Journal of Operational Research*, no. 202, pp. 328-338, 2010.

[56] S. Faiz, S. Krichen and W. Inoubli, "A DSS based on GIS and Tabu search for solving the CVRP: The Tunisian case," *The Egyptian Journal of Remote Sensing and Space Sciences*, vol. 17, pp. 105-110, 2014.

[57] R. I. Liperda, Penerapan model last mile distribution dalam optimisasi pendistribusian bantuan logistik bencana di kota pariaman dan kabupaten padang pariaman, Padang: Universitas Andalas, 2014.

[58] O. Rodriguez-Espindola, P. Albores and C. Brewster, "GIS and optimisation: potential benefits for emergency facility location in humanitarian logistics," *Geosciences*, vol. 6, pp. 1-34, 2016.

[59] P. J. Densham and G. Rushton, "Designing and implementing strategies for solving large location-allocation problems with heuristic methods," NCGIA, Santa Barbara, 1991.

[60] C. Harrell, B. K. Ghosh and R. O. Bowden, Simulation using ProModel, Singapore: McGraw-Hill Companies, 2012.

[61] A. M. Law and W. D. Kelton, Simulation modeling & analysis (second edition), Singapore: McGraw-Hill, 1991.

[62] R. G. Sargent, "Verification and validation of simulation models," in *Proceedings of the 2011 Winter Simulation Conference*, Phoenix, 2011.

[63] B. P. B. D. Kota Padang, Rencana kontinjensi menghadapi bencana tsunami kota Padang, Padang, 2013.

[64] DMTP, "Contingency planning; a practical guide for field staff," DMTP, 1996.

[65] IFRC, "Contingency planning guide," International Federation of Red Cross and Red Crescent Societies, Geneva, 2012.

[66] C. G. Rawls and M. A. Turnquist, "Pre-positioning of emergency supplies for disaster response," *Transportation Research Part B : Methodological,* vol. 44, no. 4, pp. 521 - 534, 2010.

[67] M. Hamedi, A. Haghani and S. Yang, "Reliable transportation of humanitarian supplies in disaster response: Model and heuristic," *Procedia-Social Behavioral Sciences,* vol. 54, pp. 1205-1219, 2012.

[68] T. Schlurmann, W. Kongko, N. Goseberg, D. H. Natawidjaja and K. Sieh, "Near-field tsunami hazard map padang, west sumatra: utilizing high resolution geospatial data and reasonable source scenarios," *Coastal Engineering,* pp. 1-17, 2010.

[69] C.-M. Feng and T.-C. Wang, "Highway emergency rehabilitation scheduling in post-earthquake 72 hours," *Journal of the Eastern Asia Society for Transportation Studies,* vol. 5, 2003.

[70] S. Yan and Y.-L. Shih, "Optimal scheduling of emergency roadway repair and subsequent relief distribution," *Computers & Operations Research,* vol. 36, pp. 2049-2065, 2009.

[71] S. A. Torabi, M. Baghersad and A. Meisami, "Emergency relief routing and temporary depots location problem considering roads restoration," in *The 24th Annual Conference of the Production and Operations Management Society*, 2013.

[72] U. S. Department of Transportation, Federal size regulations for commercial motor vehicles, Washington, DC: Federal Highway Administration, 2004.

[73] C. N. Koyama, H. Gokon, M. Jimbo, S. Koshimura and M. Sato, "Disaster debris estimation using high-resolution polarimetric stereo-SAR," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 120, pp. 84-98, 2016.

[74] B.N.P.B, *Peraturan kepala badan nasional penanggulangan bencana no. 3 tahun 2008,* Jakarta: B.N.P.B, 2008.

[75] Kementrian Sosial Republik Indonesia, "Kementrian Sosial Republik Indonesia," Kementrian Sosial Republik Indonesia, 2017. [Online]. Available: https://www.kemsos.go.id/content/tujuan. [Accessed 24 November 2018].

[76] D.R.R.I, "Disaster Risk Reduction Indonesia," D.R.R.I, [Online]. Available: http://drrindonesia.co.id/. [Accessed 2018 November 24].

[77] A. Doyen, N. Aras and G. Barbarosoglu, "A two-echelon stochastic facility location model for humanitarian relief logistics," *Optimization Letters,* vol. 6, no. 6, pp. 1123 - 1145, 2012.

[78] J. B. Sheu, "Challenges of emergency logistics management," *Transportation Research Part E : Logistics and Transportation Review,* vol. 43, no. 6, pp. 655 - 9, 2007.

[79] A. M. Caunhye, X. Nie and S. Pokharel, "Optimization models in emergency logistics : A literature review," *Socio - economic Planning Sciences,* vol. xxx, pp. 1 - 10, 2011.

[80] L. E. de la Torre, I. S. Dolinskaya and K. R. Smilowitz, "Disaster relief routing : Integrating research and practice," *Socio-Economic Planning Sciences,* pp. 1 - 24, 2011.

[81] S. Maarif, Pikiran dan gagasan ; Penanggulangan bencana di Indonesia, Jakarta: Badan Nasional Penanggulangan Bencana, 2012.

[82] G. Kovacs and K. M. Spens, "Humanitarian logistics in disaster relief operations," *International Journal of Phsycal Distribution & Logistics Management,* vol. 37, no. 2, pp. 99 - 114, 2007.

[83] F. Immamura, A. Muhari, E. Mas, M. H. Pradono, J. Post and M. Sugimoto, "Tsunami disaster mitigation by integrating comprehensive countermeasures in padang city, indonesia," *Journal of Disaster Research,* vol. 1, no. 1, pp. 48 - 64, 2012.

[84] R. S. Dewi, "A-Gis based approach of an evacuation model for tsunami risk reduction," *Journal of Integrated Disaster Risk Management,* vol. 2, no. 2, pp. 108 - 139, 2012.

[85] G. Lammel, D. Grether and K. Nagel, "The representation and implementation of time-dependent inundation in large-scale microscopic evacuation simulation," *Transportation Research Part C,* vol. 18, pp. 84 - 98, 2010.

[86] E. Mas, A. Suppasri, F. Imamura and S. Koshimura, "Agent-based simulation of the 2011 great east japan earthquake/tsunami evacuation : An integrated model of tsunami inundation and evacuation," *Journal of Natural Disaster Science,* vol. 34, no. 1, pp. 41 - 57, 2012.

[87] M. Di Mauro, K. Megawati, V. Cedillos and B. Tucker, "Tsunami risk reduction for densely populated souteast asian cities : analysis of vehicular and pedestrian evacuation for the city of padang, indonesia , and assessment of interventions," *Nat Hazards,* vol. 68, pp. 373 - 404, 2013.

[88] F. Ashar, D. Amaratunga and R. Haigh, "the analysis of tsunami vertical shelter in padang city," *Procedia Economic and FInance,* vol. 18, pp. 916 - 923, 2014.

[89] L. Li, M. Jin and L. Zhang, "Sheltering network planning and management with a case in the gulf coast region," *Int. J. Production Economics,* vol. 131, pp. 431 - 440, 2011.

[90] N. Noyan, "Risk-averse two-stage stochastic programming with an application to disaster management," *Computers & Operations Research,* vol. 39, pp. 541 - 559, 2012.

[91] B. Rottkemper, K. Fischer and A. Blecken, "A transhipment model for distribution and inventory relocation under uncertainty in humanitarian operations," *Socio-Economic Planning Sciences,* vol. 98, pp. 98 - 109, 2012.

[92] A. Bozorgi-Amiri, M. S. Jabalemeli and S. M. Al-e-Hashem, "A multi-objective robust stochastic programming model for disaster relief logistics under uncertainty," *OR Spectrum,* vol. 35, pp. 905 - 933, 2013.

[93] P. Kelle, H. Schneider and H. Yi, "Decision alternatives between expected cost minimization and worst case scenario in emergency supply-second revision," *Int. J. Production Economics,* vol. 157, pp. 250 - 260, 2014.

[94] X. Hong, M. A. Lejeune and N. Noyan, "Stochastic network design fo disaster preparedness," *IEE Transactions,* vol. 47, no. 4, pp. 329 - 357, 2015.

[95] N. Noyan, B. Balcik and S. Atakan, "A stochastic optimization model for designing last mile relief networks," *Transportation Science,* pp. 1 - 30, 2014.

[96] M.-S. Chang, Y.-L. Tseng and J.-W. Chen, "A scenario planning approach for the flood emergency logistics preparation problem under uncertainty," *Transportation Research Part E,* vol. 43, pp. 737 - 754, 2007.

[97] J. Salmeron and A. Apte, "Stochastic optimization for natural disaster asset prepositioning," *Production and Operation Management,* vol. 19, no. 5, pp. 561 - 574, 2010.

[98] D. Alem, A. Clark and A. Moreno, "Stochastic network models for logistics planning in disaster relief," *European Journal of Operational Research*, vol. 255, pp. 187 - 206, 2016.

[99] J. Post, S. Wegscheider, M. Muck, K. Zosseder, R. Kiefl, T. Steinmetz and G. Strunz, "Assessment of human immediate response capability related to tsunami threats in Indonesia at a sub-national scale," *Nat. Hazards Earth Syst. Sci.,,* vol. 9, pp. 1075 - 1086, 2009.

[100] J. B. Sheu and C. Pan, "Relief supply collaboration for emergency logistics responses to large-scale disasters," *Transportmetrica A : Transport Science,* vol. 11, no. 3, pp. 210 - 242, 2015.

[101] I.-S. Fan, I. K. Jennions, F. Matar, M. Bridgeford, S. Osborn and G. Vickers, "Warrior vehicle fleet sustainment using intelligent agent simulation," *Procedia CIRP,* vol. 11, pp. 213 - 218, 2013.

[102] R. Das and S. Hanaoka, "An agent-based model for resource allocation during relief distribution," *Journal of Humanitarian Logistics and Supply Chain Management,* vol. 4, no. 2, pp. 265 - 285, 2014.

[103] R. H. Ballou, Business logistics management : Fifth edition, New Jersey: Prentice Hall, 2003.

[104] H. Taubenbock, N. Goseberg, G. Lammel, N. Setiadi, T. Schlurmann, K. Nagel, F. Siegert, J. Birkmann, K. -P. Traub, S. Dech, V. Keuck, F. Lehmann, G. Strunz and H. Klupfel, "Risk reduction at the "Last-Mile": an attempt to turn science into action by the example of Padang, Indonesia," *Nat Hazards,* vol. 65, pp. 915 - 945, 2013.

[105] ESRI, "http://desktop.arcgis.com/en," 28 September 2018. [Online]. Available: http://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/algorithms-used-by-network-analyst.htm. [Accessed 10 October 2018].

APPENDIX A

EVACUATION ASSIGNMENT

Table A.1. Evacuation Assignment

Sector	Zone	Area (Hectare)	Expected Victims	Assigned Refugee Camp	Location	Moving Assignment 1st Term	2nd Term
A	Zone 111	60.00	3779	A1	Batipuh Panjang	-	3779
	Zone 115	15.00	746			746	-
	Zone 117	65.00	2129			2129	-
	Zone 118	26.00	1351			1351	-
	Zone 119	17.00	1548			-	1548
	Zone 120	63.00	2522			-	2522
	Zone 121	62.00	2517			2517	-
	Zone 122	30.00	1975			-	1975
	Zone 124	51.00	2910			2910	-
	Zone 125	18.00	501			501	-
	Zone 126	25.00	1895	A2	Bukit Anak Aia	-	1895
	Zone 127	46.00	1438			-	1438
	Zone 123	54.00	1045			-	1045
	Zone 128	17.00	377			-	377
	Zone 129	30.73	243			243	-
	Zone 130	82.00	2761			-	2761
	Zone 131	30.00	1669			1669	-
	Zone 132	65.00	3046			-	3046
	Zone 133	44.99	938			-	938
	Zone 134	58.00	4724			-	4724
	Zone 135	72.00	2225			-	2225
	Zone 136	20.00	874			-	874
	Zone 137	49.93	2085			2085	-
	Zone 138	32.26	1476			1476	-
B	Zone 95	22.62	786	B1	Koto Pulai	-	786
	Zone 96	41.00	3567			-	3567
	Zone 99	30.00	2188			-	2188
	Zone 100	59.00	1848			-	1848
	Zone 102	56.55	2792			2792	-
	Zone 103	55.00	2741			-	2741
	Zone 104	30.64	1721			1721	-
	Zone 105	33.30	2436			-	2436
	Zone 106	31.00	231			231	-
	Zone 107	58.84	1573			1573	-
	Zone 110	40.34	1119			1119	-
	Zone 116	48.07	232			232	-
	Zone 108	49.00	2543	B2	Balai Gadang	-	2543
	Zone 109	22.00	941			941	-
	Zone 112	40.00	2305			-	2305
	Zone 113	42.99	655			-	655
	Zone 114	13.00	159			159	-
C	Zone 88	36.00	3324	C1	Koto Panjang Ikua Koto	-	3324
	Zone 91	33.00	2263			2263	-
	Zone 93	44.00	2677			-	2677
	Zone 94	34.00	1355			-	1355
	Zone 97	13.00	504			504	-
	Zone 98	32.00	1039			1039	-
	Zone 101	36.00	1452			-	1452

Table A.1. Evacuation Assignment (Con't)

Sector	Zone	Area (Hectare)	Expected Victims	Assigned Refugee Camp	Location	Moving Assignment 1st Term	Moving Assignment 2nd Term
D	Zone 71	59.00	2096	D1	Municipality office, By Pass	2096	-
	Zone 74	65.00	3399			3399	-
	Zone 75	77.00	1778			1778	-
	Zone 78	47.00	5807			5807	-
	Zone 79	46.00	2162			2162	-
	Zone 82	25.00	3560			3560	-
	Zone 63	93.70	8763	D2	TVRI office, by pass	-	8763
	Zone 68	76.63	8152			-	8152
	Zone 70	91.00	6483			-	6483
	Zone 76	71.88	4990			-	4990
	Zone 77	97.00	6121			-	6121
	Zone 80	87.00	3923			-	3923
	Zone 81	98.00	5364			5364	-
	Zone 83	51.00	1110			1110	-
	Zone 84	34.00	2709			2709	-
	Zone 85	99.00	1429			1429	-
	Zone 86	36.00	995			995	-
	Zone 87	31.00	2343			2343	-
	Zone 89	25.00	1153			1153	-
	Zone 90	64.00	2771			2771	-
	Zone 92	77.00	92			92	-
E	Zone 47	53.73	4226	E1	Gunung Pangilun	-	4226
	Zone 48	101.00	10204			-	10204
	Zone 49	57.84	5935			-	5935
	Zone 50	43.00	2357			2357	-
	Zone 51	73.00	5464			-	5464
	Zone 52	52.00	1431			1431	-
	Zone 53	43.37	4425			-	4425
	Zone 54	62.00	4952			-	4952
	Zone 55	94.00	7563			-	7563
	Zone 56	48.00	4301			-	4301
	Zone 57	54.00	4441			4441	-
	Zone 59	81.43	6516			-	6516
	Zone 60	36.50	1239			1239	-
	Zone 61	100.00	10756			-	10756
	Zone 62	30.00	2042			-	2042
	Zone 67	24.00	1785			1785	-
	Zone 139	31.60	3046			-	3046
F	Zone 58	60.00	2542	F1	Sungai Sapih	-	2542
	Zone 64	48.00	1619			-	1619
	Zone 65	44.00	4604			-	4604
	Zone 66	81.00	10617			-	10617
	Zone 69	49.00	2325			2325	-
	Zone 72	53.00	4382			4382	-
	Zone 73	48.00	5296			5296	-
	Zone 140	36.50	1239			1239	-

Table A.1. Evacuation Assignment (Con't)

Sector	Zone	Area (Hectare)	Expected Victims	Assigned Refugee Camp	Location	Moving Assignment 1st Term	Moving Assignment 2nd Term
G	Zone 22	68.08	5973	G1	Kubu Marapalam	-	5973
	Zone 24	48.00	4955			4955	-
	Zone 25	40.00	4910			-	4910
	Zone 26	42.00	4177			4177	-
	Zone 27	46.00	6086			-	6086
	Zone 28	99.00	7527			-	7527
	Zone 29	54.00	4887			-	4887
	Zone 30	80.73	5683			5683	-
	Zone 32	41.00	3165			3165	-
	Zone 33	35.00	4085			4085	-
	Zone 34	67.00	4857			-	4857
	Zone 35	46.00	4405			-	4405
	Zone 36	80.00	7303			-	7303
	Zone 37	78.65	6586			-	6586
	Zone 38	25.00	2605			-	2605
	Zone 39	54.00	3817			3817	-
	Zone 40	16.00	1303			-	1303
	Zone 41	51.00	5107			-	5107
	Zone 42	24.92	2971			2971	-
	Zone 43	43.11	4314			-	4314
	Zone 44	42.29	3046			-	3046
	Zone 45	41.00	5003			-	5003
	Zone 46	38.00	3561			3561	-
H	Zone 1	85.53	1462	H1	Teluk Kabung Utara	-	1462
	Zone 2	79.65	1831			-	1831
	Zone 3	41.51	1758			-	1758
	Zone 4	51.85	1636			-	1636
	Zone 5	56.23	2186			-	2186
	Zone 6	25.96	1144			1144	-
	Zone 7	37.00	724			-	724
	Zone 8	59.24	1588			-	1588
	Zone 9	70.00	2372			-	2372
	Zone 11	52.00	1710			-	1710
I	Zone 10	46.17	488	I1	Banuaran nan XX	-	488
	Zone 12	46.31	2493			-	2493
	Zone 13	40.92	1096			-	1096
	Zone 14	56.80	1682			-	1682
	Zone 15	22.89	1063			-	1063
	Zone 16	71.36	4939			-	4939
	Zone 17	68.66	589			-	589
	Zone 18	55.47	669			-	669
	Zone 19	105.00	12212			-	12212
	Zone 20	36.00	3335			-	3335
	Zone 21	50.67	3792			-	3792
	Zone 23	53.00	5177			-	5177
	Zone 31	35.00	3854			3854	-

APPENDIX B

LOCATION-ALLOCATION PARAMETERS

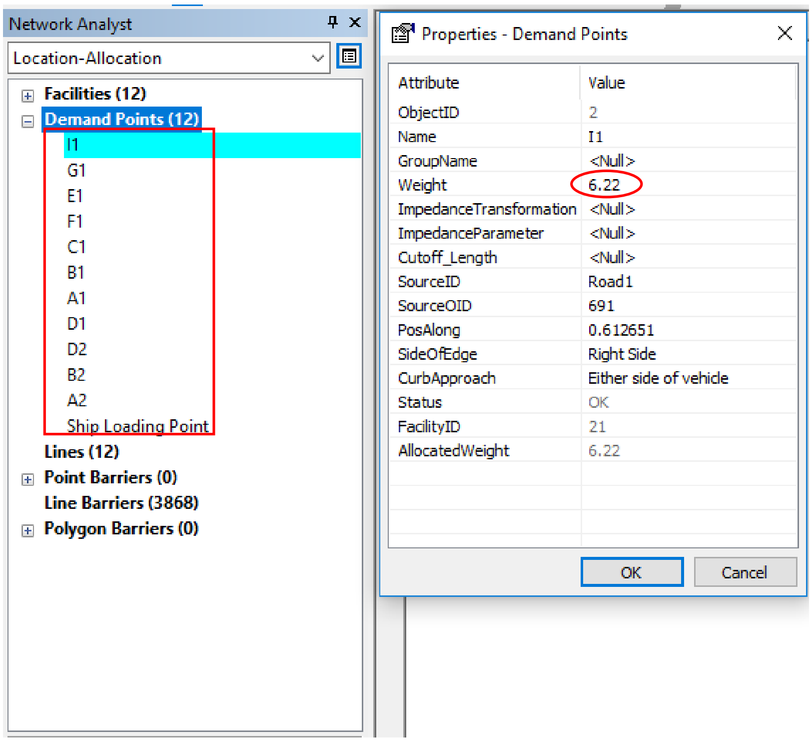


Figure B.1. Set of Refugee Camps and Weighted Factor

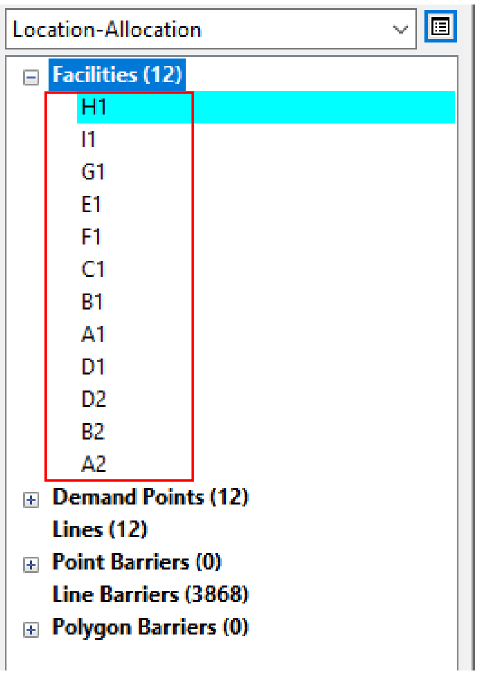


Figure B.2. Set of LDCs Candidates

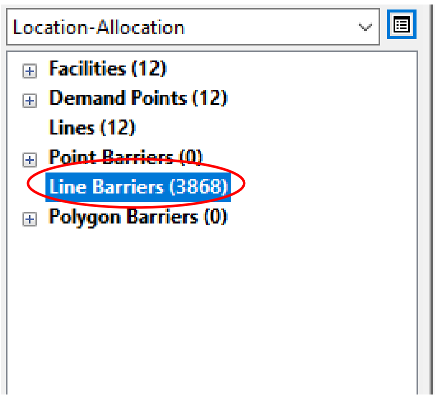


Figure B.3. Set of Road Barriers

APPENDIX C

PATH NETWORK

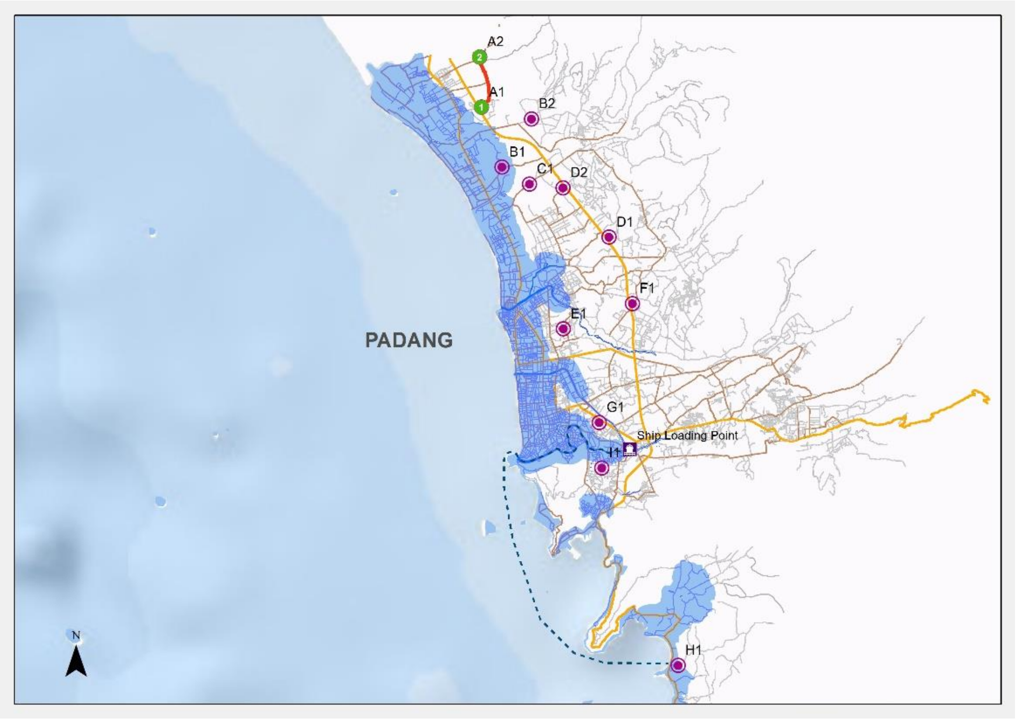


Figure C.1. Path A1 - A2

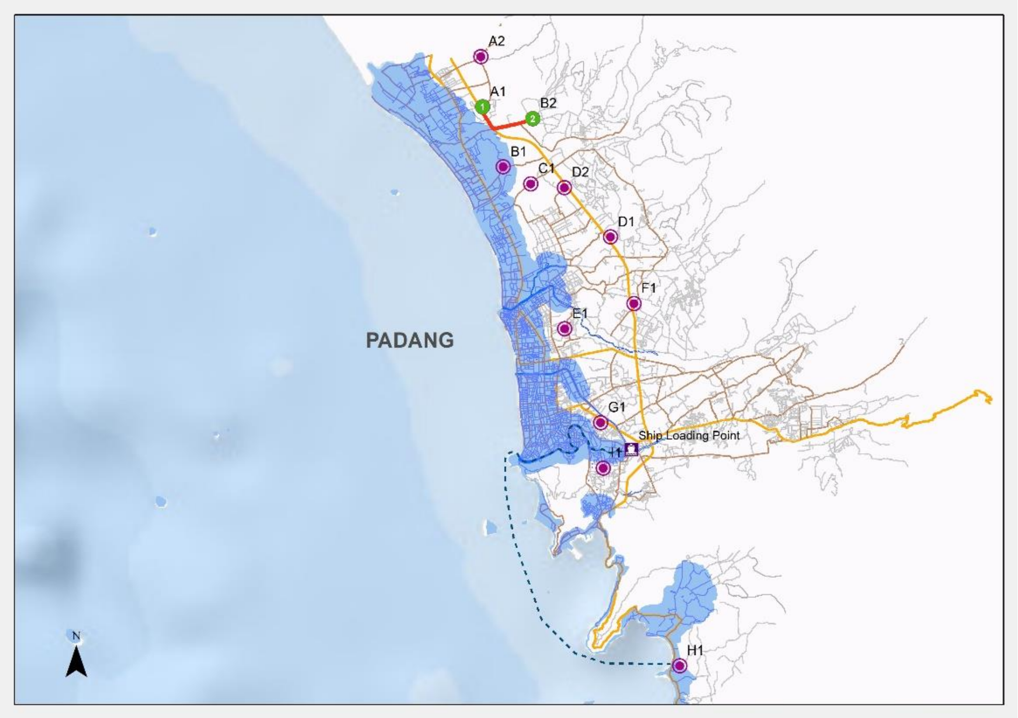


Figure C.2. Path A1 - B2

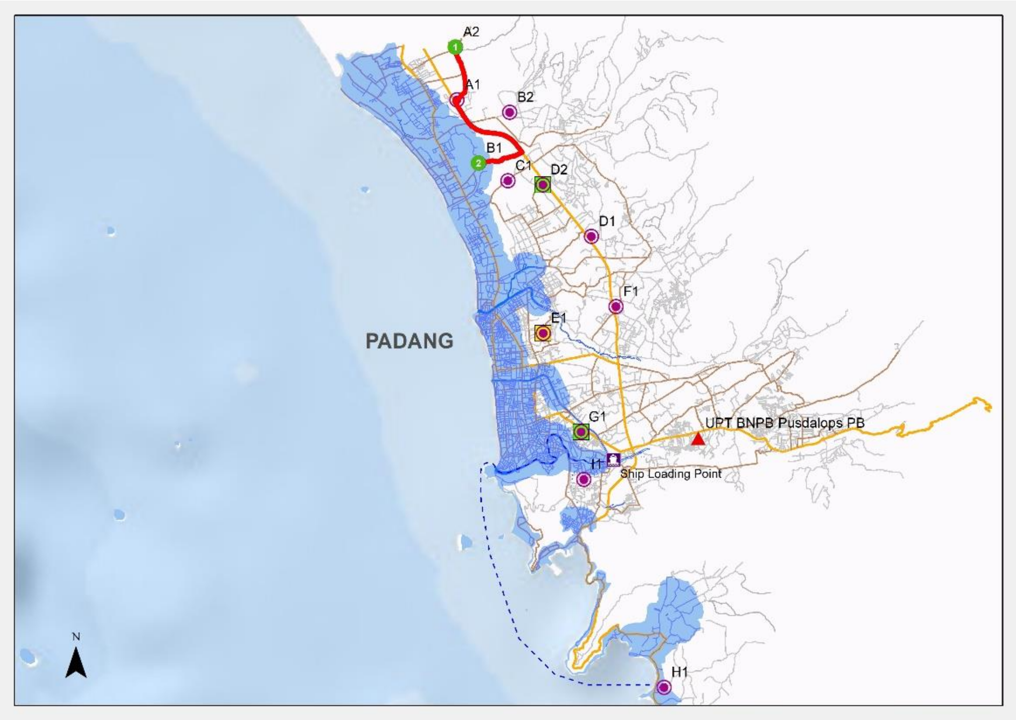


Figure C.3. Path A2 - B1

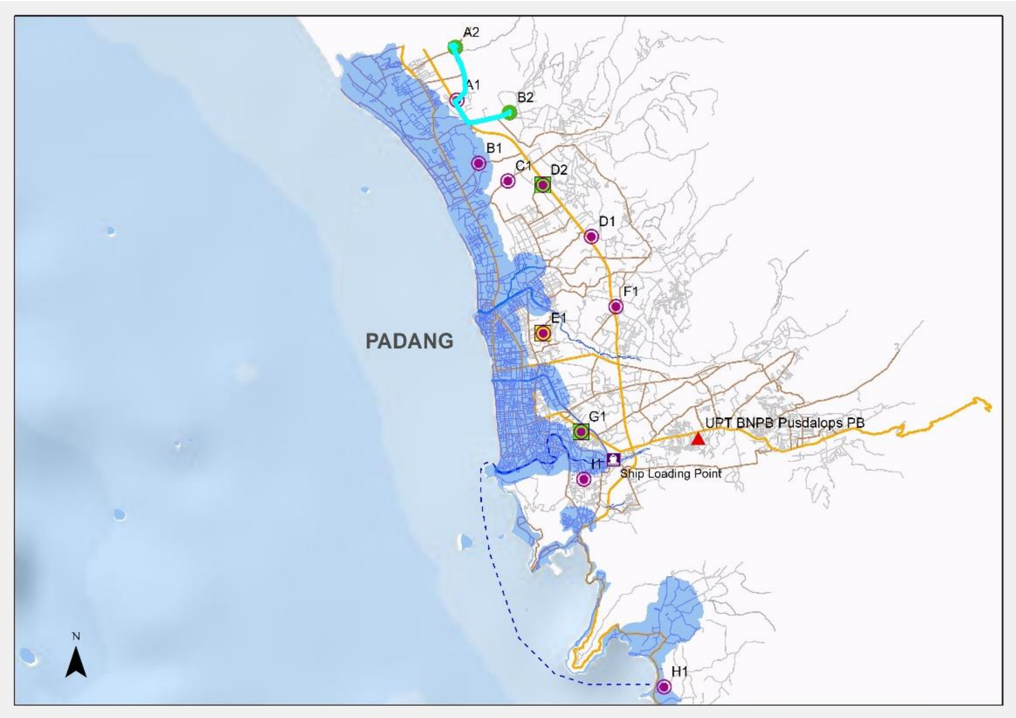


Figure C.4. Path A2 - B2

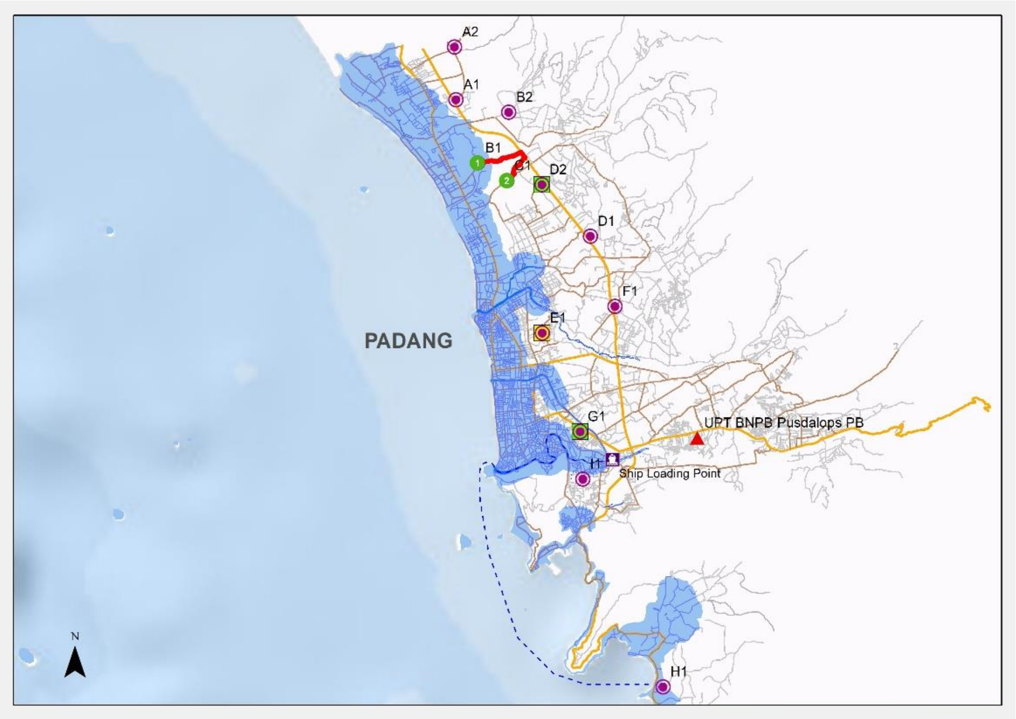


Figure C.5. Path B1 - C1

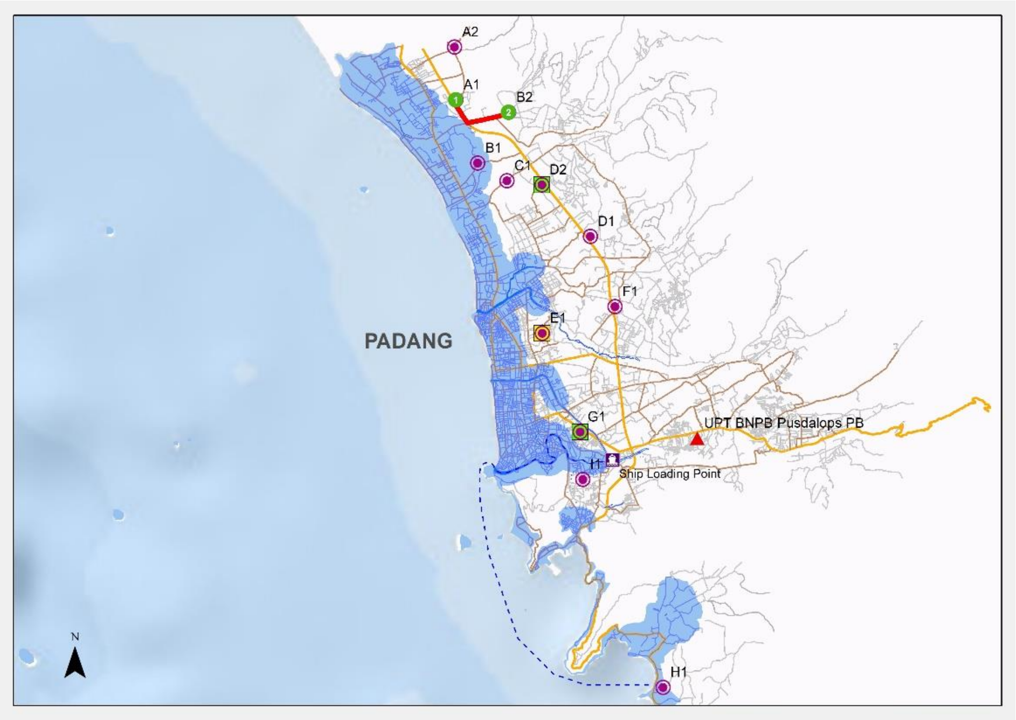


Figure C.6. Path B2 - A1

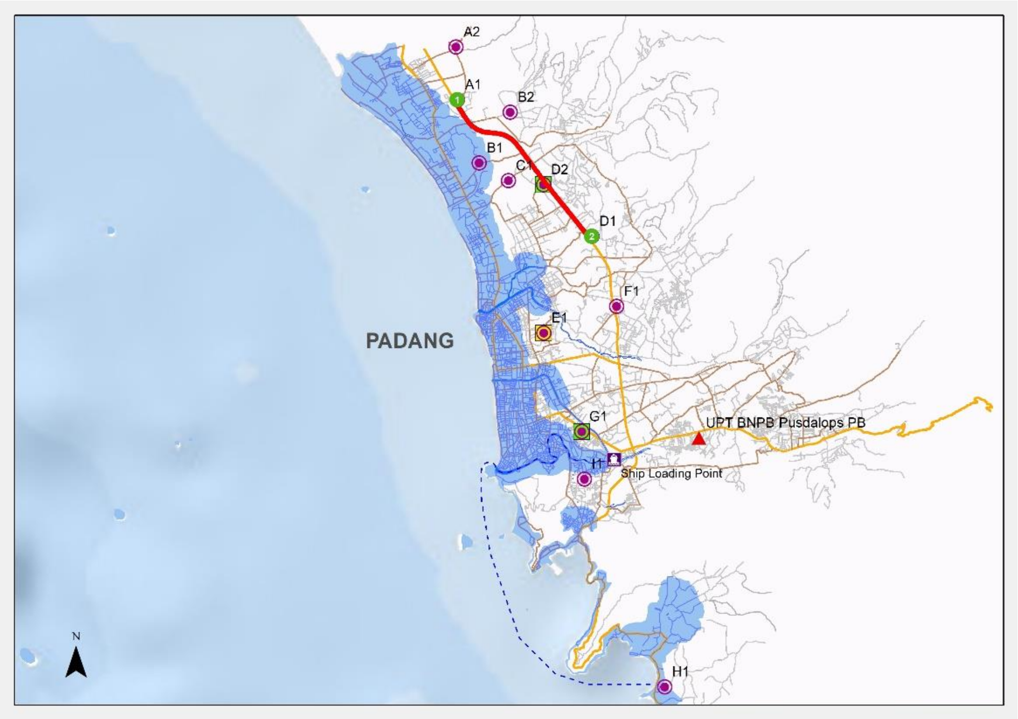


Figure C.7. Path D1 - A1

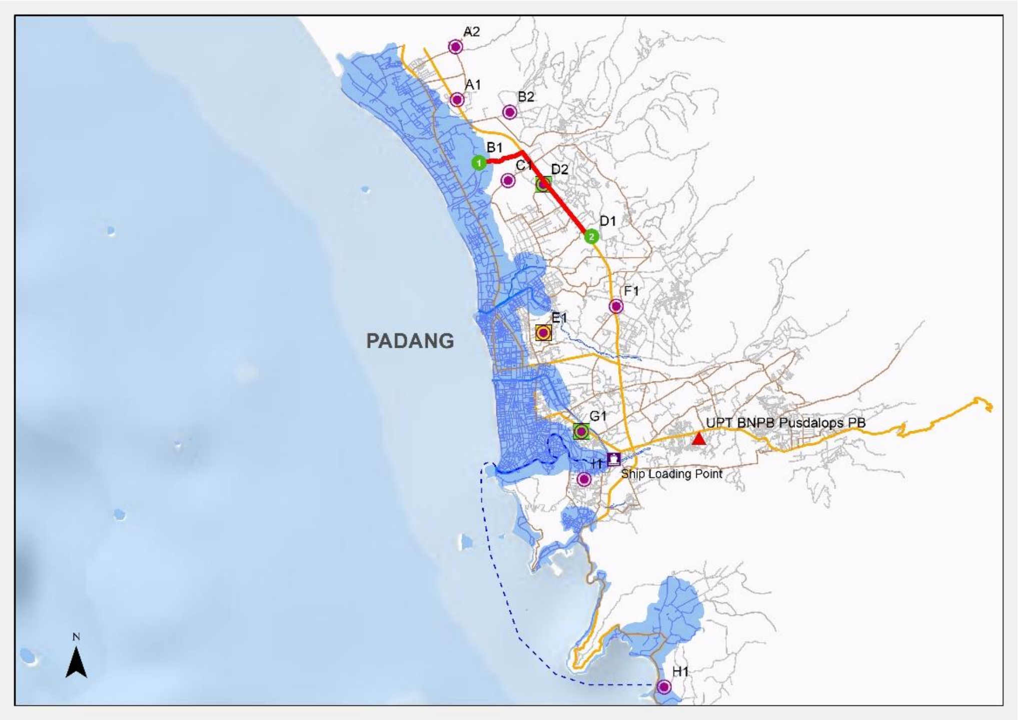


Figure C.8. Path D1 B1

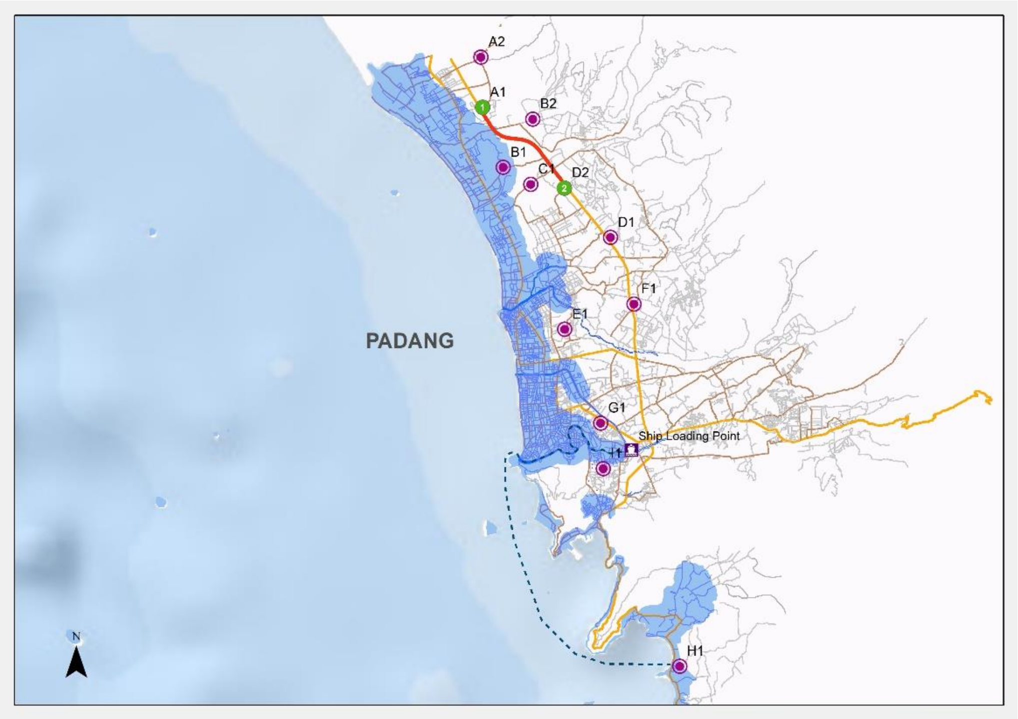


Figure C.9. Path D2 - A1

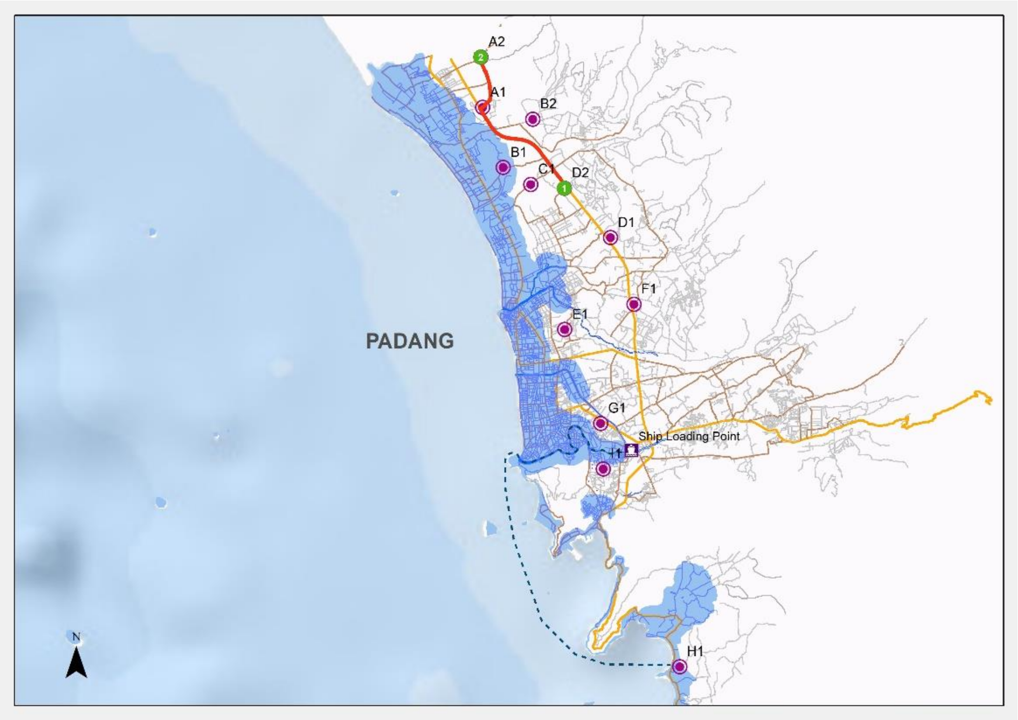


Figure C.10. Path D2 - A2

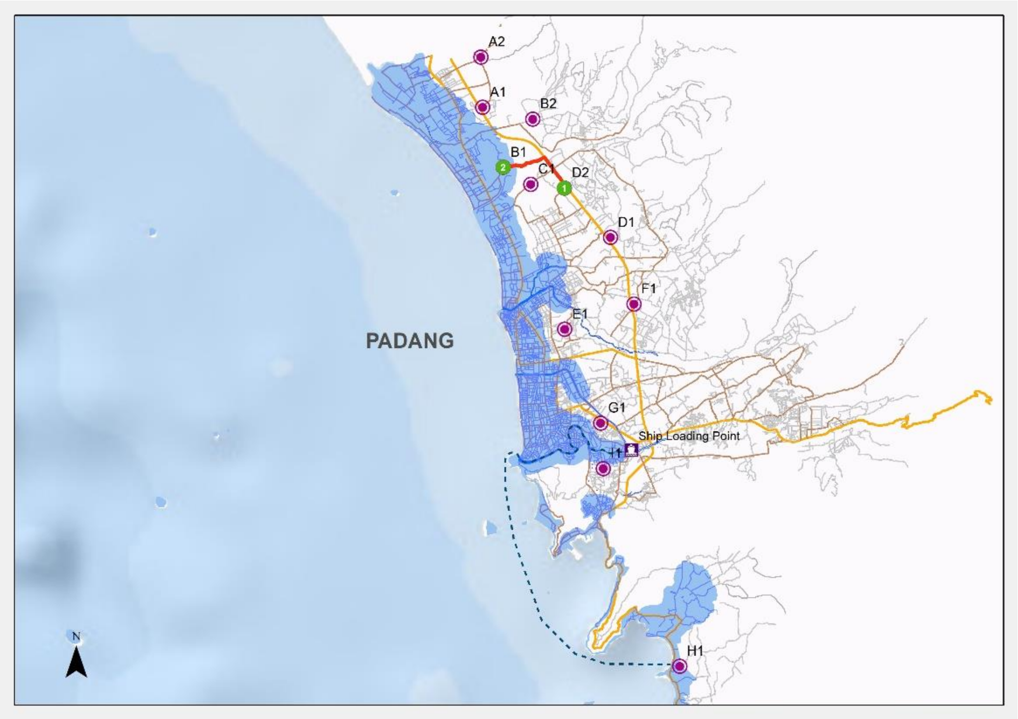


Figure C.11. Path D2 - B1

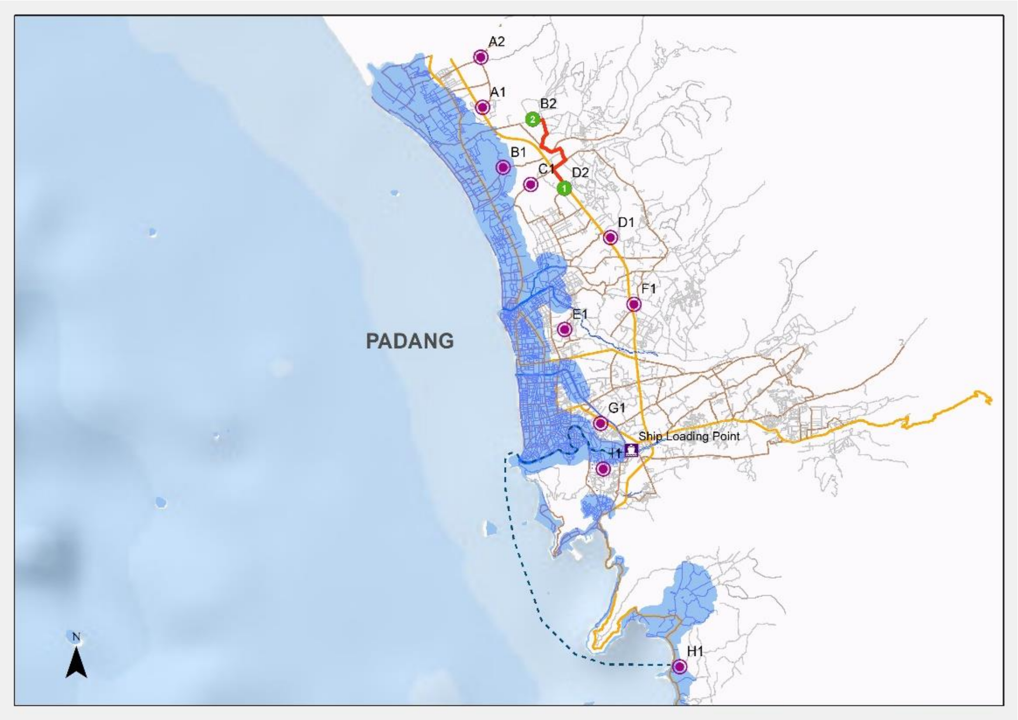


Figure C.12. Path D2 - B2

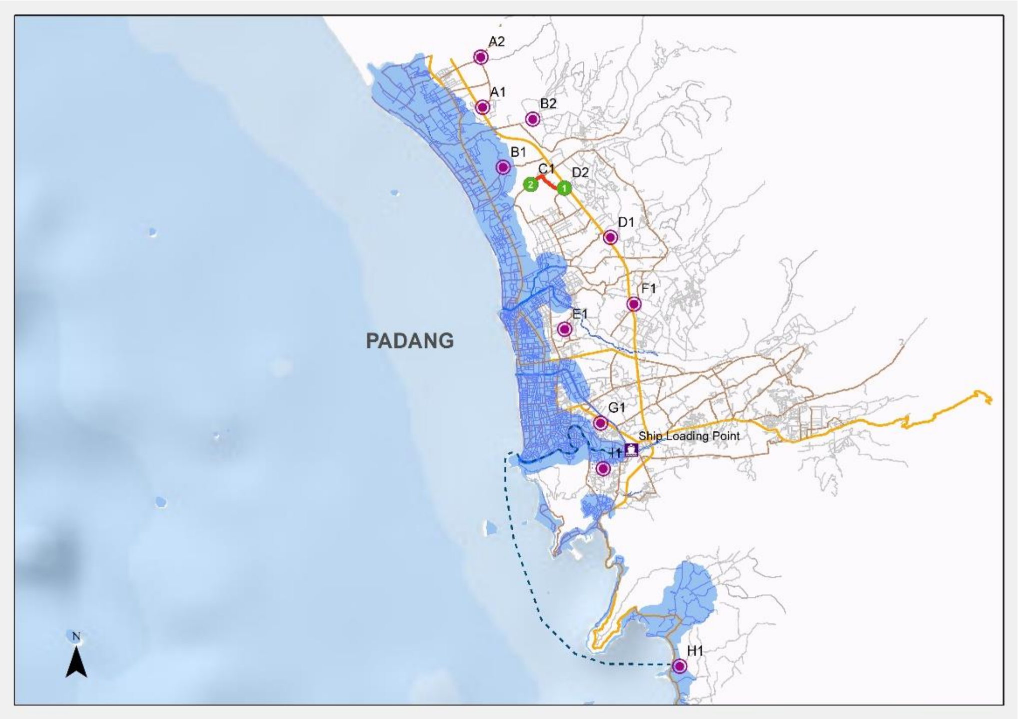


Figure C.13. Path D2 - C1

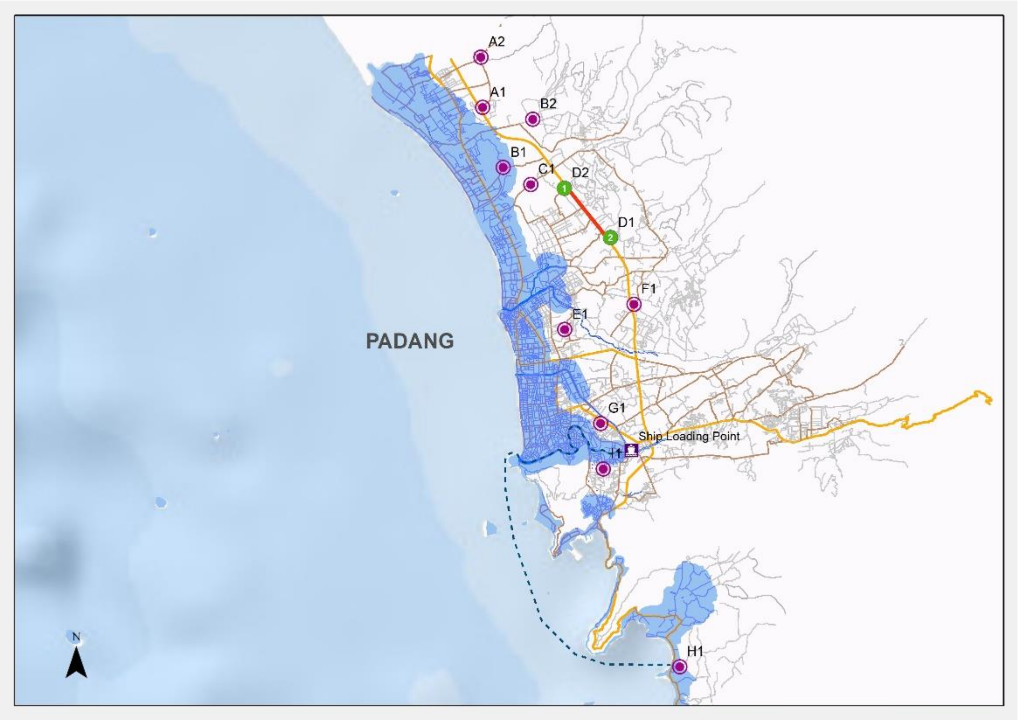


Figure C.14. Path D2 - D1

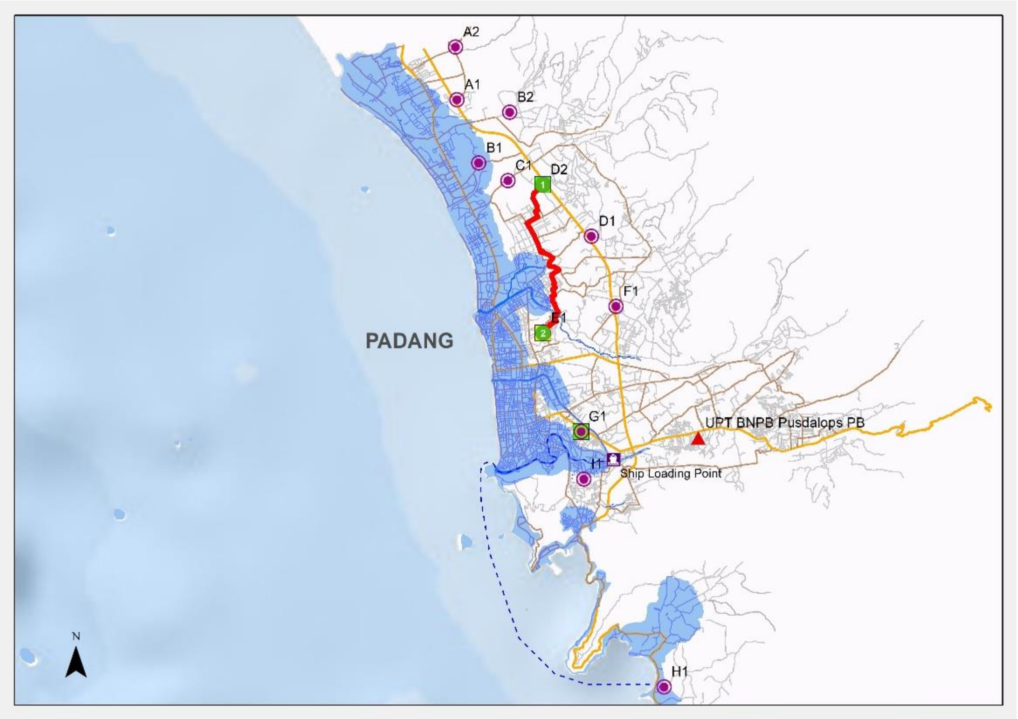


Figure C.15. Path D2 - E1

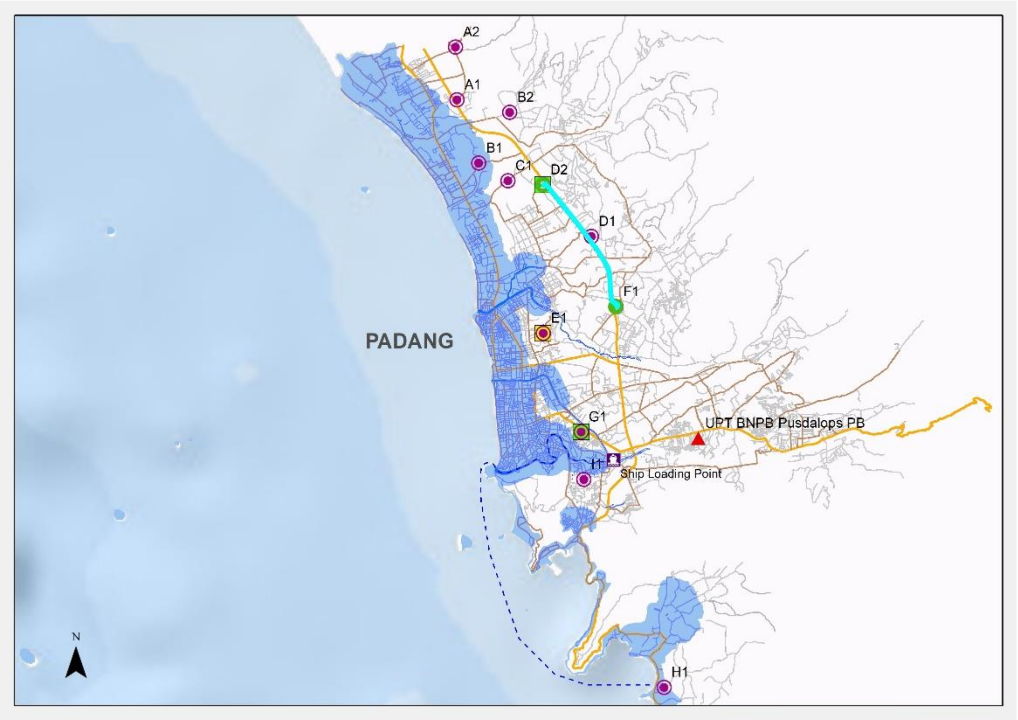


Figure C.16. Path D2 - F1

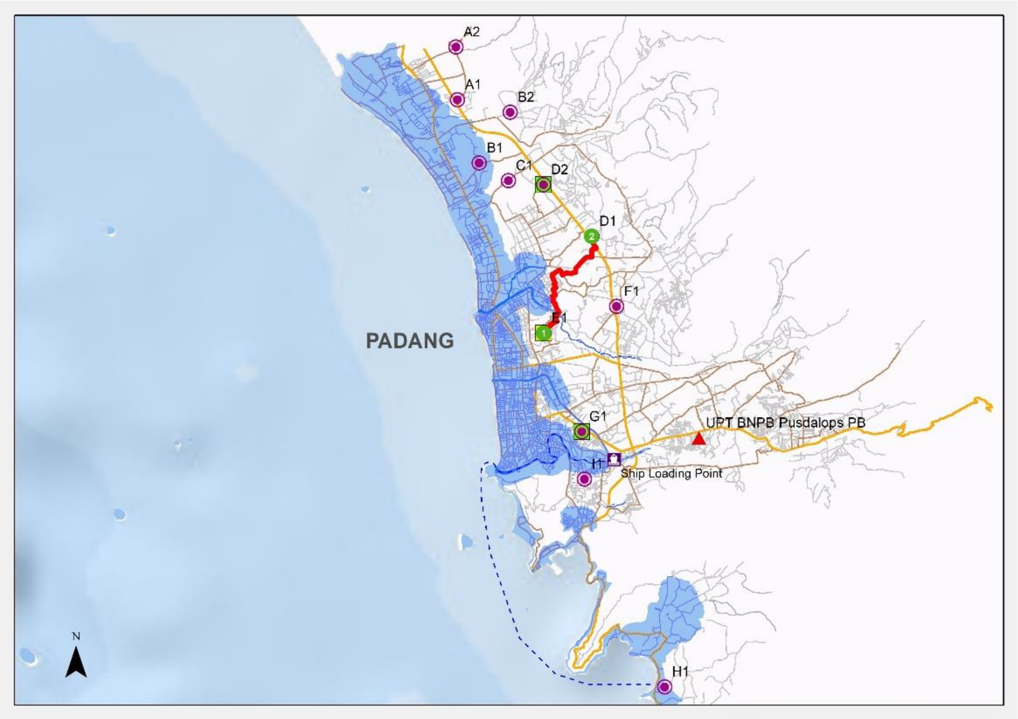


Figure C.17. Path E1 - F1

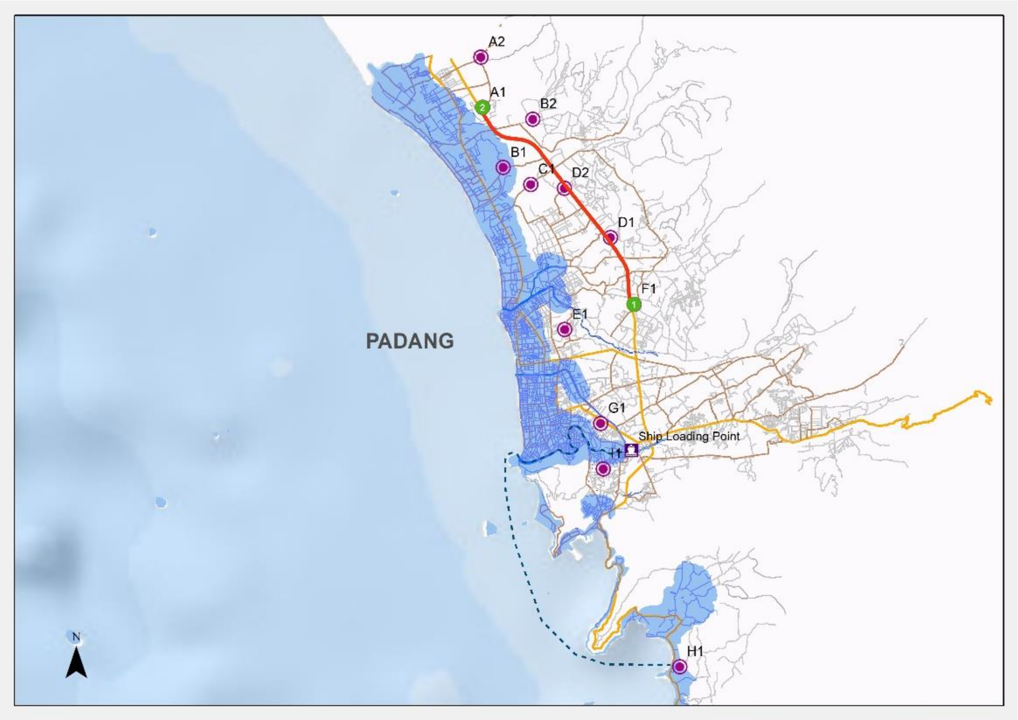


Figure C.18. Path F1 - A1

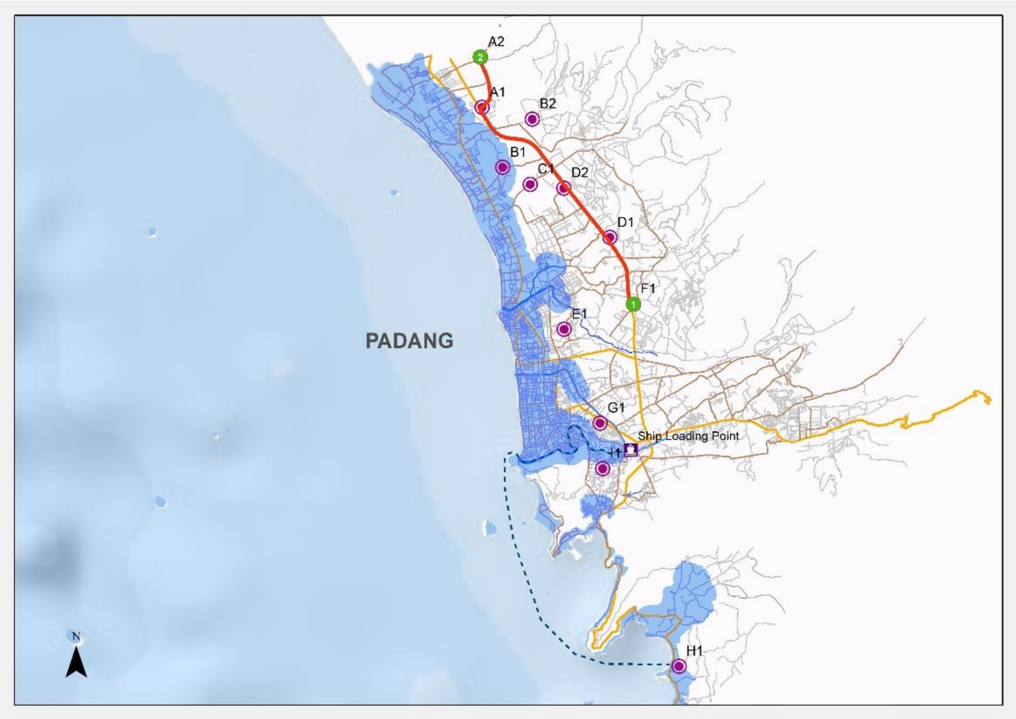


Figure C.19. Path F1 - A2

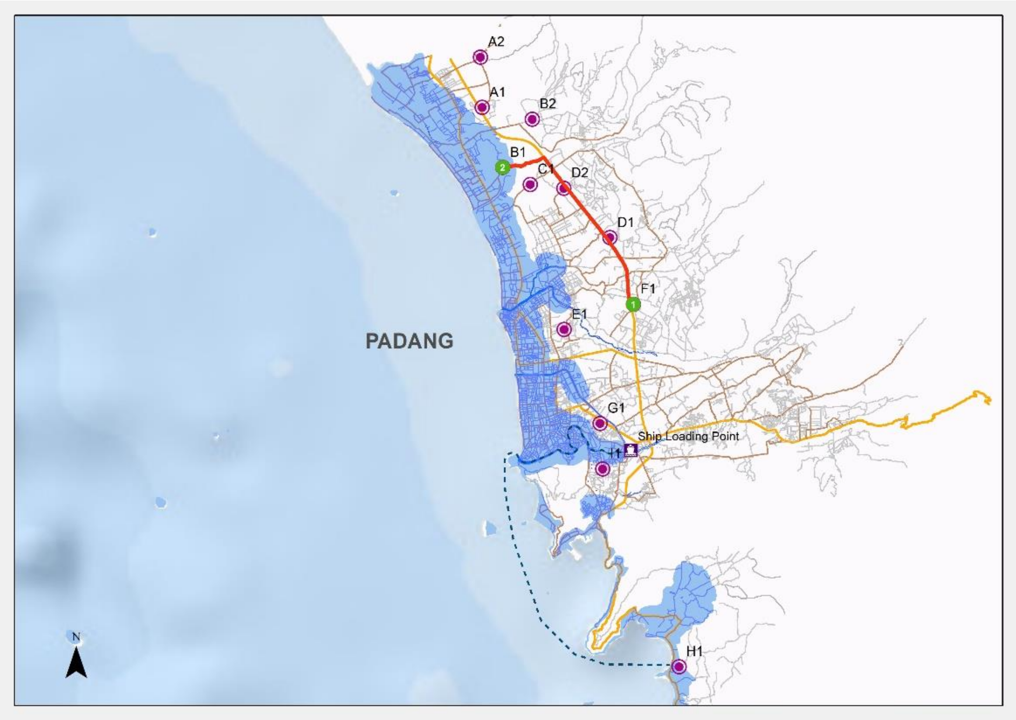


Figure C.20. Path F1 - B1

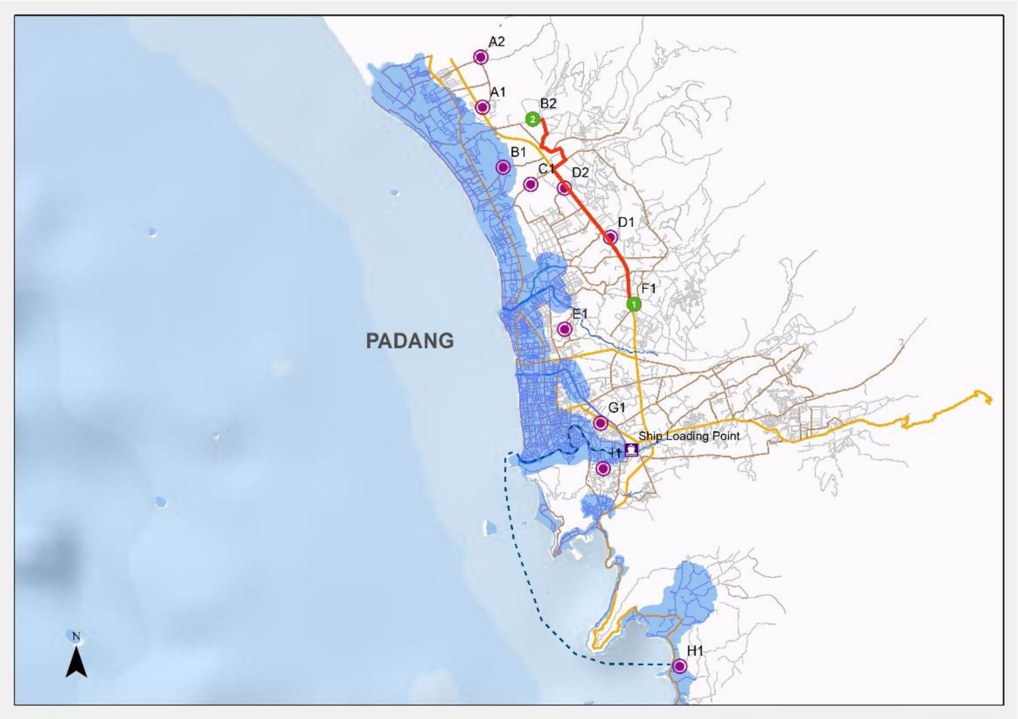


Figure C.21. Path F1 - B2

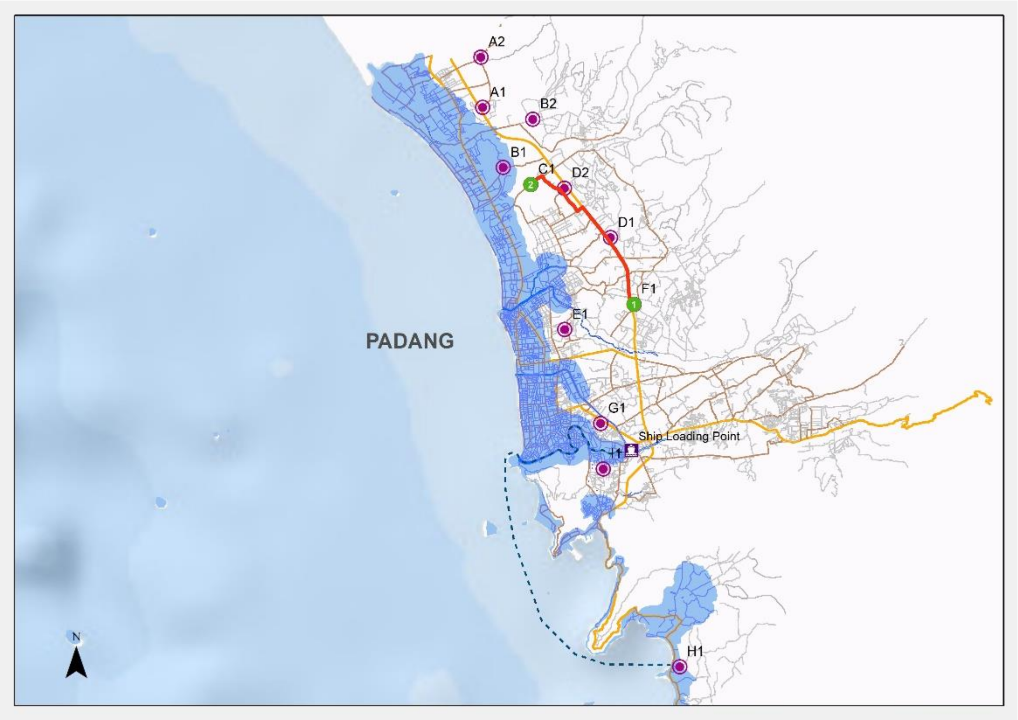


Figure C.22. Path F1 - C1

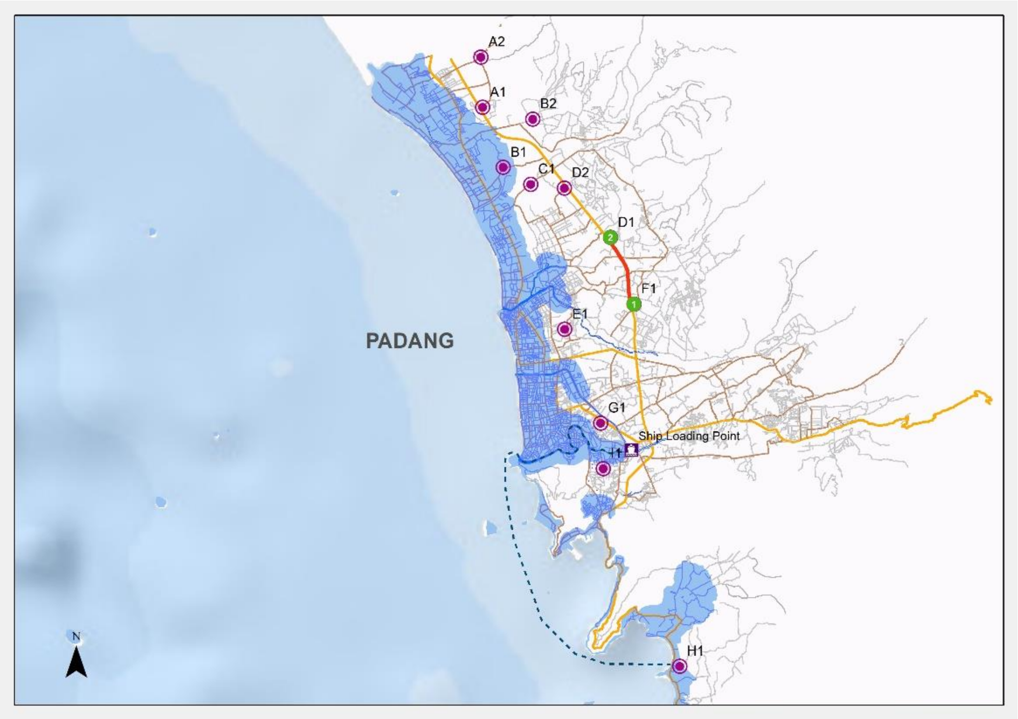


Figure C.23. Path F1 - D1

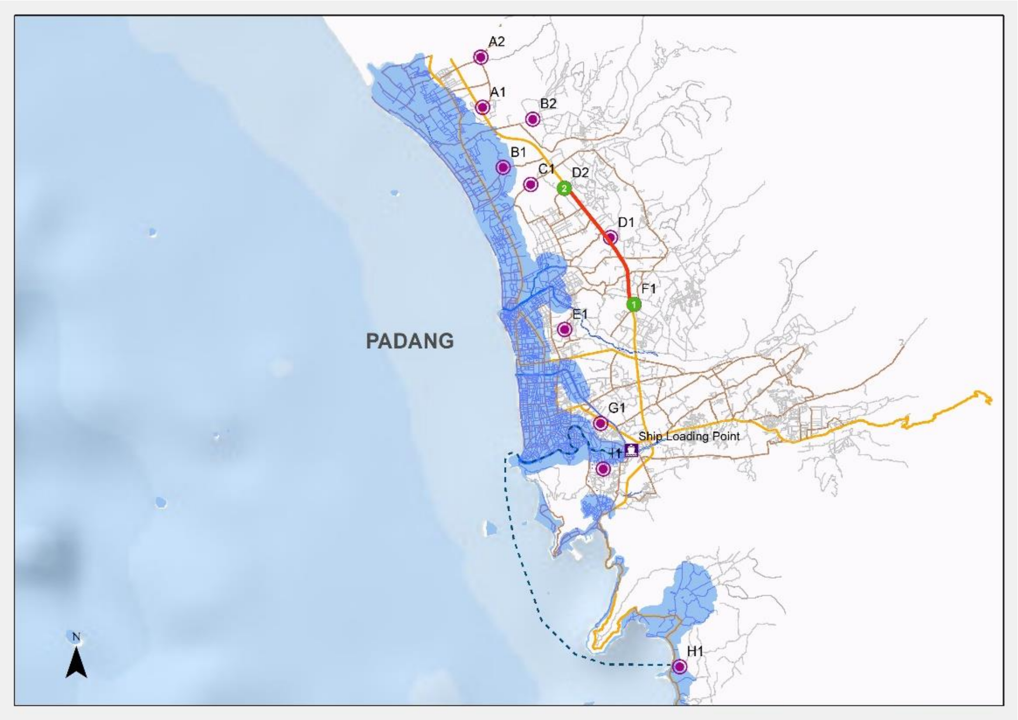


Figure C.24. Path F1 - D2

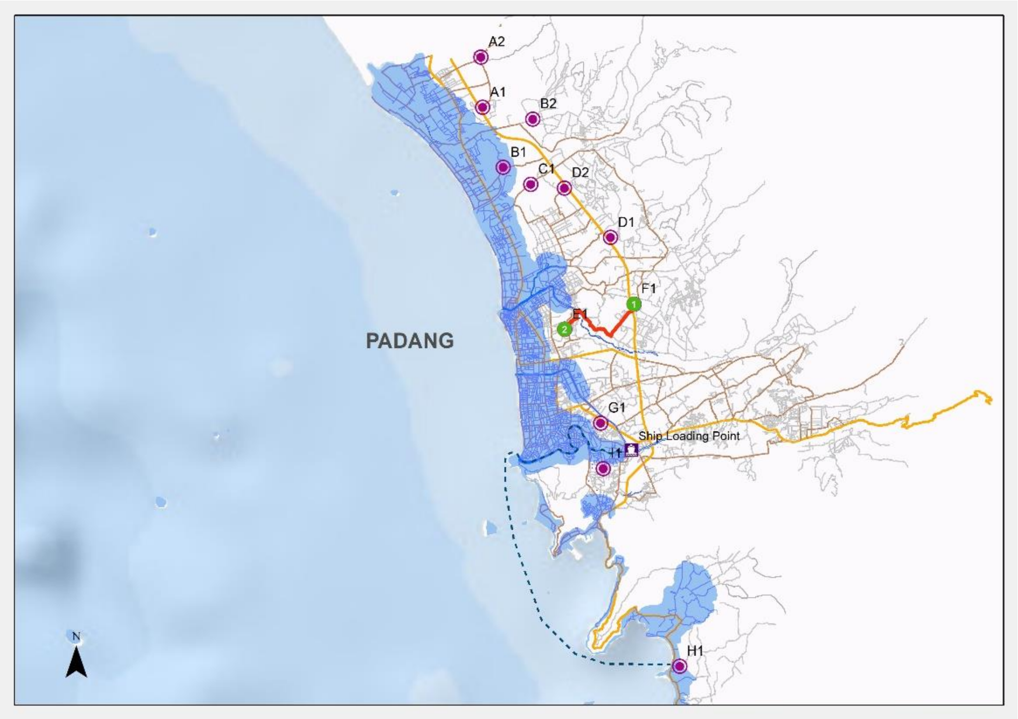


Figure C.25. Path F1 - E1

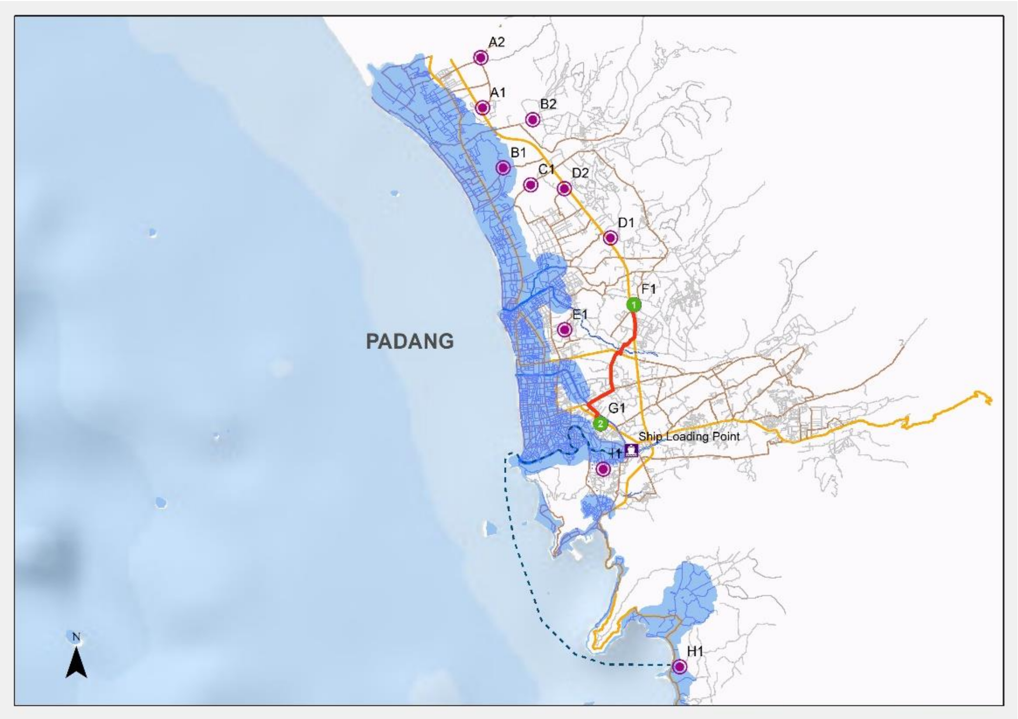


Figure C.26. Path F1 - G1

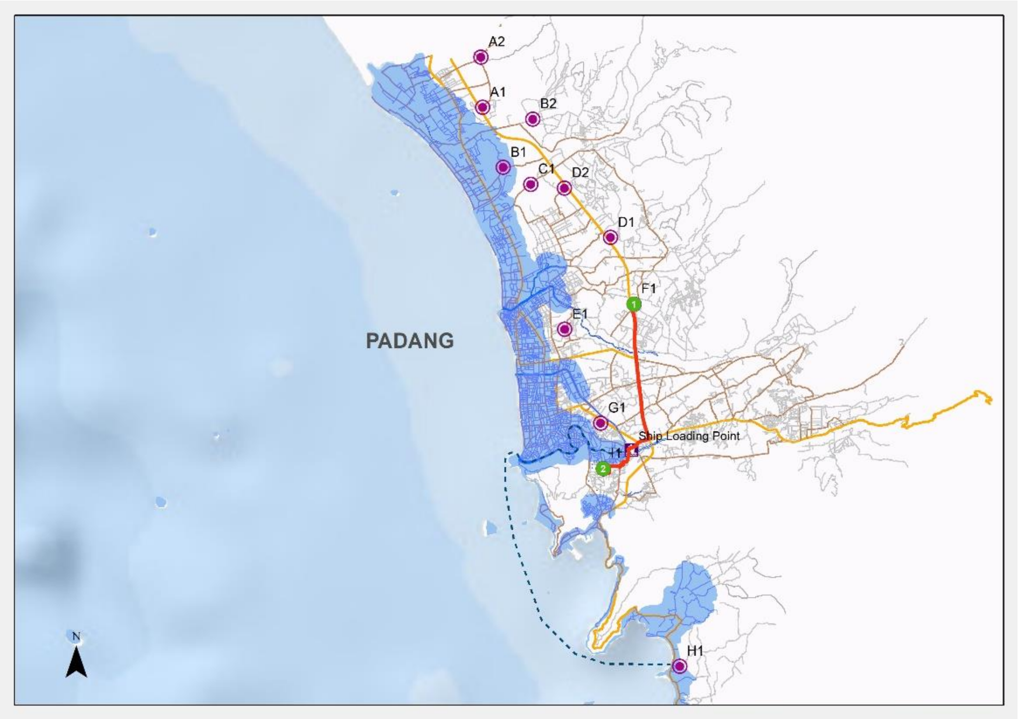


Figure C.27. Path F1 - I1

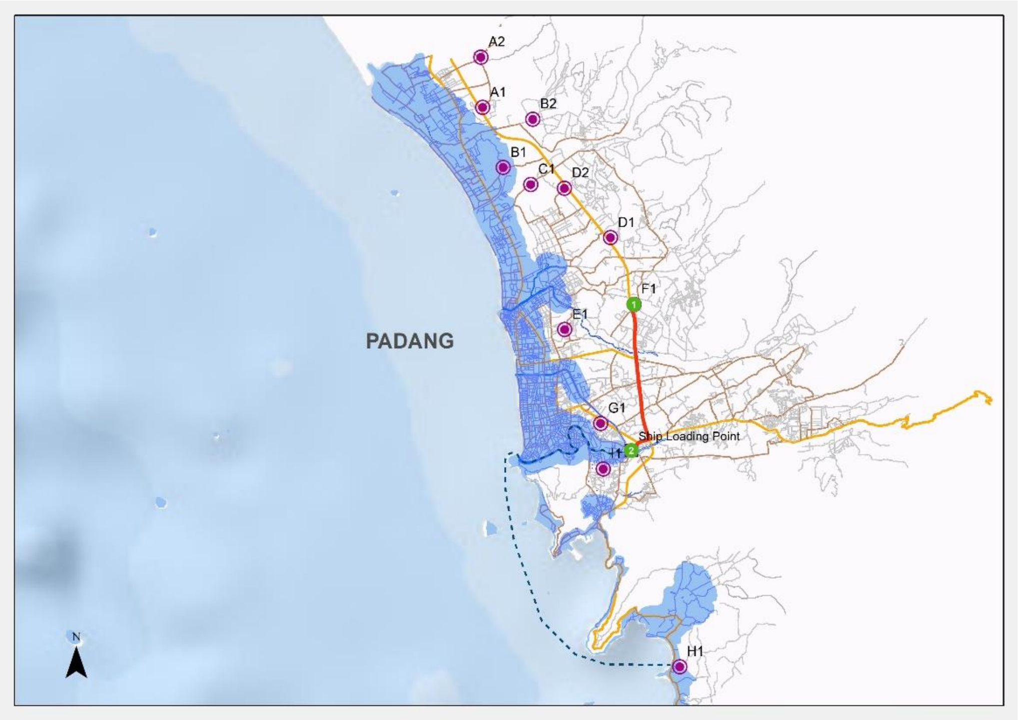


Figure C.28. Path F1 - Ship Loading Point

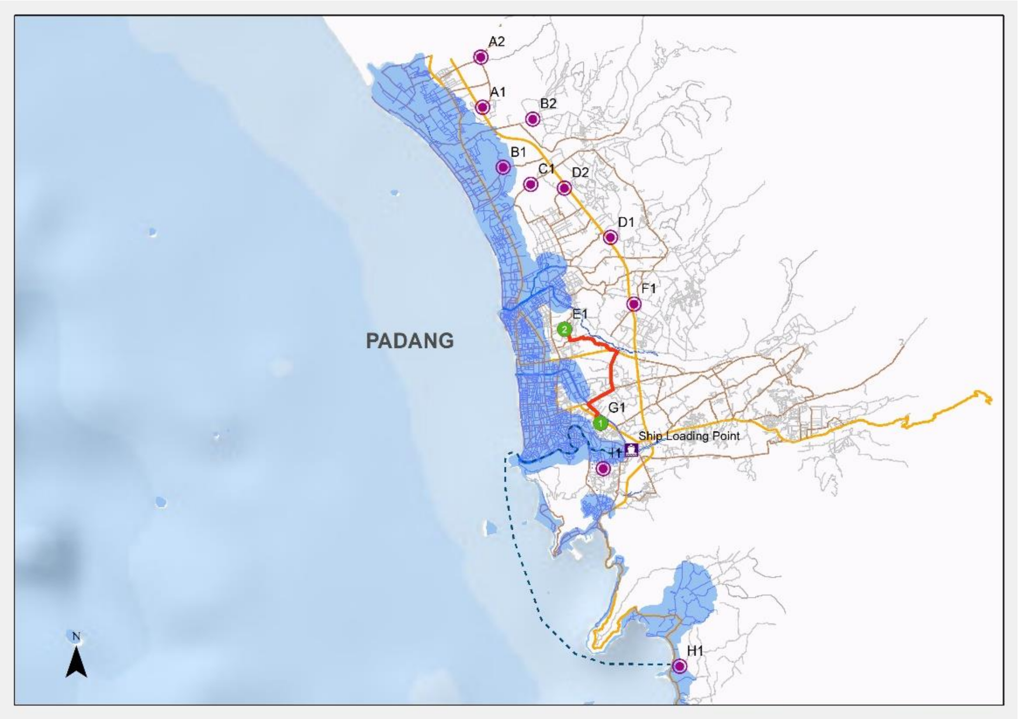


Figure C.29. Path G1 - E1

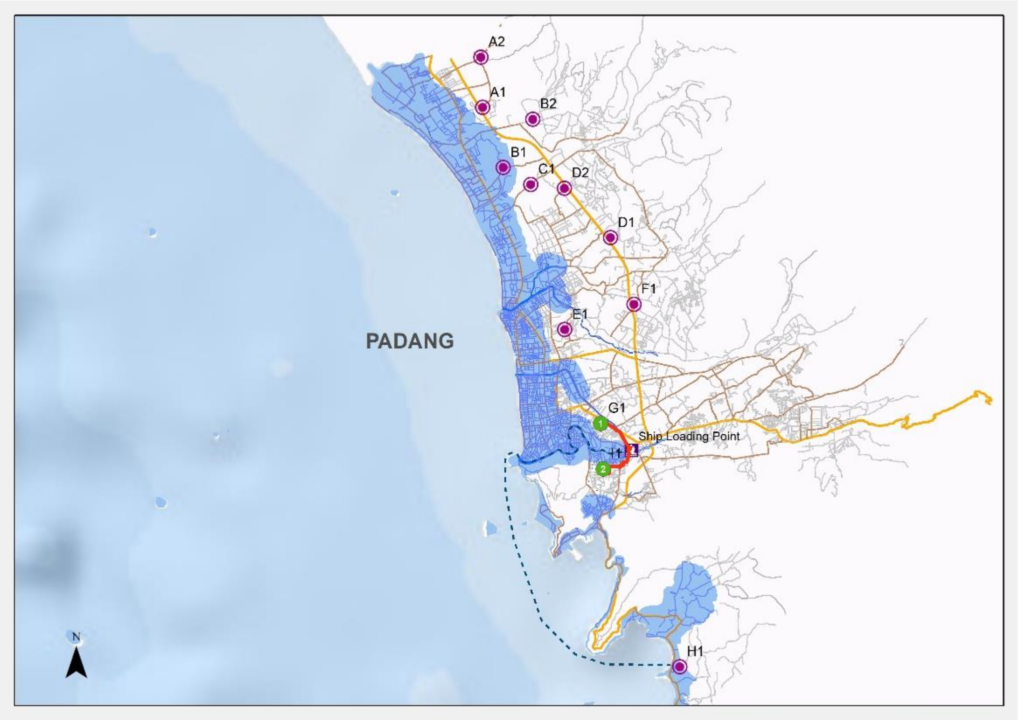


Figure C.30. Path G1 - I1

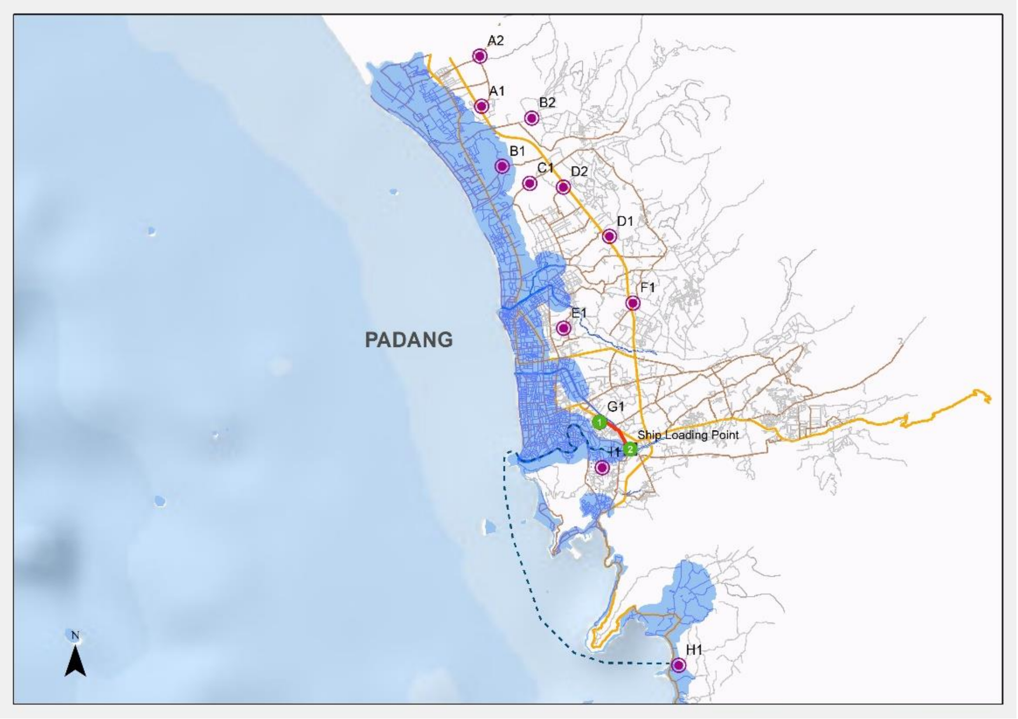


Figure C.31. Path G1 - Ship Loading Point

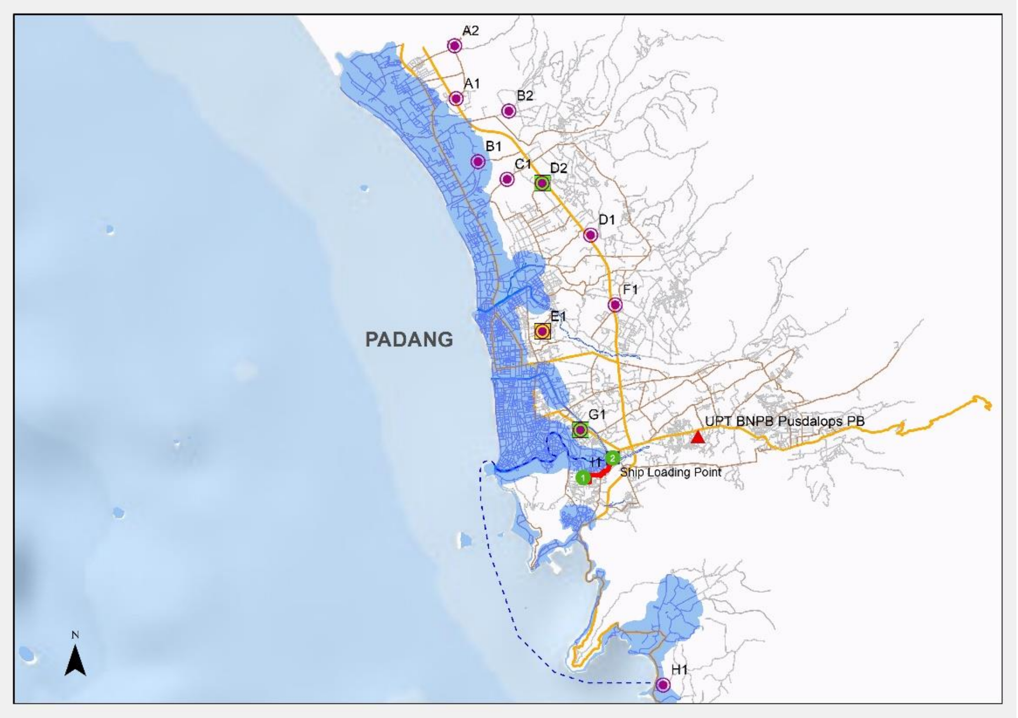


Figure C.32. Path I1 - Ship Loading Point

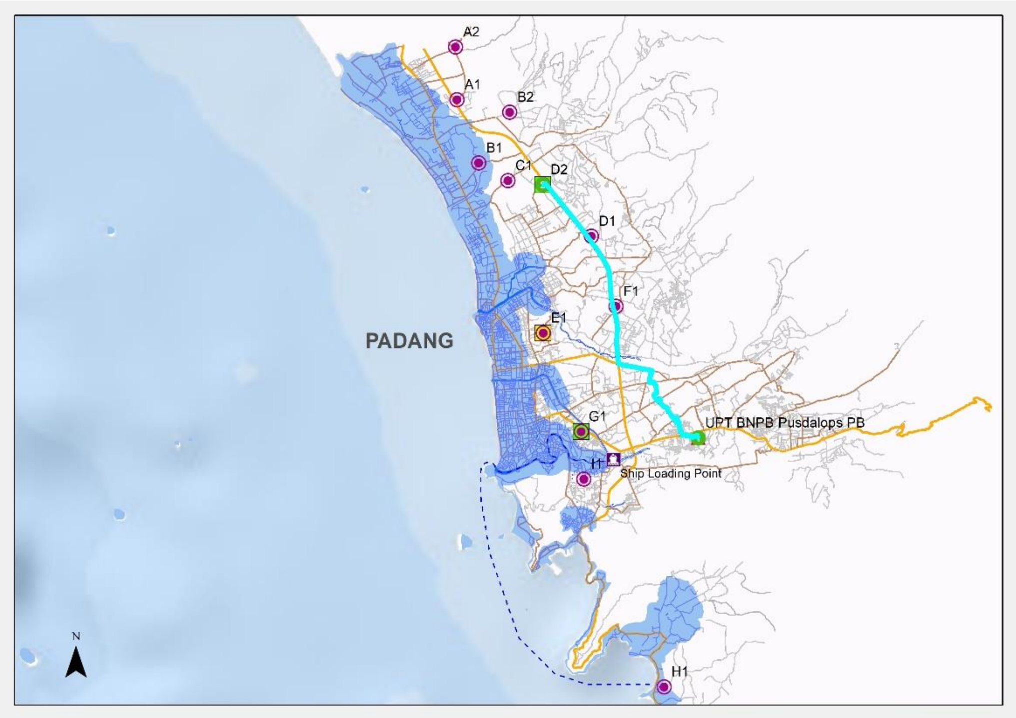


Figure C.33. Path Warehouse - D2

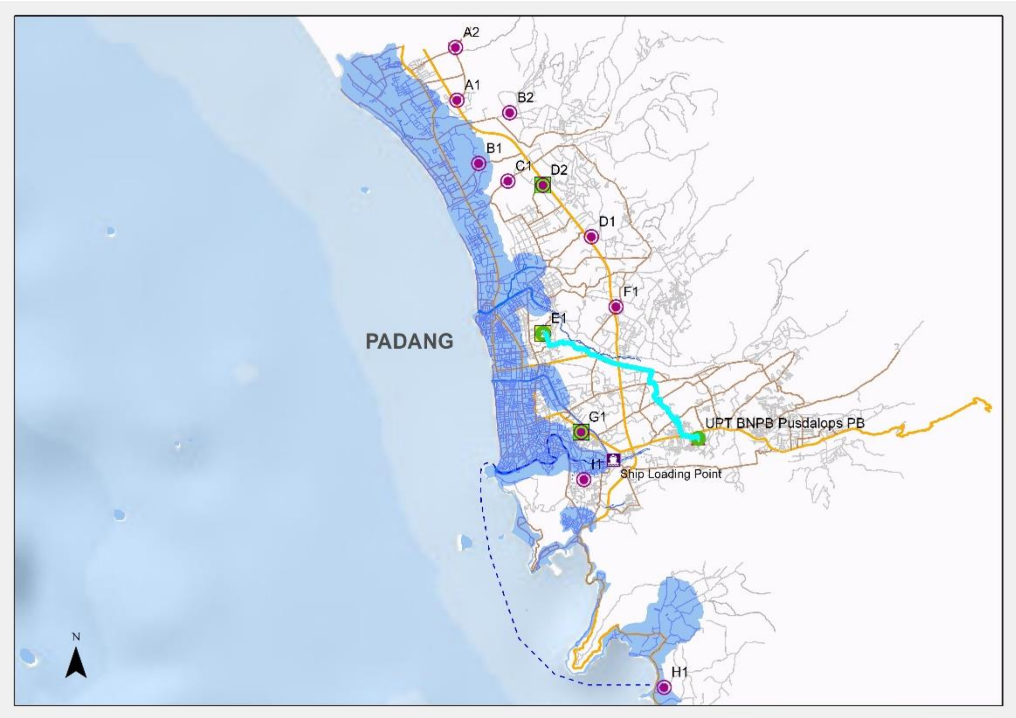


Figure C.34. Path Warehouse - E1

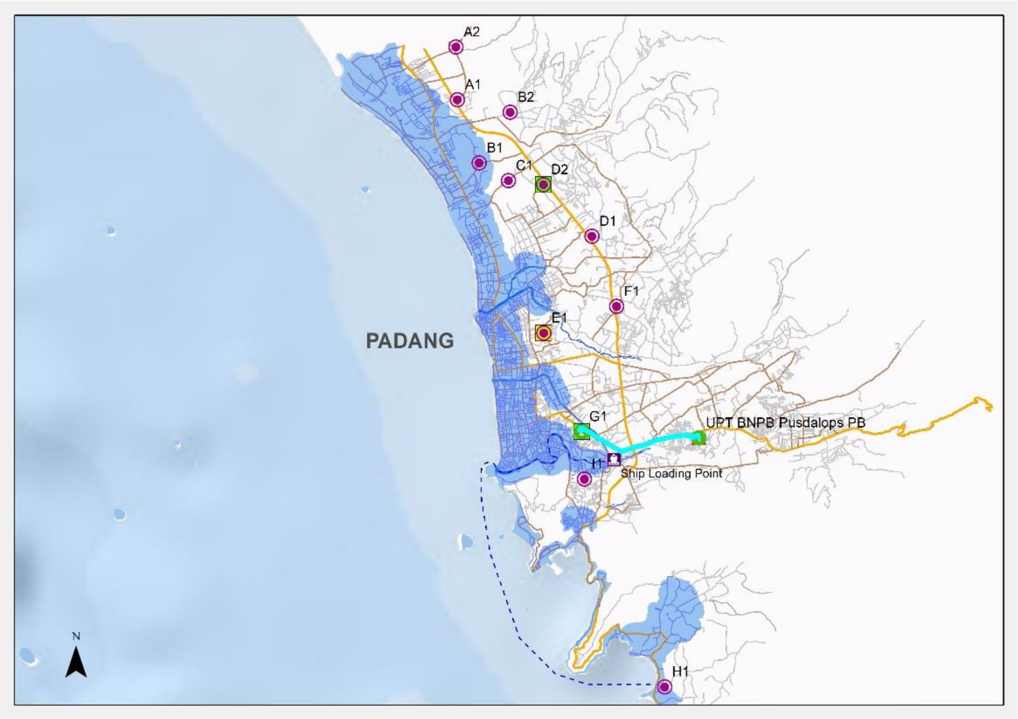


Figure C.35. Path Warehouse - G1

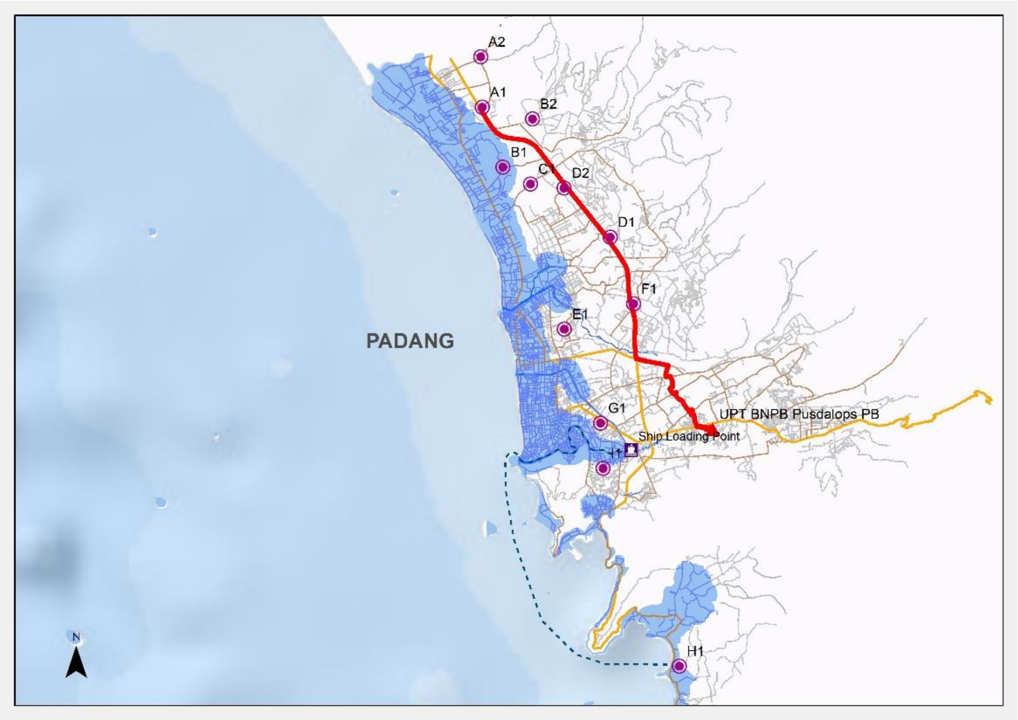


Figure C.36. Path Warehouse - A1

APPENDIX D

CVRP PARAMETERS

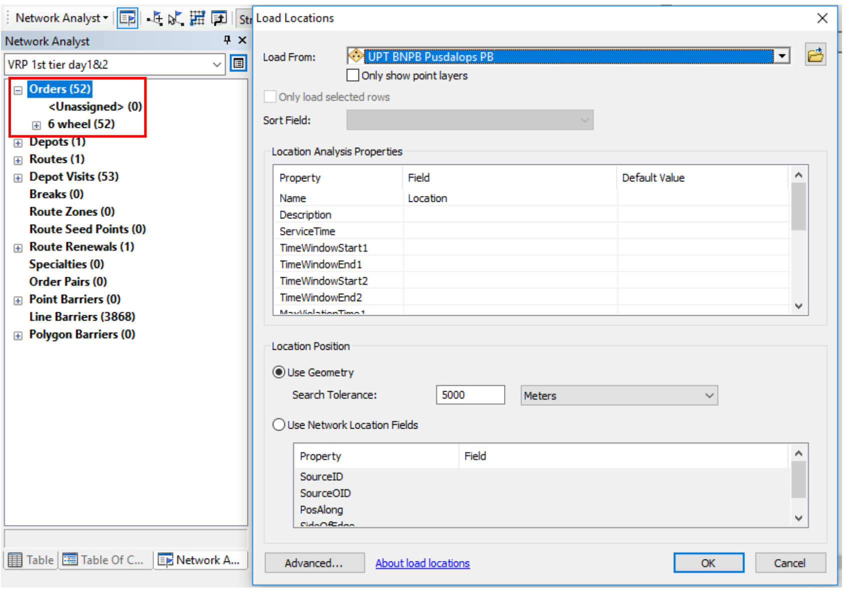


Figure D.1. Orders Setting

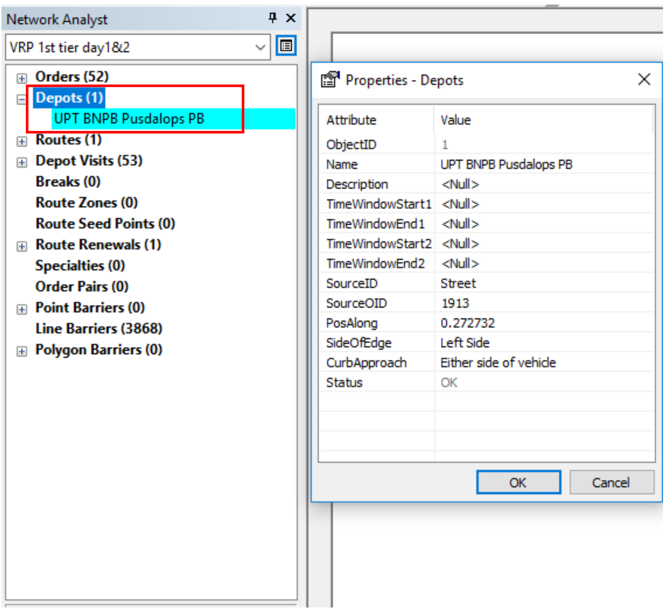


Figure D.2. Depots Setting

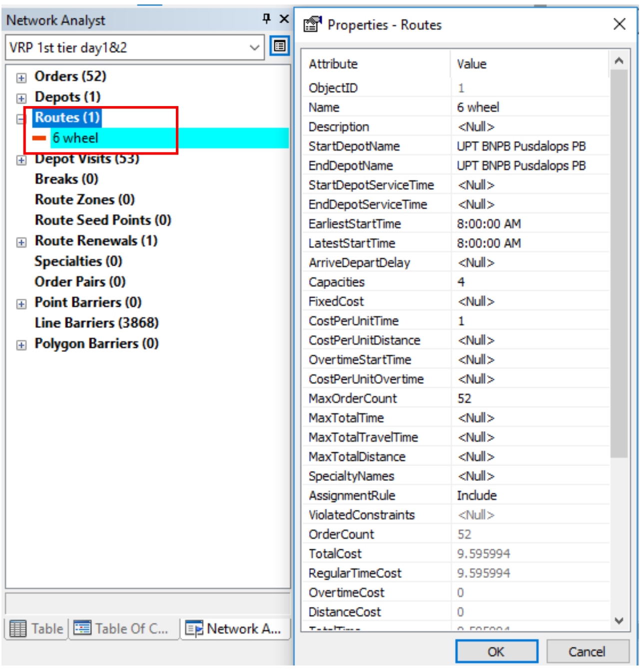


Figure D.3. Routes Setting

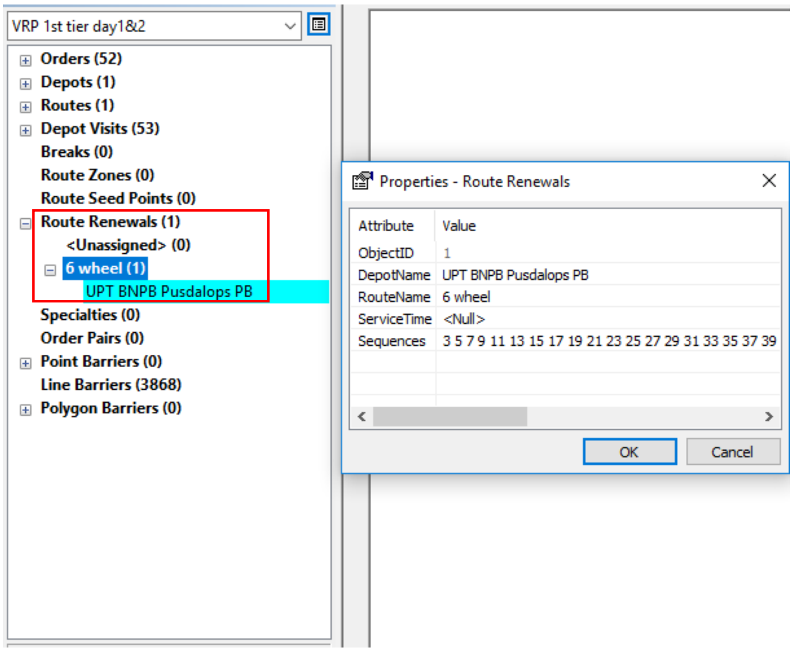


Figure D.4. Route Renewals Setting

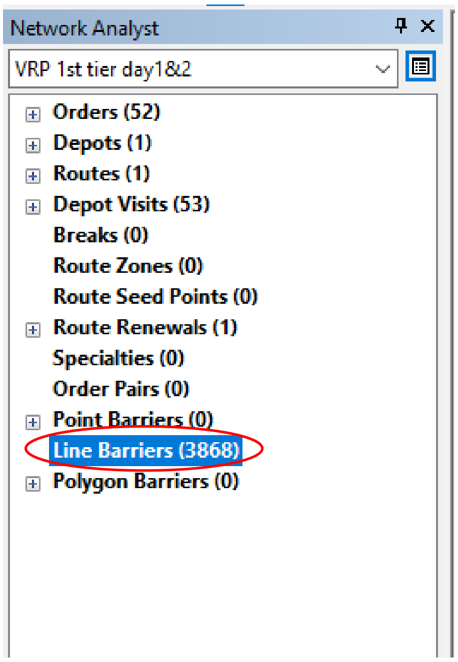


Figure D.5. Line Barriers Setting

APPENDIX E

SIMULATION PROGRAMMING

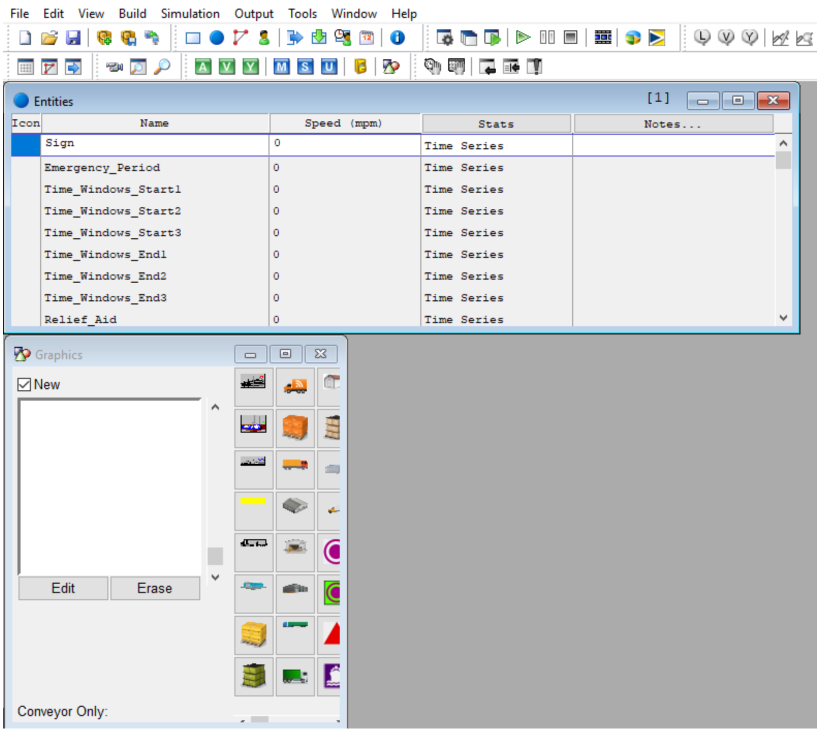


Figure E.1. Entities Setting

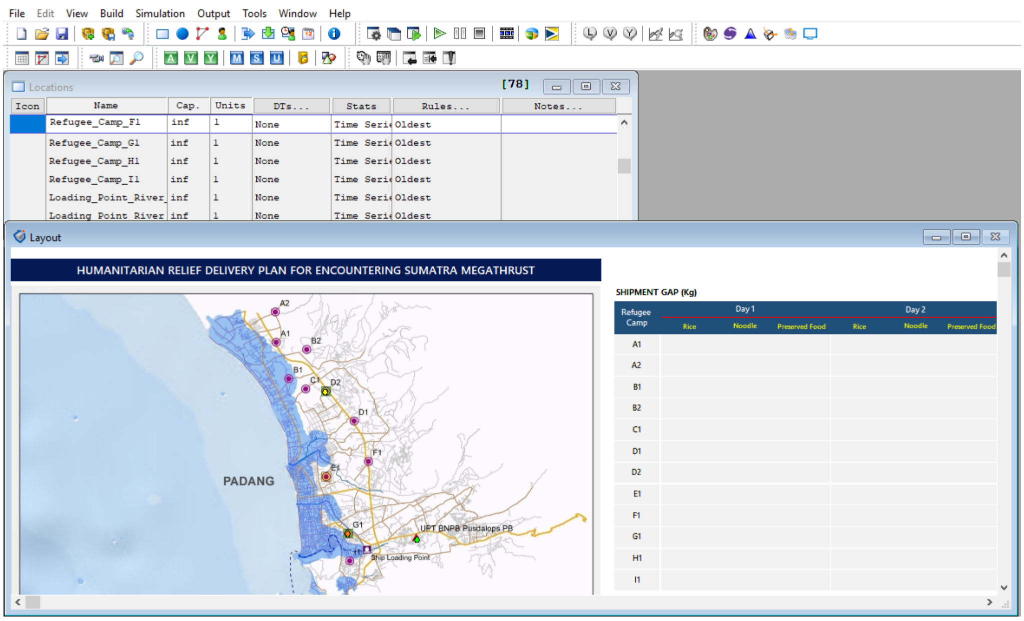


Figure E.2. Location Setting

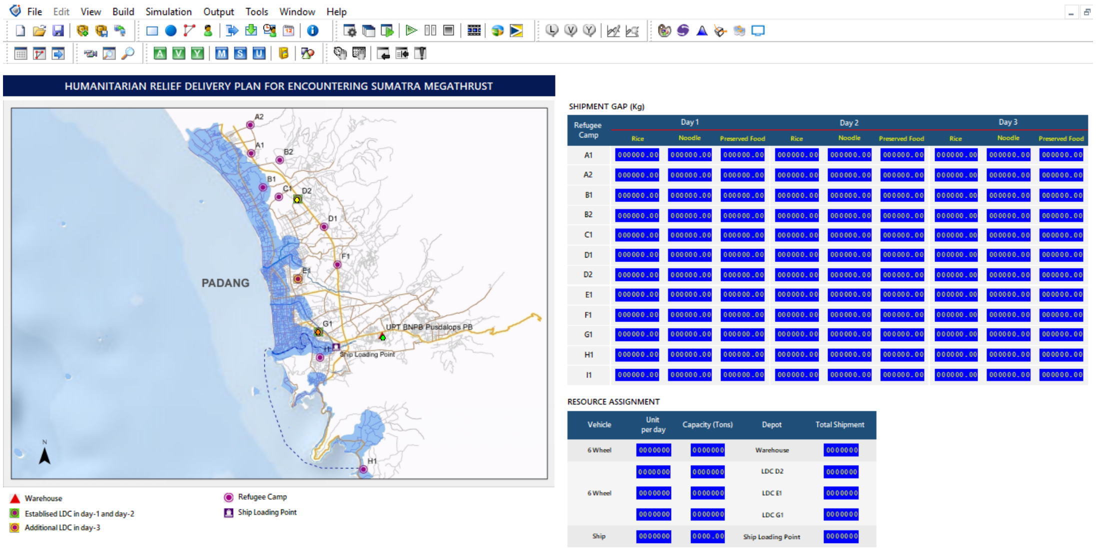


Figure E.3. Layout Setting

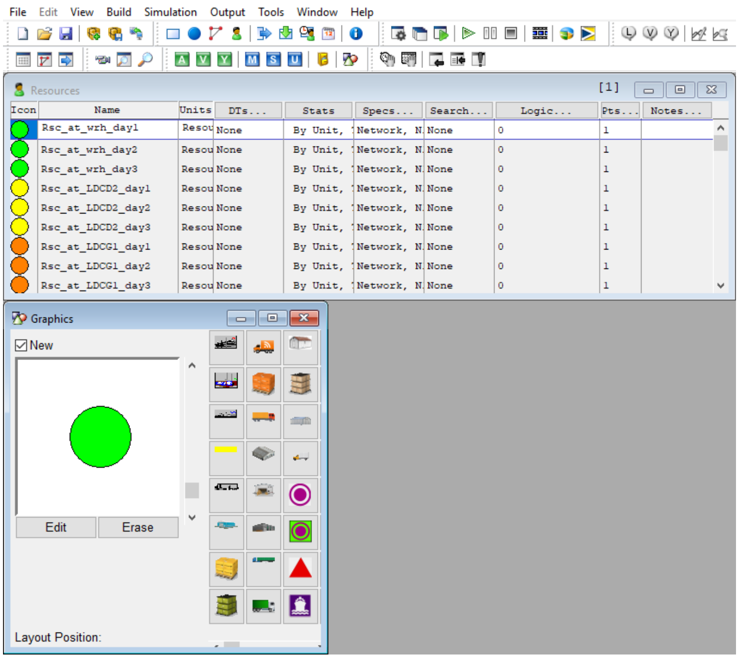


Figure E.4. Resources

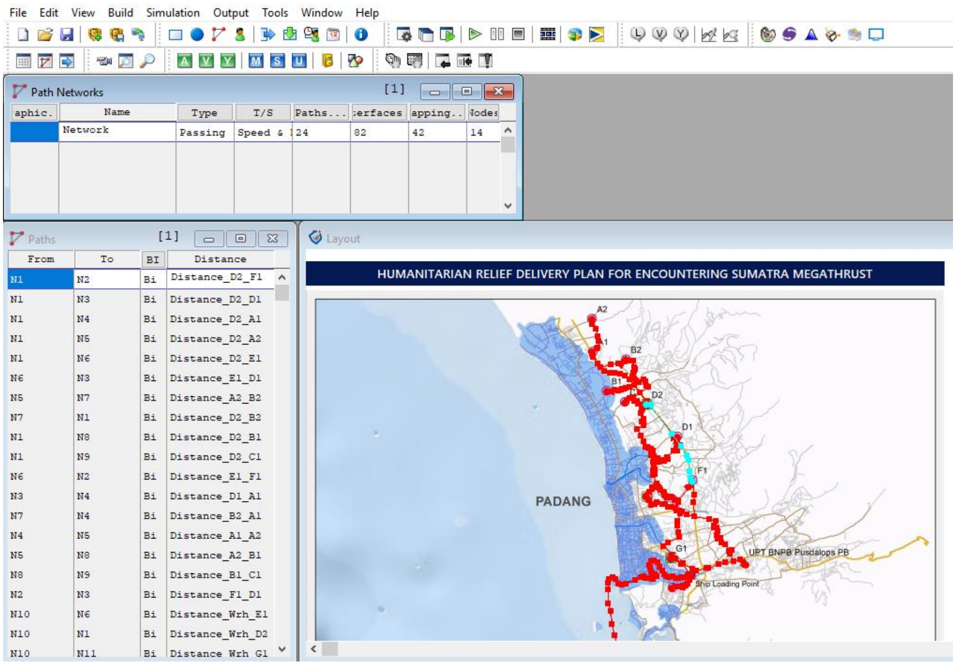


Figure E.5. Path Network

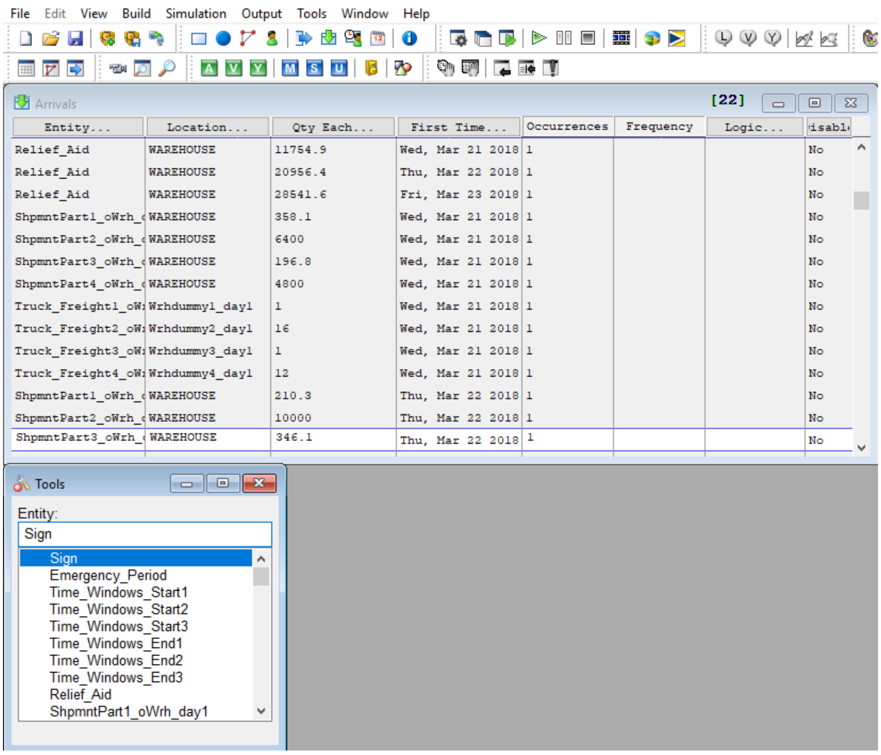


Figure E.6. Arrivals Setting

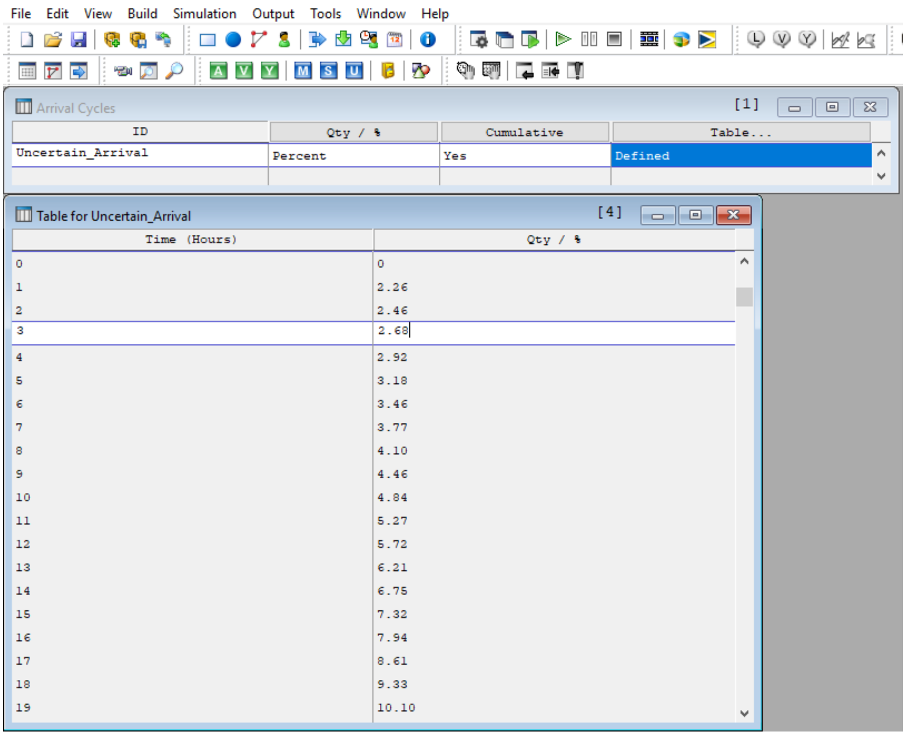


Figure E.7. Arrival Cycles

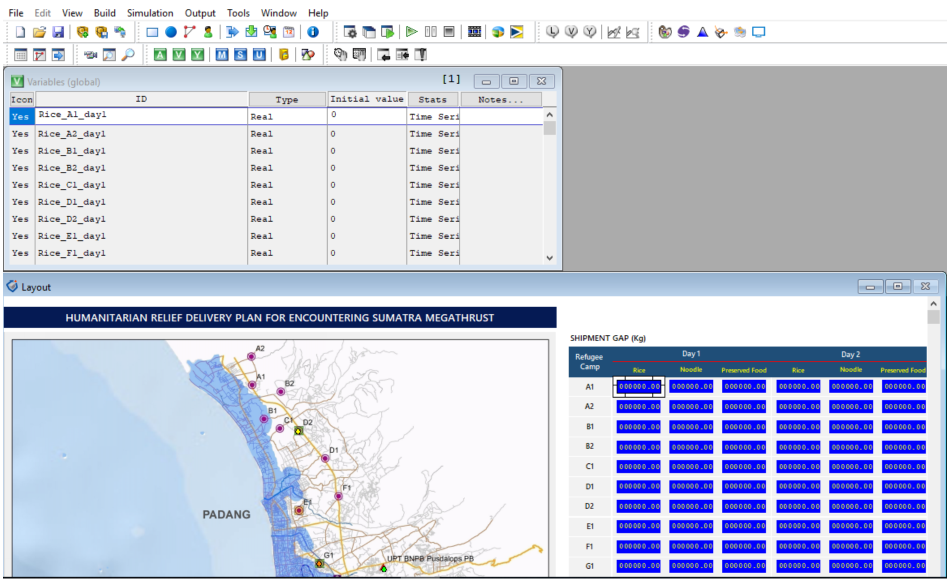


Figure E.8. Variables Setting

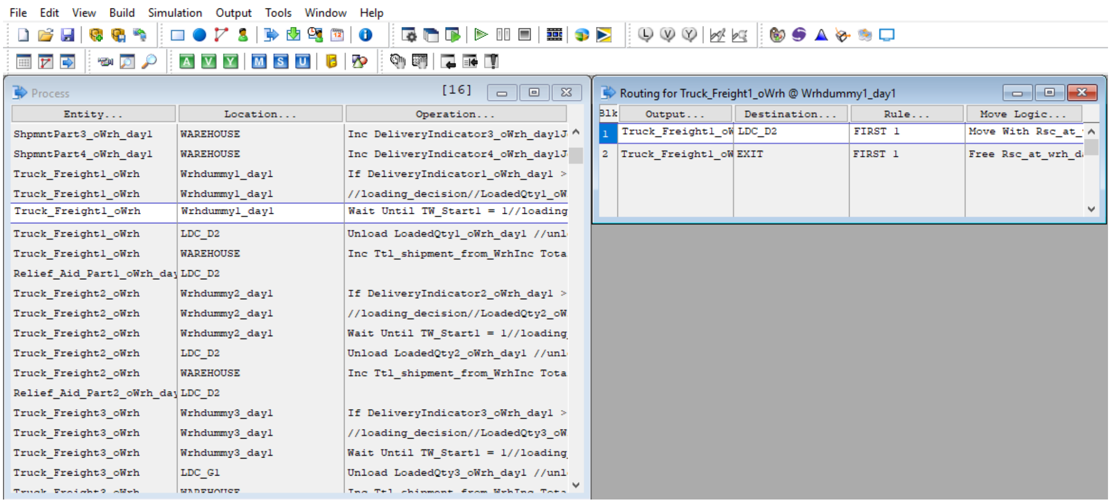


Figure E.9. Process and Routing Setting

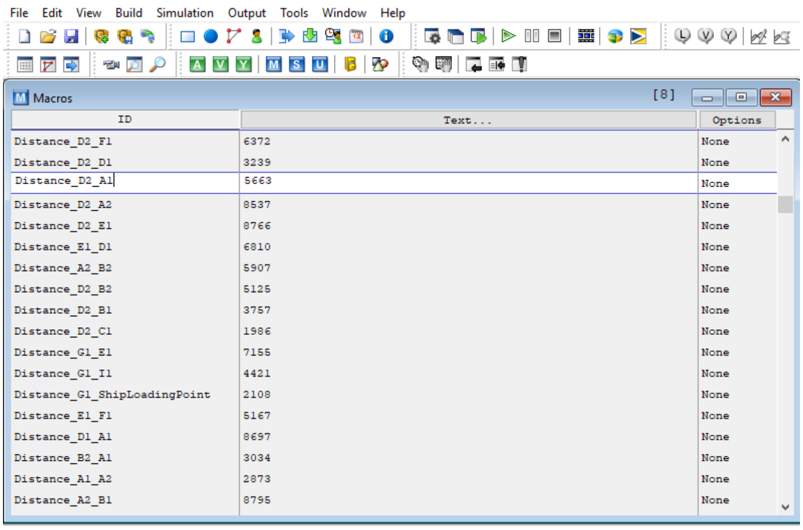


Figure E.10. Macros Setting

VITAE

Name Rahmad Inca Liperda

Student ID 5910120129

Educational Attainment

Degree	Name of Institution	Year of Graduation
Bachelor of Engineering	Andalas University, Padang, Indonesia	2014

Scholarship Awards during Enrolment

– Thailand's Education Hub for ASEAN Countries (TEH-AC)

List of Publication and Proceeding

Liperda, R.I., and Sirivongpaisal, N., 2019. The location-allocation decision under the dynamic increment of demand for selecting the Local Distribution Centers to face Sumatra Megathrust: Study case of Padang City. International Journal on Advanced Science Engineering and Information Technology.